AGRICULTURAL DRAINAGE DEVELOPMENT: A SIMULATION APPROACH FOR PUBLIC EXPENDITURE DECISIONS

A Dissertation

Presented to

The Faculty of Graduate Studies

University of Manitoba

In Partial Fulfillment of

the Requirements for the Degree

Doctor of Philosophy

by

Ranjit H. Singh

October 1978

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BY

RANJIT H. SINGH

A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

In this thesis an attempt was made to develop an analytical framework which could be employed as a management tool to assist in public expenditure decisions on agricultural drainage development. A simulation model was constructed. It evaluates the impact of alternative levels of drainage improvement in terms of the benefits generated, the net benefits, costs and benefit/cost ratios.

Because agricultural production in many parts of Manitoba is adversely affected by excess moisture remaining on the land, drainage improvement works are often considered for alleviating the problem. Provision of improved drainage can reduce the duration of excess moisture to which crops are exposed. This will, in turn, result in crop damage avoided. While crop damage reduction is the major benefit from investments in more efficient and more effective drainage there are other benefits. These include the reduced risk of crop losses, the multiplier effect from an increase in expenditures resulting from higher incomes and other unmeasurable social benefits.

Because of the large expenditures associated with drainage development there is a growing demand made by the public sector for such development projects to be economically justified. Not only should drainage be shown to be feasible but also drainage design optimum (or optimum capacities) must be identified.

A deterministic version of the simulation model was used to evaluate the feasibility of drainage improvements in the Big Grass Watershed in Manitoba. The results indicate that drainage improvement

works are feabile for only parts of this watershed, totalling 108 square miles or about 25 percent of the area. At the optimum levels of drainage development the total discounted benefits is $2.7 million. Cost of drain construction and maintenance is $2.0 million. Thus, net benefits are $0.7 million and the benefit/cost ratio for the watershed is 1.35

A stochastic simulation model was also constructed. It was used to investigate the impact of random disturbance in storm magnitude, crop prices and production costs on the output variables which are useful for decision-making - that is, benefits, net benefits, optimum channel capacity and benefit/cost ratio. The exogenous variables listed above were expected to exert the strongest influence on the dispersion of the output variables. The stochastic version of the model was applied to subwatershed 2.01.02. The statistical distributions of the output variables were estimated from a sample of 30 simulation runs. The 95 percent confidence interval estimated for various decision variables were as follows:

(i)	Benefits:	$79,000 - $95,000
(ii)	Net Benefits:	$54,000 - $68,000
(iii)	Optimum Drain Capacity (at the outlet):	99.5 c.f.s. - 105.5 c.f.s.
(iv)	Benefit/Cost ratio:	3.06 - 3.56

The results indicate a relatively stable optimum drain design since 95 percent of all optima estimated for subwatershed 2.01.02 are expected to fall within a range of six c.f.s.

The implication is that drainage design works on the basis of information on optimum capacities which are derived from the deterministic model are expected to closely approximate the true optimum. Net benefits are also narrowly dispersed about the mean. The range for the 95 percent confidence interval being only $14,000.

Given the statistical distributions of the decision variables the probable error associated with any decision taken on the basis of information obtained from the deterministic model can be estimated. Thus with the knowledge of these distributions the deterministic model constitutes an adequate model for providing information on drainage expenditure decisions.

Because changes in storm levels, crop prices and production costs are likely to cause similar movements in benefits (though not in absolute magnitude) in various subwatersheds under conditions of improved drainage it is expected that the behaviour of decision variables for these subwatersheds will tend to possess statistical distributions with similar properties to those shown for subwatershed 2.01.02. Under this assumption the information generated by the stochastic simulation analysis can be made generally applicable to other subwatersheds.

This study also showed that for the watershed evaluated land use adjustments were necessary to facilitate efficient resource use. Optimum drainage development was associated with increases in the acreages of field crops and tame hay by 50 and 34 percent, respectively. Native grassland acreage was reduced by 35 percent and bushes decreased by 54 percent.

The analytical model developed has been shown to be adequate for evaluating agricultural drainage development. It can readily be applied to other areas where similar problems in agricultural production are experienced.

ACKNOWLEDGEMENTS

The research problem chosen for this dissertation reflects my interest in the subject matter and the observation that there was a need to develop an analytical framework of the type presented in this study for evaluating drainage expenditures. This thesis relied heavily on the concepts and relationships which were developed by Dr. L. Rigaux when he served as project director on two previous studies dealing with the economics of drainage. I am, indeed, indebted to him for this and also for the valuable experience gained from him while working as a research fellow on these studies. Also, as my major advisor, Dr. L. Rigaux was extremely helpful, providing assistance on general academic matters, encouragement during the program of study and stimulation in the area of research. Because of the foregoing and also because he was always accessible for consultation, I have found my graduate program most enjoyable and rewarding. I cannot thank him sufficiently.

The Water Resources Division, Manitoba Department of Mines, Resources and Environmental Management, has shown strong interest in the development of an analytical technique for evaluating the economic feasibility of drainage expenditures. I wish to express my thanks to the Division for the permission to use the data for the Big Grass Watershed and also for general assistance with the study. In particular, I wish to thank Mr. S. Block, P.Eng., head of the Design

Section. Because of the interdisciplinary nature of the study it was difficult at times to bridge the gaps between disciplines—particularly engineering and economics. I have benefitted tremendously from the knowledge and experience of Mr. S. Block and was thus better able to develop the underlying concepts of the study. I wish to express my gratitude for this and also for his encouragement and assistance in his role as a member of the Advisory Committee throughout the entire study.

Many other individuals at the Water Resources Division were helpful and in particular I wish to thank E. Sapinski and H. Roopra who did the drainage design and cost estimates, L. Slevinsky and C. Jenkins who provided assistance in the area of agronomy and T. Wallis and H. Sagar who helped with the programming of the model.

I wish to thank Professor T. S. Major who, as a member of my advisory committee, provided rather useful comments on the thesis generally and in particular on the analytical technique. I also wish to express my thanks to other members of the committee—Dr. D. Kraft and the external examiner, Dr. W. Phillips.

I am indeed grateful to Mrs. I. Chomiak, Mrs. C. Remedios and Miss D. Duhame for typing the manuscript.

The pursuit of this level of academic training was not without considerable encouragement and inspiration from my parents in earlier years. My sincere thanks to them. Finally, I wish to express my gratitude to my wife, Laureen, who was understanding and helpful throughout the academic program.

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Chapter 1

INTRODUCTION

THE PROBLEM OF EXCESS MOISTURE

For many parts of agricultural Manitoba excess moisture is a major land resource limitation. One reason accounting for this fact is that important crops in the Province such as wheat, oats, barley and flax are quite sensitive to excess moisture exposure during the growing period. The importance of excess moisture as a resource limitation in Agro-Manitoba is evidenced by the fact that for many areas of the Province frequent crop losses are experienced because of the occurrence of excess moisture on the land. Concern about alleviating the problem arises because technical solutions, in the form of improved artificial drainage, are readily available and for many areas such solutions may be both economically and financially feasible.

The magnitude of the problem is reflected by depressed yields in certain areas, regional demands for better drainage as expressed by municipalities, government departments and farmers, by lower farm incomes (than potentially possible) in certain areas and by indemnity payments by the Manitoba Crop Insurance Corporation (MCIC) for crop losses from excess moisture.[1, 2] A more general reflection of the extent of the excess

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[1] It has been shown that for an area in south-east Manitoba, the average annual crop loss per acre due to excess moisture ranged between $13 and $16 for insured crops. See: L.R. Rigaux and R.H. Singh (1973: 5).

[2] The Manitoba Crop Insurance Corp. indicated in 1975 that excess moisture was the major cause of crop loss in eight of the 15 risk areas in the Province. Source: (unpublished information).

moisture problem (spatially) in the Province is shown by the agricultural soil capability maps.[3] Large areas have been classified as having a wetness limitation according to the Canada Land Inventory Classification.

Excess moisture on agricultural lands can introduce a number of adverse effects into farm production. Specifically, moisture conditions at seeding time may delay seeding, thus shortening the available growing period which generally tends to lower yields. These conditions may exist for an extended period thus leaving too short a growing period for cereal crop production. Periodic occurrence of excess moisture during the growing season tends to reduce both the plant population (number of stands) and the output per plant. During the mature stages the presence of excess moisture can cause losses in the quality of grain.

It should be noted that these adverse effects on plant productivity result primarily because excess water induces oxygen deficiency in the root environment (Williamson and Kriz, 1970: 216). This situation is referred to as an "oxygen stress".[4]

In addition to the foregoing, waterlogged soils are associated with efficiency costs with respect to agricultural production because of greater machine and labour time requirements, higher fuel consumption,

---

[3]Soil capability for agriculture are mapped by: Canada Land Inventory, Department of Regional Economic Expansion, Soil Capacility for Agriculture (Ottawa: Queen's Printer, 1966).

[4]An "Oxygen" stress is defined as an undesirable effect caused in the plant by an oxygen deficiency in the root zone of the plant. On the other hand "water stress" is defined as the adverse effect of water deficit on plant growth.

lack of production flexibility, reduced effectiveness of chemical inputs and uncertainty.

The problem of excess moisture is generally confined to areas of the Province where natural drainage is poor. The flatness of such areas preclude efficient drainage by the natural system.

Since a major purpose of drainage is to provide a root environment which results in optimum crop yields it is no surprise, therefore, to find that for a large percentage of the areas in the Province with agricultural moisture excess problems, a significant amount of artificial drainage exists.[5] The continued existence of the problem (probably to lesser degrees) for areas already provided with artificial drainage seems to suggest that the current standard of drainage service may be inadequate. Improved service for agricultural land use may include both a more effective system and a more efficient system. Effectiveness refers to the extension of the drainage system from the main channel to the agricultural fields. This necessitates the provision of a complete system - that is the main channels, collection drains and on-farm drains. Efficiency refers to the ability of the system to remove the excess moisture in a relatively short time. In this sense a system with larger capacity is more efficient because it removes a given amount of water in a shorter period of time.

---

[5]Useful background information on agricultural drainage, drainage expenditures by municipality and total amounts of drain is presented in: The Manitoba Water Commission Reports: A Review of Agricultural Drainage in Manitoba.

Response by the public sector to the demands for improved drainage, expressed in various forms, involves allocative decisions with respect to large expenditures. While the economic benefits from public expenditure on drainage may be large, there still remains important decision - making questions to be answered. These include - the question of economic feasibility - do the benefits justify the costs; the question of what level of drainage protection will maximize economic benefits; and the question of how well drainage projects compare with alternate projects designed for the agricultural or other sectors.

This study is concerned with resource allocation by the public sector to improve the efficiency of agricultural production in the Big Grass Watershed. Therefore, it attempts to provide information to public sector decision-makers on the economic desirability of public expenditure for drainage development and on the system design which will maximize net economic benefits. The objectives of the study are presented next.

OBJECTIVES

The broad objectives of this study were firstly, to develop an analytical framework for the economic evaluation of drainage development for the purpose of land resource modifications and secondly, to apply this framework to Big Grass Watershed in Manitoba. The framework developed should provide the capability for evaluating areas typified by the Big Grass Watershed with diverse soil characteristics and variability in land use and hydraulic characteristics. Specific objectives were as follows:

1. To consolidate the available information for this Watershed on agronomic and economic factors affecting land use and to use this information to select the realistic agricultural land use possibilities in this Watershed.

2. To determine the present level of agricultural drainage protection for the various subwatersheds by compiling: (i) hydrologic data such as drainage capacities, slopes and drainage areas, and (ii) data on land use (cover) and soil textures.

3. To establish for analytical purposes alternative levels of improved drainage service in each subwatershed based on the existing level of service and agricultural capability of the land.

4. For the levels of service identified above to estimate the associated costs for drainage development.

5. For each level of drainage improvement included in the analysis to determine the highest economic use of the land resource from the subset of alternative land use identified for this watershed and economic constraints.

6. To estimate the benefits resulting from the improvement in the various levels of drainage service where the highest economic use is assumed.

7. To compare the benefits and costs over an assumed project life and to critically assess the completeness of such information (single-valved estimators and results) to determine the economic feasibility of investment in agricultural drainage improvement in the various subwatersheds and to anticipate what other information is desirable.

8. To investigate the factors which may inhibit the highest economic use and to add further elements that may exert influence on the benefit-cost analysis so far.

9. To investigate the stochastic characteristics of certain variables in the model and to incorporate these characteristics into the analysis to determine the confidence limits for the important output variables.

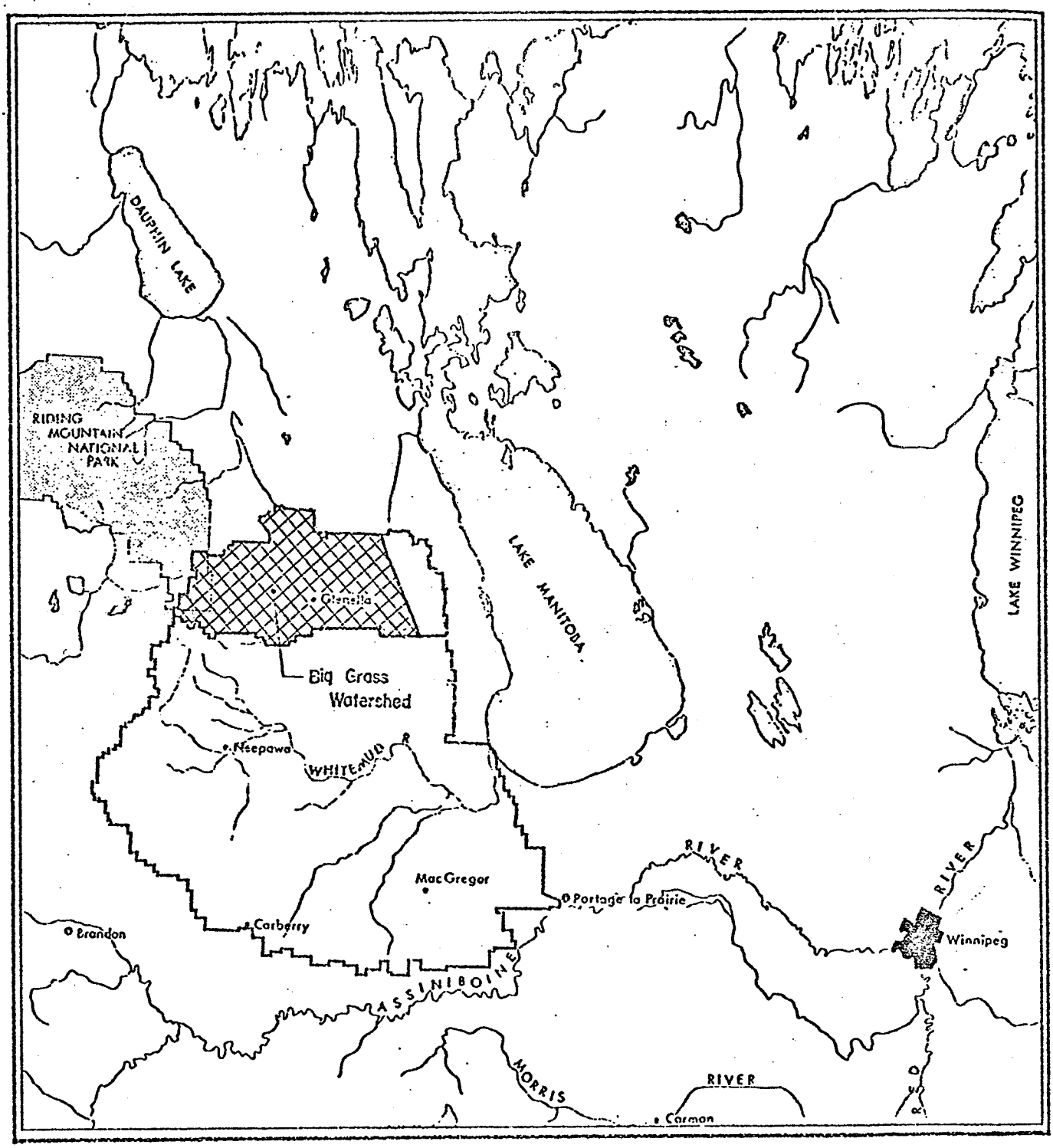
CHARACTERISTICS OF THE BIG GRASS WATERSHED

Area for Drainage Improvement

While this study covers the entire watershed it is necessary to consider drainage improvement works only for the area below the escarpment (Map 1.2). Provincial Highway No. 5 is taken as an approximate boundary. The economic analysis is therefore confined to subwatersheds below the escarpment. However, the hydrologic interdependencies between the escarpmental drainage areas and downstream areas and the resulting economic effects on drainage development are included in the analysis. The area below the escarpment constitutes about 83 percent of the total watershed area.

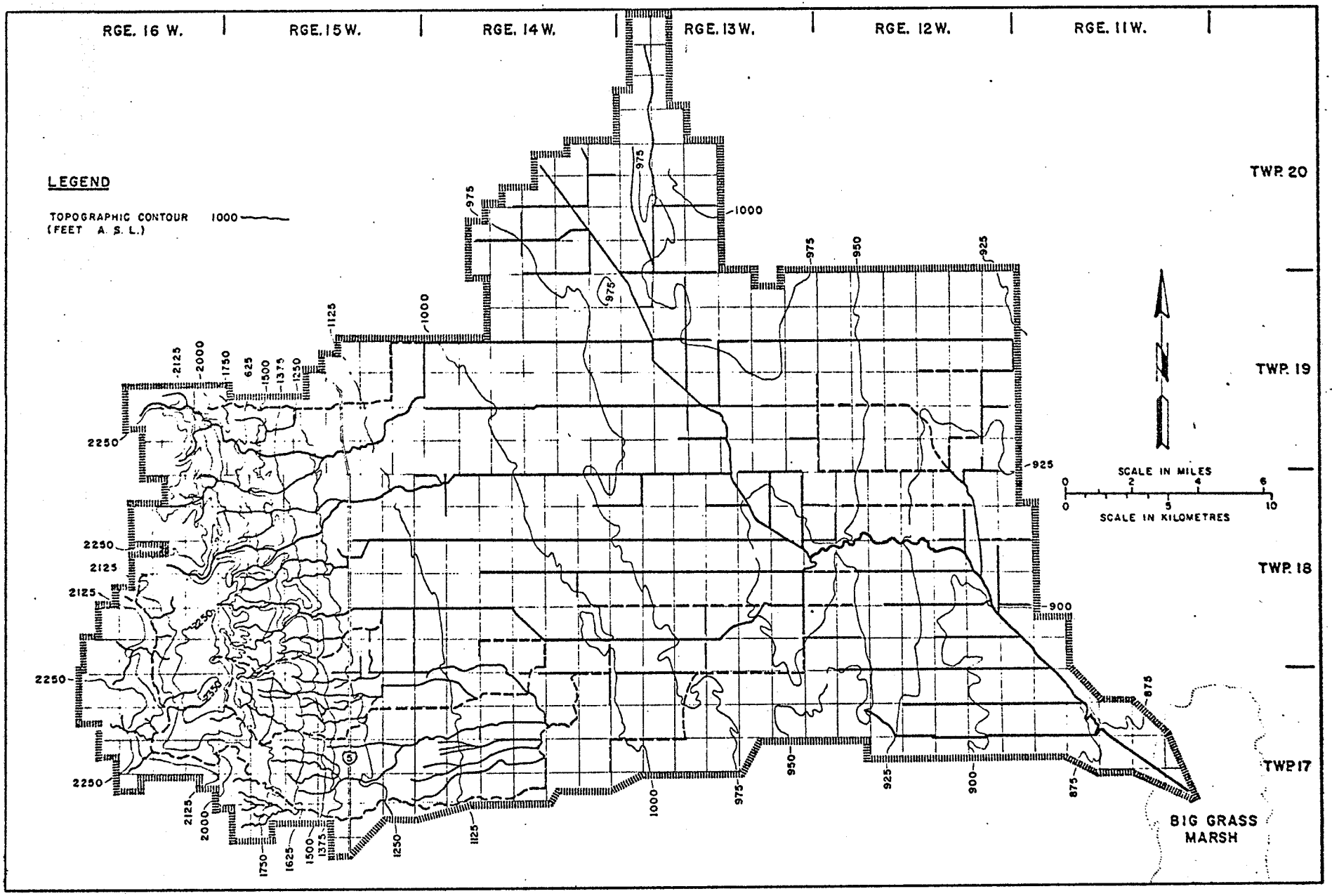
Physical Features

The Big Grass Watershed (shown on the location Map 1.1) extends eastward from the escarpment at the south-eastern corner of the Riding Mountain National Park to the inlet of the Big Grass Marsh. It covers an area of about 412 square miles with a length of approximately 35 miles and a width of about 24 miles. At the highest point the elevation is 2325 feet above sea level which drops to 900 feet above sea level near the outlet. In its upstream extremity the watershed is steep showing an average gradient of about 136 feet per mile for the first eight miles. The remainder of the watershed is much flatter. It is comprised of: (1) the lowland till plain located in the lower reaches



Map 1.1

Location of the Big Grass Watershed



Map 1.2 - Contour Map of the Big Grass Watershed

(below the 950 feet elevation contour); and (2) the sub-escarpment which lies between the Riding Mountain Escarpment and the lowland till plain as shown on Map 1.2.

The Big Grass Watershed contains numerous soil types ranging in texture from clays to coarse sands and gravel. These are dispersed in irregular patterns throughout the watershed. Soils in this watershed, that is for the area below the escarpment, have been classified according to predominant soil texture for each soil type. Table 1.1 gives the area associated with each of the soil textures. Clay loam is the predominant texture and accounts for about 64 percent of the area. Only a small amount of clay soils (about 6 percent) are found in this watershed. Loams account for about 14 percent of the area and sands for about 13 percent. In addition to the above, parts of the watershed are in bog or half-bog condition. These constitute 2.56 percent of the area.

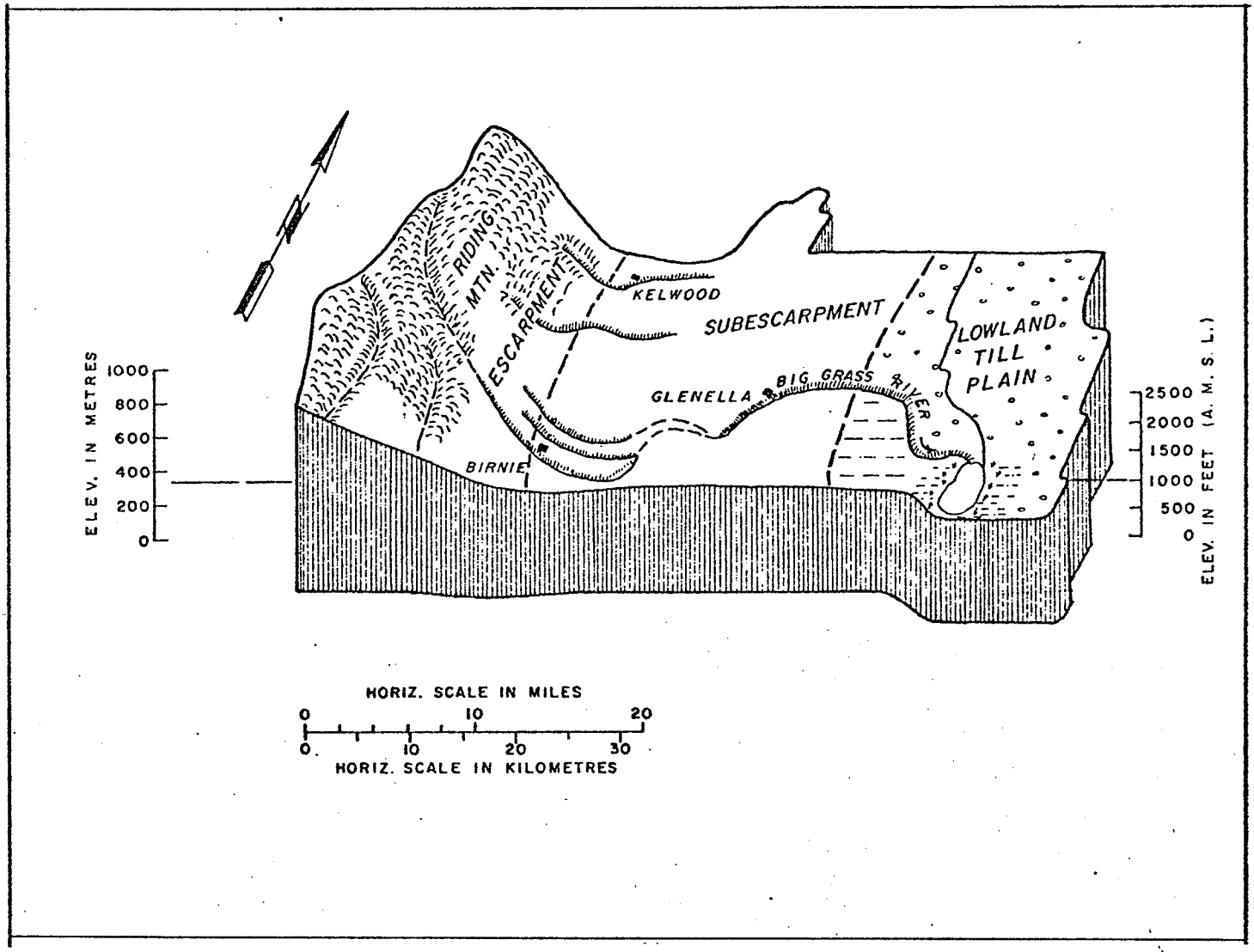
Table 1.1

Soils in the Big Grass Watershed

Soil Texture	Acres	Percent of Watershed*
Clay loam	141,436	64.35
Loam	30,584	13.91
Sand	28,552	12.99
Clay	13,644	6.21
Half Bog	5,072	2.31
Bog	520	0.24

Source: Manitoba Soil Survey; Reconnaissance Soil Survey of West-Lake Map Sheet Area, Soils Report No. 8 (1958).

* Includes only the area below the escarpment. Total area = 219,808 acres (343.4 square miles). This constitutes about 83 percent of the total watershed's area.



Map 1.3

Physiographic Regions in the Big Grass Watershed

The soils of the till plain vary from loamy sands to clay loam. These were developed on calcareous boulder till. Surface stoniness is severe in some areas (Jenkins, 1974: 13-15). The sub-escarpment is characterized by numerous low ridges. Because of the steeper gradient on the western portion, the main drainage channels show extensive erosion in the area of the ridges but in the flatter eastern parts these ridges impede drainage creating wetlands and marshes in some locations. The dominant soil associates of the sub-escarpment area are the Rendzina (or high lime), the calcareous meadow and the imperfectly drained dark grey wooded soils.

The Riding Mountain Escarpment consists of soils which are predominantly of the Grey Wooded Associates. The surface texture varies from coarse sands to clay loams with loose and easily erodible bedrock shales in parts. These soils in the escarpment are generally well drained. Because of steep gradients the escarpment is characterized by many natural channels which are well entrenched into the landform.

The various types of soils in this watershed are found scattered in small pockets, narrow strips and diffused irregularly throughout the watershed, thus resulting in an extremely variable soil productivity pattern. Because of this characteristic it is likely that the level of drainage service warranted will itself vary greatly within the watershed.

Present Land Use

The predominant land use in the watershed (below the escarpment)

is agricultural production. Field crops occupies about 47 percent of the total area below the escarpment (Table 1.2), cultivated forage about ten percent and native grassland about 16 percent. Approximately 25 percent of the land remains in trees and bushes. While crops are grown in small pockets on the escarpment the landscape is dominated by woodland where trees are generally over 20 to 30 feet high. In the north-central, south-central and north-eastern parts of the sub-escarpment (where soils are not very fertile) a high percentage of land is in native grassland use with smaller amounts in crops. The remainder of the sub-escarpment and lowland areas are predominantly in crops and forage production.

Table 1.2

Present Land Use in the Big Grass Watershed

Land Use	Area (ac)	Percent of Watershed (Below Escarpment)
Crops	103,753	47
Forage	22,670	10
Native Grassland	35,478	16
Trees	54,403	25
Other	3,504	2
Total	219,808	

Source: Canada census, 1971

Agricultural Capability

Soils are classified into seven groups by Canada Land

Inventory based on relative potential for supporting agricultural production. Capability class one is the most productive and class seven is the least. While a capability class is comprised of soils having the same relative degree of productive limitation, the sub-classes separate the soils of each class into groupings with similar kinds of limitations. Generally, capability classes one to three can support the production of crops while class four is capable of marginal production. The limitations of the sub-escarpment are generally reflected in the class five soils. Soils in this class are usually best suited for permanent pasture and hay. Class six is best suited for wild pasture and class seven is not suited for either crops or pasture.

The dominant soil capability is class four which comprises about 32 percent of the watershed's area below the escarpment (Table 1.3). Class two, three and five soils account for 18, 23 and 22 percent of the area, respectively. Only about two percent of land belongs to capability class six.

Moisture excess is the major limitation of the soils in this watershed. Approximately 60 percent of the watershed's area below the escarpment have a moisture excess limitation. The problem is greatest in areas where class four and five soils predominate. Table 1.3 shows that about 84 and 75 percent of the soils in class four and five, respectively, have a moisture excess limitation. In addition to moisture excess, other limitations include moisture deficiency, stoniness, high salt content and lack of fertility.

Table 1.3

Agricultural Soil Capability in the Big Grass Watershed

Soil Capability Class	Percent of Watershed Area (Below Escarpment)	Percent of Cap. Class With Wetness Limitation
2	18.4	46
3	22.9	30
4	32.0	84
5	21.8	75
6	1.7	100
0 (Organic)	3.1	

Source: Canada Land Inventory

Wildlife Capability

The natural vegetation and habitat in the Big Grass River is suitable for the support of wildlife including white-tailed deer, elk, moose and waterfowl (primarily ducks). The wildlife capability classification is not necessarily an indication of present habitat suitability but in fact the potential of the land resource to support a particular wildlife specie. The resource study (Jenkins, 1974:83) provided seven big game (wild ungulate) capability classes ranging from excellent (class 1) to extremely poor (class 7). Most of the lower portion of the sub-escarpment was rated as class four indicating moderate limitations. The white-tailed deer is the most important game in this area. The upper portion of the sub-escarpment showed ratings of class two and four. While, generally, the white-tailed deer is the most important big game, the capabilities of units on the Riding Mountain Escarpment (class two and three) are better suited for moose and elk.

Much of the land in the Big Grass River Watershed has waterfowl capabilities ranging from class four to seven, indicating moderate to severe limitations. The Big Grass River flows into the Big Grass Marsh which is an important wetland area. It is an important staging area for migrating waterfowls but because of fluctuating water levels it is less ideal as a production area, being rated as class two or three.

Crop Yields

The crop production survey data from the Manitoba Crop Insurance Corporation for the period 1966-75 show average yields of 21.3, 30.3 and 23.4 bushels per acre for wheat, oats and barley, respectively. The survey data indicated that the lowest yields were obtained from crop production on sandy-textured soils (Table 1.4). For wheat and oats the second lowest yields were obtained on the clay soils whereas their best yields were from the loamy soils. Barley crops showed the highest yields in the clay loam soils.

Table 1.4

Average Yields in the Big Grass Watershed

	Average Yields (Bu/Ac)		
Soil Texture	Wheat	Oats	Barley
Clay	16.1	19.5	22.7
Clay Loam	22.0	31.0	24.7
Loam	22.6	36.6	21.1
Sand	14.6	18.7	16.5

Source: Manitoba Crop Insurance Corporation - Crop Production Survey Data: 1966-1975.

THESIS OUTLINE

The literature review for this dissertation is presented in Chapter 2 and in Chapter 3 the conceptual framework for the model is given. Chapters 4 and 5 are concerned with the economic theory. In the former the underlying theory related to public projects are discussed and in the latter the theoretical model is presented. After the chapters on economic theory the analytical models are specified - the deterministic model is given in Chapter 6 and the stochastic model in Chapter 7. Chapter 8 discusses agricultural drain design and costing. Chapter 9 is concerned with the preparation of data. Chapters 10 and 11 discusses the results of the analysis. Finally in Chapter 12 the summary and conclusion of this dissertation is given.

Chapter 2

LITERATURE REVIEW

INTRODUCTION

The evaluation of economic feasibility of improvments in agricultural drainage is well suited to the methodology of traditional benefit-cost analysis. However, the characteristics of the problem make this application rather involved. The problem's interdisciplinary dimensions include concepts which are related to meteorology, hydrology, engineering design, agronomy, soil physics and economics. There are a large number of underlying technical relationships which must first be established before actual application of the benefit-cost framework can be initiated. In reviewing the literature greatest emphasis was given to work which are closely related to the problem. The review begins with a look at the development of the general benefit-cost methodology. In the present century, this methodology has found wide application, particularly in the field of water resources research. Significant contributions in this area are discussed in the next section. In the third section, studies which employed simulation techniques for evaluating benefit and costs are reviewed. From this broad background, the review focuses on specific works on the economics of agricultural drainage. Underlying the economic relationship are the basic physical forces which determine the effect of excess moisture on plant productivity. Contributions in this area are also reviewed. The final section of this chapter summarizes the concepts drawn from the literature which are most relevant to the present study.

BENEFIT-COST ANALYSIS

Benefit-cost analysis, as a methodology, has long been associated with the evaluation of public projects. Its foundations in welfare economic theory make it particularly suited for this type of analysis. As a formal methodology its history can be traced to the mid-nineteenth century. The application of benefit-cost analysis was not widespread until the present century and in the last two decades the methodology has found extensive application, particularly in the U.S. where water resources, education, highways, health, defense and other public projects have been evaluated.

In spite of its long history, benefit-cost analysis is still a subject area of much controversy. The state of the art in measuring benefits and costs remains to be perfected. Like the parent subject, welfare economics, "cost-benefit can be made to look deceptively simple, whereas there are everywhere pitfalls for the unwary" (Mishan, 1971:1).

The underlying welfare theory in benefit-cost analysis is adequately treated in most economic textbooks dealing with public finances. Noted articles on the subject have been written by I.M.D. Little (1957), Mishan (1960, 1967) and J. Dev. Graaf (1957).

Similarly, the concepts embodied in the benefit-cost methodology have been discussed at length in many textbooks on public finance, in journal articles and in research reports. In 1965 a survey of the subject was written by Prest and Turvey. But complete volumes have been written by McKean (1958), Haveman (1965), Marglin (1968), Eckstein (1958), Mass et al. (1962), James and Lee

(1971) and Kneese and Smith (1966). More condensed volumes which are useful guides to the application of benefit-cost analysis are those by Sewell et al (1961), Howe (1971), the Treasury Board of Canada (1976) and DasGupta et al (U.N.I.D.O., 1972).

Mishan (1971) gives a rather rigorous and detailed treatment of the concepts in benefit-cost methodology. He introduces his book with brief examples of benefit-cost application but thereafter concentrates on theoretical concepts. McKean and other authors cited above were primarily concerned with water resource systems in the U.S. These volumes generally discussed both the concepts in benefit-cost analysis and the application of the methodology to water resources case studies.

The work by Howe (1971) presents the benefit-cost concepts in a more condensed form than previous citations and thus the book is a useful guide to the application of the methodology to water resources problems. The publications by Sewell et al. (1961) and the Treasury Board (1976) offer a more general guide to application of the benefit-cost framework. A good discussion on the criteria and methods for water resource planning is given by Dobbs et al (1971). The authors discuss various criteria which are applicable when weighing all elements and alternatives for water resources planning. The theoretical problems associated with these are also discussed. Finally, the authors examine the suitability of various methods such as benefit-cost analysis, linear programming, input-output analysis and simulation for evaluating water resource projects.

Benefit-cost analysis like other methodological frameworks has its shortcomings. The actual importance of these limitations depends on the objectives of the particular study and the nature of the problem. For example, as one of the major limitations Dobbs et al. (1971:48) cite the fact that such studies fail to explicitly examine the effects of alternatives. While the analytical framework can be modified to consider a limited number of alternatives, the authors indicate that it is preferable to use a framework within which the different alternatives can be evaluated in a single more generalized model. If one of the objectives of the study is to identify the optimum combination of structures in a water resource project or to determine the optimum scale, then the use of a more generalized framework may in fact prove to be more suitable. Simulation is a more general approach to the study of models which can be used to evaluate alternatives on the basis of the benefit-cost methodology. Thus, it is suited for studies where optimization is desired.

Another characteristic of benefit-cost analysis is its treatment of stochastic influences. Traditional benefit-cost analysis assumes that variables are known with certainty; but in actual fact all projects are associated with varying elements of uncertainty. Accordingly, when selection must be made from among a number of projects or if it is desirable to have information on the sensitivity of output variables to stochastic exogenous influences, then the deterministic framework becomes an important limitation. Water resources research is a good example of an area where this problem is relevant. Margolis (1959:98) notes that analysts have not altered the benefit-cost criteria because of uncertainty. Others,

such as Howe (1971) and Eckstein (1958), suggest adding a risk premium to the discount factor. But Margolis (1959:102) indicates that this is inadequate since choice should be based on the expected values together with an estimate of the variability of these values.

In an effort to surmount the above criticism of benefit-cost analysis Taylor and North (1976) used a Monte-Carlo simulation approach to estimate the mean and standard deviation for the benefits, costs, benefit-cost ratio and net present value for a case study. But at best, their approach can only be considered naive. The values of the output variables generated are not the direct result of changes in the values of the stochastic variables in their model, but are randomly generated from subjective probability distributions of the output variables themselves-that is, from the probability distributions for each of the various benefit and cost components. Triangular probability density functions are construced from subjective estimates (by the planning agency) on a most likely outcome, an optimistic outcome and a pessismistic outcome. No direct consideration is given to the underlying stochastic variables.

SIMULATION STUDIES

The best method for explicity considering the uncertainty characteristics of a system is to incorporate the random behaviour of the stochastic variables in a simulation model. The technique as applied to economic systems is treated at length by Naylor (1968,1971) who is one of the principal contributors in this area. The volumes cited are entirely devoted to the subject matter. All relevant concepts in computer simulation are discussed and the methodology for the construction of simulation models is presented in detail. These books also give case studies of economic systems where computer simulation models were applied.

The work by Mass et al. (1968) is considered the most complete description of simulation modelling techniques as it relates to water resource evaluation and economic phenomena. The authors give detailed treatment of relevant concepts and methods in formulating models. Broadly, it deals with the identification and evaluation of objectives of design, the translation of these objectives into design criteria, the system design and finally the evaluation of plans which are developed. Hufschmidt and Fiering (1966) give a similar treatment of simulation techniques for the design of water resource systems.

There are a number of case studies where computer simulation is used to evaluate the feasibility of multiple purpose river basin development. Noted among these, as one of the largest applications, is the study by Hamilton (1969) on the Susquehanna River Basin.

ECONOMICS OF AGRICULTURAL DRAINAGE

In many of the river basin studies in the U.S. agricultural benefit is only one of a number of different types of benefits. Benefits to agriculture result from either flood protection of arable lands in the flood plain zone, or the drainage of reclamable land. In a survey of a number of projects for watershed planning in the U.S., Tolley and Riggs (1959) estimated that 75 percent of all benefits were agricultural. Benefits were ranked in terms of magnitude as follows: flood prevention, drainage, irrigation, recreation and wildlife, and municipal and industrial water.

Literature on the application of benefit-cost analysis to land drainage projects which are designed to improve agricultural productivity is scant. Some examples of land drainage reclamation projects are available.

Economic evaluation of a reclamation drainage project is relatively simpler than projects designed primarily for productivity improvement of lands already in agricultural use. Examples of the former type of study include an expost evaluation of drainage in the Interlake Region of Manitoba by Norton and MacMillan (1970); a study on the competition for wetlands in mid-west (U.S.) between agricultural (in which case drainage is required) and wildlife uses (Goldstein, 1971); Menz (1964) on a California project, Harris and White (1971) in Arkansas and Cook (1965) in Oklahoma.

A rather interesting doctoral dissertation by Jansma (1964) evaluates the secondary effects of upstream watershed development. The study examines the benefits from flood control and soil erosion works.

The project increases farm production and reduces production costs, both factors contributing to higher farm incomes. The estimated net local multiplier is 1.62. A major part of the secondary benefits accrued to agri-business, such as grain elevator companies, farm machinery dealers and farm supply stores.

With respect to the literature on drainage for productivity enhancement, James and Lee (1971:273) in their discussion on drainage presents a conceptual approach for economic optimization of drainage projects. It is the only case found in the literature where the problem is couched in marginality concepts and where the authors recognize the importance of soil characteristics to the analysis of benefits. James and Lee (1971:273) suggest that "economic optimization of a drainage project requires separate marginal cost curves for each homogenous segment of the total area studied." As the depth of water is lowered in the soil profile by means of drainage, yields are expected to increase. Benefits are therefore directly related to the depth of water (that is, the water surface) from the land surface. However, the author fail to consider the most crucial variable - the length of time during which the root zone is flooded.

Cotner (1967) evaluates the role of agricultural land drainage in economic growth in a 42-county region in lower Michigan. The study concludes that significant efficiency benefits from field drainage accrue to producers or consumers depending on demand elasticities. The increased returns to owners of drainable land constitute economic rent. While the model considers detailed information on soil type and quantity, productivity and location, the actual

measurement of changes in yield as a consequence of drainage seems crude. The method uses data from a farm drainage survey to compute average yields for both drained lands and lands where excess moisture was the dominant soil problem. The difference in average yields was used as a measure of potential productivity improvement which can result from drainage. This together with projected yields (for 1980) for various soils were used to estimate average yield response. The model fails to introduce the marginal relationship between yield and the level of drainage. As a result, the single level of drainage considered may be at considerable variance from the optimum. Additionally, the categorization of lands as being either well drained or poorly drained does not allow for variability in the amount of drainage which may currently exist. Consequently, yield differences estimated from the survey data are likely to provide an inaccurate measure of productivity benefits.

While the above discussion identifies crucial weaknesses of the study, there are other interesting results. The farm survey showed that only one-fifth of the farmers who thought drainage would pay had plans to invest in additional field drainage. Farmers indicated that internal capital rationing was the main reason for not investing. Inadequate outlets for field drainage was also a significant factor in retarding drainage adoption.

Langvatn (1959) in a study on the implications of field drainage in Norway was concerned with the effect of excess moisture on the efficiency of farming. It was estimated that 20 percent of the country's farmland had an excess moisture problem. Drainage improvement

of these lands, he suggests, will have as its most important effect the increase in yields. This will result from better soil condition, better fertilizer use and earlier seeding. Other effects from drainage which were cited are: more efficient use of machinery, for which he estimates approximately 20-25 percent reduction in working time in the heavier soils; more flexibility in working hours; increased flexibility in production; and reduced uncertainty.

Van der Graaf (1968) in a study of drainage in Pakistan suggests that drainage is a function of cropping pattern, crop varieties and growing stage in addition to the duration of flooding. He was concerned with moisture remaining on the land which was defined as the rainfall in excess of drain capacity.

In a study by Rigaux and the author of the current study (1975) 15 small watersheds in Manitoba were evaluated for drainage improvement. These were selected to represent varying soil characteristics, topography, hydrologic conditions, drainage and intensity of agricultural use. Four alternative levels of drain designs were included in the study. The study represents the first attempt to be found in the literature where marginal relationships between crop yield and excess moisture were estimated. The duration dimension of excess moisture was cited as the causal factor for crop damage and thus benefits were induced by faster removal of excess moisture. A regression model was used to estimate the relationships between crop yields and precipitation excess along with other explanatory variables. The crops considered were wheat, oats, flax and barley and the production of these on the four major soil textures - clay, clay loam

loam and sand. The results (vol. 2:37) showed that greatest damage from crop exposure to excess moisture results to crop grown on clay soils. Negligible damage occurs when crops grown on sandy soils are expossed to excess moisture.

The benefit-cost results showed that drainage improvement was economically feasible for five of the 15 watersheds studied. These were generally areas with heavier soils. The assumed project life was 15 years. Sensitivity analysis showed that the results were relatively insensitive to extensions of the project life beyond 15 years at the discount rate applied (vol. 3:138). For the particular case evaluated in the sensitivity analysis the benefit/cost ratio increased from 1.4 for a project life of 15 years to 1.6 for a project life of 50 years.

The above work on the relationship of excess moisture to crop yield was based on non-experimental data. There exists very little material in the literature on the experimental studies dealing the effect of excess moisture on plants. These are discussed in the following section.

PHYSICAL EFFECTS OF EXCESS MOISTURE ON PLANTS

There exists a paucity of quantitantive studies in the literature evaluating the effect of excess moisture or "oxygen stress" on crop yields. Among these is the study by Ibrahim (1977) which reports on the effect of drainage on crop yields. The Egyptian Government is carrying out an extensive land drainage program which was initiated in 1972 and from which it is estimated that 1.6 million hectares will be improved. While the project involves tile drainage rather than surface drainage, the impact on yields gives indications of the possibilities for land drainage. Ibrahim compares the yield increases in the first three years of the project to the pre-project levels. To assess the net increase in yield due to drainage the values obtained above are discounted by amounts equalling the increases observed outside the project area. Yields were observed in four catchment areas - each having different extent of moisture excess problem. Greatest increases in yields were obtained for the catchment areas which originally had the lowest yield or the greatest moisture excess problem. For wheat production the net increase in yield is as high as 59 percent. Average yield of wheat was 1473 kg. per feddan in 1970-71. In the first year of the project, yields showed a net increase of 207 kg. per feddan. The net increases in the second and third years were 235 and 228 kg. per feddan, respectively. The average net increases of 14, 16 and 15 percentage points over the three years of the project were assumed to be primarily attributable to drainage improvement.

Williamson and Kriz (1970) reviewed experimental studies which dealt with the response of agricultural crops to flooding, depth of water table and soil gaseous composition. Excess water as such does not affect plants; rather, it is the oxygen deficiency in the root environment which is caused by the presence of excess moisture. In summarizing previous finds, the authors conclude that "short term oxygen deficiency can cause an increased resistance to water movement through roots, reduced root respiration, reduced nutrient uptake and formation of toxic products in plants. Continued poor aeration results in death of cells, increase in cell permeability and death of roots." In an experiment on the effect of flooding on crop yields it was found that the response due to watering depends on the soil type. Coarse textured soils required a higher water table for optimum yields than fine-textured soils. The authors suggest that this difference is accounted for by the greater capillary rise in fine-textured soils. Crops grown under high water table condition are more susceptible to injury from flooding since roots are located near the soil surface.

Howell et al. (1976) conducted experiments to determine the effect of flooding on grain sorghum. Plants were inundated for a 12-day period at three stages - the early vegetative, the early root and the heading growth stages. Grain yields were reduced by 30, 26 and 0 percents, respectively for the three growth stages. It was observed that flooding at the early vegetative stage resulted in plants requiring 7 days longer to mature than other treatments. The redution in grain yield resulted from both a redution in the number of stands and a reduction in yield per plant.

In a study by Leyshon and Sheard at the University of Guelph (1974) on the effects of flooding on barley, the authors reviewed previous studies on the subject. They indicate that research by Stolzy and Letey (1964), Grabel (1966) and Kramer (1969) have shown the supply of oxygen (O_2) in the root environment of the plant directly affects the up-take, translocation and concentration of elements in the top of the plants. Consequently, during periods of flooding when the root environment is deprived of an adequate O_2 supply the nutrient (or ion) concentration decreases thus affecting growth, adversely. It follows that plants affected in this manner will generally produce less. If the exposure to excess moisture is prolonged the nutrient starvation may be sufficient to fully destroy the plants.

On a relative basis among crops, Bryant (1934), Vlamis and Davis (1944) found that the low O_2 supply in the root zone during flooding affected barley more than other plants.

Research on the actual magnitude of the effects of excess moisture include that by Borget et al. (1961) who found that barley was most susceptible to flooding in the two leaf stage and that most of the damage to the yield-capacity occurred in the first seven days of flooding.

Leyshon and Sheard, in their experiments, found that flooding significantly affected barley yields. Under greenhouse conditions on a silt loam soil, the study showed that the yield of plants subjected to 7 days of flooding (followed by artifical drainage) at 28 days old was 55 percent less than the non-flooded plants. For older plants 35-day old, the reduction in yield was

less than 37 percent after the same period of flooding.

Another interesting aspect of the study relates to the recovery of plants after flooding. While it was found that, generally, vulnerability of plants to excess moisture decreased with age, the recovery of younger plants was much better than for older plants. Specifically, it was found that barley plants which were 14 days and 21 days old at the initiation of a 7-day flooding recovered their growth rates whereas 35-day old barley showed no such recovery.

It followsfrom the above that generally for cereal crops a moderate period of flooding (seven days) may result in a greater reduction of yield if this occurs during the more advanced stage of the plant than during early growth - primarily because of the recovery ability of younger plants. However, prolonged flooding which occurs when plants are in the early growth stages can cause complete destruction (and thus no recovery) much more readily than if the same flooding occurred during a more mature stage of the plant.

The effects of excess moisture on forage crops are similar in nature to those shown for cereal crops. However, the actual degree of susceptibility is different. Research at Swift Current in Saskatchewan by Heinricks (1972) showed that flooding caused the yellowing and dropping of leaves in legumes. This was quite noticeable in sainfour, cicer milk vetch, seeet clover and alfalfa after five days of flooding. Crude protein content was also observed to decrease as the yellowing of foliage increased. On the basis of overall results the author concludes that the amounts of flooding which can be tolerated

are as follows: Sainfour - 5 days; cicer milk vetch and sweet clover - 10 days; alfalfa, alsike clover, red clover - 15 days; strawberry clover, white clover and birdsfoot trefoil - 20 days.

A researcher[1] at the Brandon Research Station suggests that for Alfalfa excess moisture will not only cause a reduction in yield because of slow growth and loss of foliage but also from a reduction in the number of stands. This latter factor will be responsible for reduced output both in the year of flooding and in subsequent years. While visual evidence of damage in Alfalfa may become apparent after five days of flooding, it is suggested that damage is likely to begin from the first day of flooding. However, recovery from short periods of flooding such as five days or less is likely to be high. Thus the extent of damage depends on both the duration of flooding and the opportunity for recovery.

SUMMARY

The abundance of literature on benefit-cost analysis is useful in providing guidance in the general application of the methodology. Material relating to agricultural drainage are quite sparce. The most closely related work to the problem investigaged in this study is that by Rigaux and Singh (1975). However, there are a number of limitations associated with that study which arise primarily from the scope of that

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[1] L.D. Bailey is involved in forage research, particularly alfalfa. Information was obtained from discussions with him.

study and the nature of the problem, as dictated by the characteristics of the areas studied.

Firstly, fourteen of the watersheds had areas ranging from 13 to 60 square miles. Because of their smallness there was no need to consider precipitation variability over the watershed nor the hydrologic interdependencies among subwatershed units. However, these factors are important in the study of larger watersheds where the spatial distribution of precipitation and contributing flows from various tributaries affect the moisture excess situation. Secondly, the soils within each watershed were relatively homogenous or very nearly so - a fact which obviated the need to develop a model to consider variability in soil characteristics and quantity within each watershed. The current study area shows extreme diversity in soils and so the model must consider this feature. Thirdly, most of the watersheds studied were in intensive grain production (at least in the arable portions) consequently there was no need to build into the model flexibility to permit land use modifications after drainage. The possibility of land use changes in the current study area cannot be ignored. Also factors, such as the economic interdependency among subwatersheds in terms of impact on downstream areas as a consequence of upstream developments, which were not very relevant for small areas should now be considered.

Finally, the Rigaux - Singh study, like most benefit-cost studies failed to provide information to decision-makers on the variance of project benefits, costs, benefit/cost ratios and net benefits.

Because of the underlying stochastic nature of storm events and economic variables, project outputs are likely to show great variability. Decision-makers are interested in this characteristic of the output data. The current study therefore deviates from the approach in the above study by introducing a simulation method of evaluating benefits and costs.

Chapter 3

DEVELOPMENT OF A CONCEPTUAL FRAMEWORK

INTRODUCTION

In this chapter those concepts which are relevant to the problem being investigated are drawn together in a framework. In the first section the discussion focuses on the factors which give rise to the excess moisture condition together with the relationships important in assessing the magnitude of the problem. The relevance of excess moisture is in its effect on crops and agricultural output. The important relationships here are presented in the second section. But given that there is a problem the nature of the technical solution is of interest. The type of drainage system planned is discussed in the third section. The last section of this chapter deals with economic relationships which are relevant in assessing the desirability of alleviating the problem through drainage.

EXCESS MOISTURE

In this study, excess moisture is defined with respect to agricultural land use. The occurrence of storms over a given area results in moisture on the land but this by itself does not necessarily imply that a significant amount of excess moisture will be experienced. The volume of precipitation in conjunction with the infiltration capacity of the soils, interception and the surface drainage facilities (natural and artificial) which determine firstly, whether an excess moisture situation will result and secondly, the extent of the problem.

The moisture received over a watershed in the form of rainfall is the initial exogenous factor which can cause the problem to agriculture production with which this study is concerned. While moisture is a vital

input in the production process, a preponderence of it over a limited time period can be harmful to plant growth if land drainage is inadequate. But given that rainfall is an element of nature, its adverse effects on agricultural land use must be dealt with by instruments available to man - adjustments in land use and/or adopting methods which can modify the adverse effects.

Attempts to modify the effects of rainfall through drainage calls for prior knowledge about the storm events which are likely to be experienced. Therefore, as a first step in dealing with the problem of excess moisture it is necessary to consider storm characteristics. This includes information on the magnitudes, frequencies, pattern, seasonal variability and areal distribution of storms over the study area. But given that a storm has occurred, it remains to be determined the amount of excess moisture which is likely to result as a consequence of the storm. In attempting to do so it is instructive to review the related physical processes. The relationships embodied here concern that portion of the hydrologic cycle between the incident precipitation and subsequent surface runoff - the Runoff Cycle. Generally, in the runoff cycle, rainfall at the beginning of a storm is stored on vegetal cover as Interception and in surface puddles as Depression storage[1]. These two processes together with evaporation consitute SURFACE RETENTION. As precipitation continues to fall the resulting accumulation of water on the surface referred to as Surface Detention causes flow to begin overland towards the drainage channel wherein it becomes Surface Runoff.

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[1]For a full treatment of the runoff and the runoff cycle see Linsley (1949: 260, 405).

Rain that reaches the soil surface tends to infiltrate, but when rainfall rates exceed the infiltration rates of the soil depressional storage and surface detention occurs. Surface detention then produces overland flow. Water infiltrated into the soil may either become subsurface flows, entering surface channels at various points or may percolate to the water table.

The amount of water resulting in runoff is essentially that which remains after losses through interception, depression storage and infiltration. Infiltration consists of three components: soil moisture, groundwater, and interflow.

When water infiltrates into the soil surface some of the moisture is absorbed by the soil as soil moisture. The remainder is pulled downwards by the force of gravity to either the water table or it may become interflow. Water movement in the form of interflow eventually enters the stream channel at various points. Some of the water reaching the water table may become groundwater flow and thus contribute to channel flow (Linsley: 1949: 411).

The extent of the excess moisture problem on agricultural lands is primarily determined by the total volume of water held in surface detention, the discharge from upstream areas and the ability of the drainage channels to remove the excess water in a reasonable time period. The problem of excess moisture can therefore be assessed by comparing the total volume of water (to be drained off the land) to the drain capacities.

The amount of moisture from a given storm resulting in surface runoff depends on a number of factors. Firstly, interception is largely determined by vegetative cover. Secondly, the amount of moisture retained

as depressional storage is a function of the micro-relief of the watershed's surface. Total infiltration is dependent on soil characteristics which include soil moisture saturation, soil structure and land use. Because infiltration capacity of a given soil tends to decrease with increasing levels of soil moisture, runoff can vary greatly depending on the level of soil moisture. Soil structure is an important factor in any runoff model since some soils, such as the fine-textured clays, have a high swelling potential, thus becoming relatively impervious to water transmission. Others,such as the coarse-textured sands and gravels allow rapid transmission of water downwards, thus accounting for high infiltration capacities. Land use is also an important factor in assessing the proportion of precipitation which is likely to be lost through infiltration. For example, land which is left in fallow condition have greater infiltration capacities than land used for pasture since in the latter situation soils are compacted, making them more impervious.

Predicting runoff therefore calls for quantitative measures of these factors. To this end, the soil conservation service of the U.S. Department of Agriculture have developed in the National Engineering Handbook rather satisfactory methods (U.S.D.A., 1971, Sect. IV). These procedures were used to synthesize historical data for a statistical analysis of runoff function in the study by Rigaux and Singh (1975: Vol.1).

But given that runoff can be predicted, the question which remains is how can runoff from a storm be translated into measures of excess moisture. Before attempting to resolve this, it is necessary to establish the dimension of excess moisture which is relevant for the problem in this study. Studies cited in the literature review together

with actual field experience by farmers have shown that it is the duration of excess moisture rather than the depth of flooding which is the important dimension determing the extent of crop damage. This measure of excess moisture is referred to in this study as Precipitation Excess (PE). When drainage channels are not sufficiently large to immediately remove the surface runoff generated by a storm, water is detained on the land. The length of time of water detention is reflected by the characteristics of the discharge hydrograph, the volume of runoff and the drain capacities. A synthetic hydrograph model developed in the Rigaux - Singh Study (1975: Vol. 1) for measuring precipitation excess is adopted with some modifications for use in the current study.

Applying the methods cited above for estimating runoff and subsequently PE is more complex than revealed thus far. In a watershed with varying hydrologic, topographic, land use and drainage characteristics it is obvious that precipitation excess levels from a given storm-event will differ widely among various segments. It becomes necessary to look at PE for the various segments individually. Because PE over a segment will be assumed constant it is important to define the boundaries of these hydrologic units or subwatersheds so that the hydrologic conditions within each are relatively similar.

Attempts to estimate the PE within each unit calls a recognition of the fact that water detention on the land can result from both upstream runoff and local runoff. In the case of the former, discharges from upstream areas flowing through the subwatershed can produce stages in

the main channel which exceed prairie level[2], thus delaying the drainage of local runoff on the land until the stage level falls below prairie. In addition to the problem caused by upstream runoff in the main channel, lateral and on-farm drains may not be adequate for the removal of local discharge in a desirable time period. This may result from both inadequate channel capacities and intensity of drainage channels.

In estimating PE for various segments of the watershed it is therefore necessary to look at all runoff components - upstream and local. This calls for a recognition of the facts that not all upstream segments and tributaries may contribute to runoff and that depths of discharge from various parts of the watershed are likely to vary widely since storm magnitudes will tend to vary spatially. Probability measures can be appropriately introduced to accommodate these variable and random characteristics. Finally, in determining runoff it is necessary to explicitly consider the hydrologic interdependency among subwatersheds. Flows from various segments accummulate to produce runoff in tributaries and these confluence at various locations along the higher order channels. Such relationships are important in determining the amount of runoff flowing through various locations in the watershed.

EXCESS MOISTURE AND AGRICULTURAL PRODUCTIVITY

The occurrence of significant periods of excess moisture on

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[2]Prairie level is defined as the elevation of land adjacent to the drainage channel. Accordingly, when water level in the channel (stage of the channel) rises to prairie level, there tends to be a reduction in the rate of local inflow into the main channel. Local inflow will completely cease when the stage in the channel is higher than the surface water elevation of local runoff.

agricultural lands can adversely affect the returns to farming in several ways. Directly, output can be reduced. The various means by which this can occur were given in Chapter One. Indirectly, production costs can be inflated. Contributing to this greater inefficiency are the increased uncertainty in farm production and the reduced flexibility which excess moisture introduces in the farming operation.

Certainly, the most significant loss from excess moisture is the reduction in output. This is reflected by depressed average yields observed for fields which have been exposed to excess moisture. Losses may result from a general reduction in the number of stands (plant population) and reductions in plant productivity. This may occur throughout the entire field or for specific locations of the field where the micro-relief allows excess moisture to accummulate.

ALLEVIATING THE PROBLEM: DRAINAGE TECHNOLOGY

The detention of excess moisture on agricultural fields for periods of time sufficiently long to adversely affect agricultural production can be partially avoided by drainage improvement. Drainage technology is varied - the particular type adopted depends on the nature of the problem experienced. For example, in areas where subsurface drainage is needed, tile drainage is appropriate. However, in the present study the primary problem arises from surface water. In some parts of the watershed standing surface water may result because of both the limited permeability of the soils and a high water table. Open ditch drainage is the most effective system for alleviating the problem of surface water. Even for areas where a high water table exists, open ditch drainage can assist (to a limited extent) in removing subsurface water.

In the design of public drains consideration must be given to minimizing erosion, siltation and consequently maintenance. Designs must also provide crossings to permit accessability of farm machinery to the fields. On-farm drains should be designed to minimize the loss of productive lands and should not present any impediment to the use of machinery in field operations.

The drainage system can be conveniently separated into three parts - the main channel, the collection or lateral drains and the on-farm drains. In this project, on-farm drains are designed in the form of a shallow 'V' having depths of less than 1.5 feet, sides of 1:8 and top width of approximately sixteen feet. This design permits the cultivation of the surface area of the on-farm drains and presents no significant obstacles to use of farm machinery in field operations. The lateral or collector drains and the main channel are designed with sloping sides and velocities not exceeding 2.5 feet per second. In steeper areas of a watershed, gradient control structures are required to maintain velocities at or below the limit specified. Additionally, culverts or bridges must be included at public roadways and at railway crossings.

ECONOMIC CHARACTERISTICS OF WATERSHED DRAINAGE DEVELOPMENT

The economic analysis in this study viewed benefits and costs from the stance of the Provincial economy. While primary benefits are expected to be confined to the occupants of the watershed, costs tends to be diffused. Drainage improvement costs will be incurred by farmers, municipal governments and the Provincial Government. All of these result in the preclusion of alternative resource use in the Province and thus they consitute costs to the Provincial economy. Secondary benefits may

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not be confined entirely to the Province since the multiplier effect of increased aggregate demand can extend to distant regions, particularly as a result of input purchase.

BENEFITS

The primary benefits from agricultural drainage improvements are realized because drainage channels remove the excess water from agricultural fields in a shorter period of time than was possible before project construction. In so doing agricultural productivity is enhanced because of the following factors which were previously given:

(i) crop damage avoided

(ii) lower production costs

(iii) reduced uncertainty

(iv) more efficient input usage

(v) production of crops in areas which were formerly too wet or the production of higher valued crops.

Items (i) to (iv) can appropriately be referred to as PRODUCTIVITY BENEFITS whereas item (v) constitutes RECLAMATION BENEFITS.

After implementation of a drainage project the magnitude of the primary benefits realized is directly related to number of times protection is warranted for the crops grown because of the occurrence of excess moisture on the land surface. It is also related to amount of additional protection which is actually provided by the new system for each storm event. The total primary benefits generated by an improved drainage system is therefore the aggregate of crop damage avoided and other gains from improved efficiency for all storms which occur during the life of the project. Essentially, this is equivalent to the increase in net returns

from agricultural production over the project life.

Watershed drainage improvement for agricultural land use will also tend to induce secondary economic benefits. Increases in the efficiency of agricultural production and in the net returns to farming are likely to stimulate demand for agricultural services and inputs. These may be confined within the watershed or diffused over the region. In the case of the Big Grass Watershed the latter situation is more likely since farm input and services are generally obtained from nearby towns outside of the watershed's area. Higher incomes are also likely to stimulate demand for consumer goods and services. The multiplier effect of increased demand levels constitute one category of secondary benefits. Secondary benefits of an intangible nature may also result because of increased economic activities in the watershed. These include the benefits derived by residents of the area from improvements in infrastructure and other public services.

Unmeasurable social benefits are also possible from watershed drainage development and may result from income redistribution effects and/or the redistribution of income earning potential of farmers in the watershed. With respect to the former, drainage investments which are partially financed by the Provincial treasury are likely to consitute a redistribution of income from individuals outside of the watershed to those within the watershed. In the latter case, the variable nature of the amount of increased protection provided for various segments of land area will be an important factor in redistributing income earning potential. Unmeasurable social benefits are also likely to occur from improved rural living conditions which can be induced because of the primary benefits which occur.

The economic benefits from expenditure incidence are likely to be diffused not only to areas outside of the watershed but also outside of the Province. These include expenditure on heavy machinery rental, labor and material input such as lumber (for bridges) and culverts.

While this study recognizes the existence of other primary benefits, secondary benefits, intangible and unmeasurable benefits from improved agricultural drainage protection these have nonetheless been excluded from the analysis primarily because they are likely to be relatively small when compared to crop damage protection benefits. Langvatn (1958) suggests that is the case for agriculture in Norway. Further, the difficulty in obtaining data to estimate other primary and secondary benefits together with the problems inherent in using suitable estimation procedures (such as input-output to measure secondary benefits) do not seem to justify their inclusion in the accounting framework in this study on the basis of their likely marginal contribution to the accuracy of the decision-making data.

This study therefore concentrates on the major primary benefits - benefits from crop damage reduction and from land use modifications. These will be reflected by higher net returns.

After the drainage project is constructed its usefulness or the protection benefits for which it is designed will only be realized when rainstorms, of magnitudes which are harmful, occur. Because of the stochastic nature of rainstorms and because precipitation data show wide variability it follows therefore that benefits are also likely to show variability both over the life of the project and from one project period to another. Decisions are therefore likely to be crucially influenced by the stochastic behaviour of the exogenous precipitation variable.

Its stocahstic influence was therefore allowed for in this study.

Benefits from drainage improvement are also influenced by economic variables such as crop prices and costs of production. Both these variables are exogenous to the system and are stochastic in nature. While crop prices have generally shown more variability relative to costs, together they can cause extreme variability in the net returns to farming and consequently in the benefits. During periods of depressed prices projects which are shown to be non-feasible may yet prove feasible in other periods of more bouyant crop prices. The effects of the variability in these variables both within a project period and among different periods are considered in this study.

COSTS

The oppotunity cost of resources used to improve drainage constitutes the economic cost of the project. These include the cost of channel construction, bridges, culverts, gradient control structures and right-of-way costs. While the jurisdiction over drainage is divided between the farmers (for on-farm drains) and the public sector (for the public drains) the economic accounting framework considers cost of the total drainage system. In addition to the capital expenditure, maintenance costs are incurred over the project life to ensure that drainage efficiency is preserved.

The possible adverse effects of watershed drainage improvement and the costs associated with must be considered. Because changes in the drainage system can cause flooding effects downstream the impact of these changes must be evaluated. The externality cost may consitute either the cost of additional protection downstream to avoid the increased flooding from improvement or the losses to property, agricultural production or wildlife habitat.

CHAPTER 4

THE UNDERLYING THEORETICAL RELATIONSHIPS IN THE ECONOMIC EVALUATION OF DRAINAGE

OVERVIEW

Watershed resource development, initiated by the public sector, has as its primary goal the improvement of welfare of individuals in the communities within the watershed. In this study the specific instrument proposed is drainage development. This modification of the resource base is expected to increase productive-efficiency thereby conferring additional economic surplus[1] or economic rent to farm operators with land requiring better field drainage. On the other hand consumers of the project's output are not expected to enjoy any increase in consumers' surplus since the relevant demand functions are almost perfectly elastic. This results from the fact that volumes of the major commodities produced, which are cereal grains, comprise only small shares of the respective market supply. Nevertheless, the

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[1] Economic rent or economic surplus accrues to owners of factors of production. The analogous concept for consumers is consumer's surplus.

Economic rent is defined on the reward paid for the use of a factor in excess of the minimum payment necessary to keep that factor in its present use. Rent arises because of inelasticity in factor supplies. The inelasticity itself reflects the way in which the factor services affect individual utility. When the supply of a service or a good is inelastic, the intra-marginal units are rewarded the same on the last unit supplied. Such payments exceed the minimum amounts required for the use these intra-marginal factor units. Thus, the accrual of economic rent.

Consumer's surplus is defined as the maximum a consumer will pay for a given amount of a good, less the amount which is actually paid. For further discussions on these concepts see: Mishan (1971:31-56), Millward (1971:57-73).

increased economic rent accruing to producers will tend to increase their economic welfare. Development is expected to result in larger expenditure budgets being attained by farm families, thus allowing them to consume a combination of goods producing a higher level of satisfaction than was possible before development. Other favorable impacts include the improvement in income stability, reduced risk and uncertainty, greater flexibility in production planning and operation. Better farm living, including food, shelter, health and leisure are some of the factors which tend to improve satisfaction.

This chapter explores the theoretical basis for social welfare improvement for occupants of the watershed as a result of drainage development. It is shown in the second section that the Pareto conditions for efficiency in the economy together with a well-defined social welfare function can define, theoretically, a unique bliss point (optimum optimorum), but from a practical viewpoint these concepts do not provide a useful quantitative approach for evaluating the desirability of alternative projects. Establishing the social welfare implications of a project and making a choice among projects are generally conducted using the GNP criterion. Rationalization of the GNP criterion for this purpose is the focus of the third section. The discussion in the two sections which follow assumes that drainage improvement does effect an increase in productive-efficiency. The theoretical basis for such an assumption is examined in the section in which the micro-economic behavior of the individual producer is analyzed to demonstrate how drainage can induce efficiency changes and how

producer rent accrues.

WELFARE THEORY AND ECONOMIC EFFICIENCY

Consumer theory assumes "consumer sovereignty"—that is, the individual is solely interested in his own welfare and he is the best judge of his own welfare. Satisfaction or utility increases when more goods are consumed. Accordingly, the individual whose consumption is limited by a budget tends to consume the bundle of goods and services which maximizes his satisfaction or utility. This relationship may be represented in the following general form:

$$V = V(q_1, q_2, \ldots, q_n, m)$$

where: $\frac{\partial V}{\partial q_1} > 0$

and: V = level of utility or satisfaction obtained from consumption

$q_1, \ldots, q_n$ = goods consumed

m = budget constraint.

For purposes of exposition, consider the case where the consumer's choice is limited to two goods. His utility function is:

$$V = V(q_1, q_2)$$

Firstly, any particular level of utility, V^o, can be derived from the consumption of various combinations of the two goods. The locus of such combinations of q_1 and q_2 which gives the consumer a constant level of satisfaction is called the Indifference Curve. Consumption of greater amounts of q_1 and q_2 or both will result in a higher level of

satisfaction, such as that described by the indifference curves I_2, I_3, etc. as shown in Figure 4.1. These contours therefore provide ordinal ranking of the individual's satisfaction since utility is not a cardinal measure.

Given relative prices for the commodities q_1 and q_2 and a budget constraint, the consumer attempts to maximize satisfaction. With a budget such as m_1 (Figure 4.1) the maximum satisfaction attainable is I_1 which requires a combination of goods such as q_1q_2. When the consumer's budget increases to m_2 (as is the case when additional economic rent accrues to farm operators) the maximum satisfaction attainable is now I_2 which is more than I_1. The relationship holds true for any number of commodities and individuals.[2]

Social welfare or the welfare of the community is defined as some function of the levels of satisfaction of the individuals who comprise the community. Such a function may be represented as follows:

$$W = W(V_1, V_2, \ldots, V_n)$$

where: W = welfare level of society

$V_1, \ldots, V_n$ = utility levels of individuals $1, \ldots, n$

and, $\frac{\partial W}{\partial V_1} > 0$

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[2] The above discussion assumes convex to the origin indifference curves to derive maximum utility at points of tangency. End point maxima are obtained when indifference curves are concave from below or if the curves are convex from below but at all points are less steep than the budget line (see Henderson and Quandt, 1958:8-15).

Improvement in the level of satisfaction of one or more individuals without a reduction in the satisfaction of any others in the community is defined as an improvement in social welfare. In welfare economics terminology, after the famous economist, Vilfredo Pareto, any economic organization of production and consumption which provides the maximum social welfare attainable under the conditions of given technology and resource supply is said to be Pareto Optimal or Pareto Efficient.

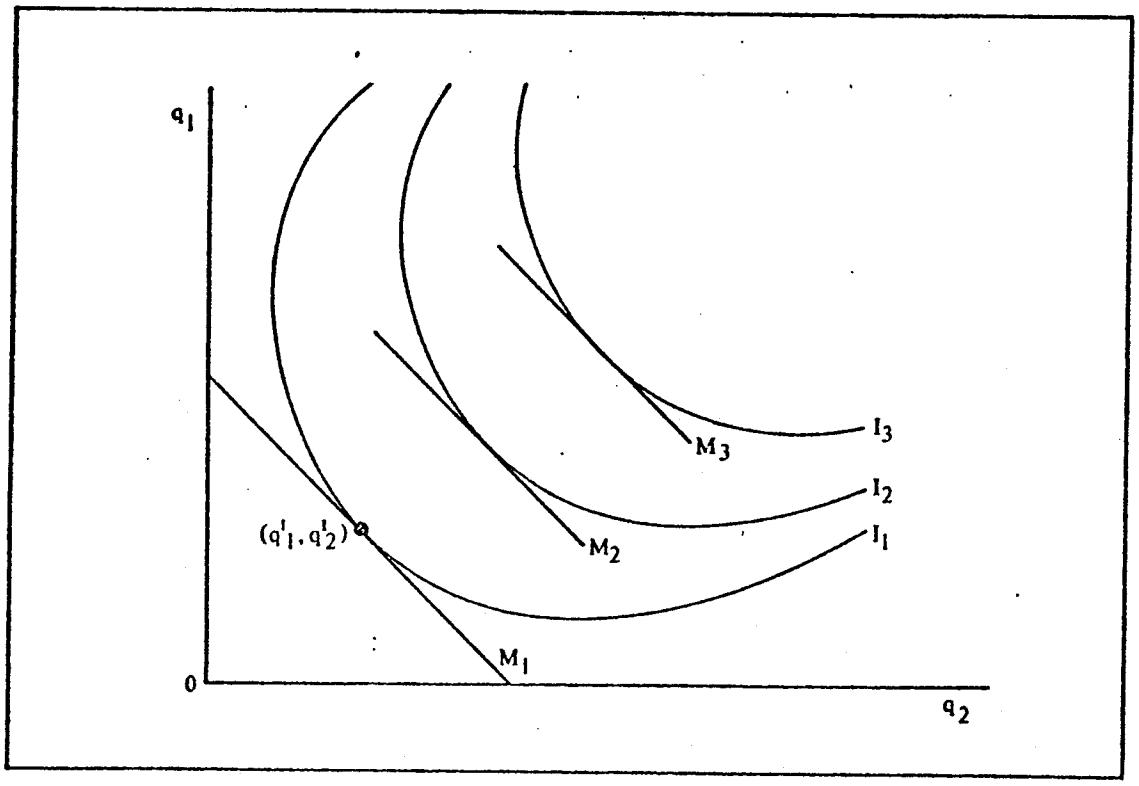

Figure 4.1 - Indifference Curves and the Budget Constraints

Any reorganization of the economy from a Pareto Optimal status cannot improve the level of welfare of any one individual without having a reduction in the welfare level of one or more other individuals.[3] The locus of such points described in the utility space represent

[3] For further discussions on welfare economics see Millward (1971:9-34, 85-108), Little (1957).

efficiency in the economy (Figure 4.2) and is refferred to as the Grand Utility Possibility Frontier. Obviously there exists an infinite number of alternative organizations of the economy which are efficient.

In order for the economy to attain Pareto efficiency, there must be efficiency in both the producing sector and the exchange of goods and services sector. This is achieved when the marginal rate of product transformation equals the marginal rate of commodity substitution among all consumers and for all goods. Each Pareto efficient point therefore corresponds to a combination of goods produced for which exchange is efficient and the rates of substitution are equal. Of course, the usual assumptions about technology, consumers' taste, producers' motivation and perfect competition are not sufficient conditions to ensure the attainment of Pareto efficiency in the economy. Externalities, lack of perfect information, immobility of resources and uncertainty are some of the causes of market failure[4] and consequently a non-Pareto organization of the economy.

Thus far the discussion has provided no criterion to identify the Pareto efficient organization of the economy which maximizes social welfare. Theoretical welfare economics relies on a social welfare function to locate the Pareto efficient organization of the economy which maximizes welfare. Thus, the social welfare function provides a normative (unique) ordering of society's preference for distribution of satisfaction levels among individuals. For the illustration in Figure

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[4]For an analytical discussion of market failure see Bator (1958).

4.2, the organization of the economy which corresponds to utility levels V_A^1 and V_B^1 for individuals A and B, respectively (assuming a two-person society), maximizes social welfare, given the particular welfare function.

But while welfare functions and utility functions are useful in understanding the concept of welfare maximization it is not possible to develop a practical approach for measuring the impact of a project, since their functions are not readily specified. The gross national product (GNP) criterion, based on the tenet of productive-efficiency, is most commonly used to appraise projects, determining in a rough way the extent to which society gains from a project.

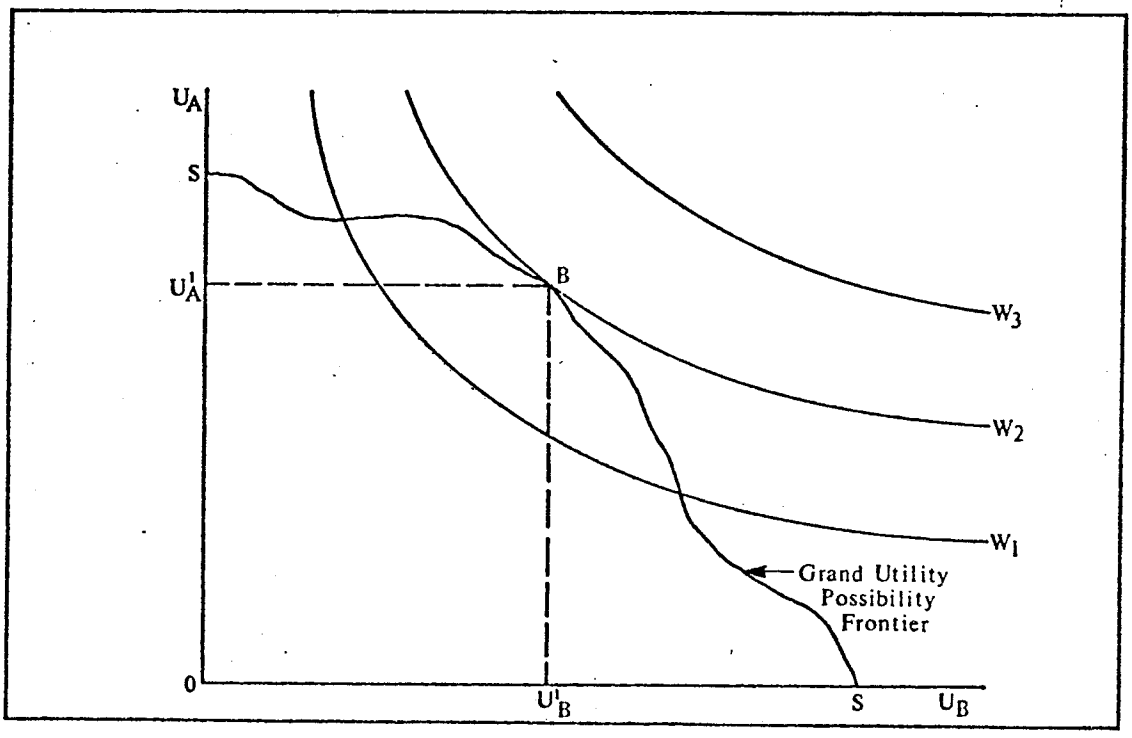

Figure 4.2
Maximum Social Welfare

THE GNP CRITERION FOR WELFARE IMPROVEMENT

In spite of a number of shortcomings, the GNP criterion is yet the most practical criterion for project appraisal and resource allocation decisions. Resource allocation decisions on the basis of this criterion will improve social welfare only if assumptions of equitable income distribution and the absence of market power in the relevant sector of the economy are not violated to any appreciable degree.[5] The GNP criterion has appeal to the quantitative analyst because it relies on quantifiable magnitudes (of goods and services) rather than abstract utility or social welfare functions for the choice among projects which results in the greatest improvement in social welfare.

The GNP criterion, as a measure of social welfare, is based on the assumption that efficiency in production together with an output mixture for the economy dictated by market forces is consistent with consumer demands and the goal of maximizing individual satisfaction and consequently social welfare. The greater the GNP, the more value is derived from the total goods consumed and the higher is the level of social satisfaction. Of course, the foregoing assumes an acceptable income distribution and an absence of significant market imperfections. Given limited resources, "an economy is said to be productively-efficient if it is producing as much of every good and service (rather than

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[5] At least, if these occur there should be mechanisms to deal with them in a manner which will result in efficient resource allocation. (See Dorfman and Dorfman, 1972:XXV.)

utility) as is technically possible" (Dorfman and Dorfman, 1972:XXV). The locus of maximum production of various goods attainable from given resources is the Production Possibility Frontier. In the example illustrated in Figure 4.3, it is assumed that only two goods, wheat and forage, are produced in the economy. The curve XY describes the maximum combinations of both goods which can be produced from fixed resource supplies. While all output combinations in the region OXY are technically feasible, only the set located on XY are technically efficient.

As an example, consider the problem situation in the current study. The frequent condition of excess moisture in the study area results in inefficient resource use. Under such a situation the production possibility can be thought of as a constrained locus, such as CD, inside the efficient frontier, XY. The extent of the outward shift

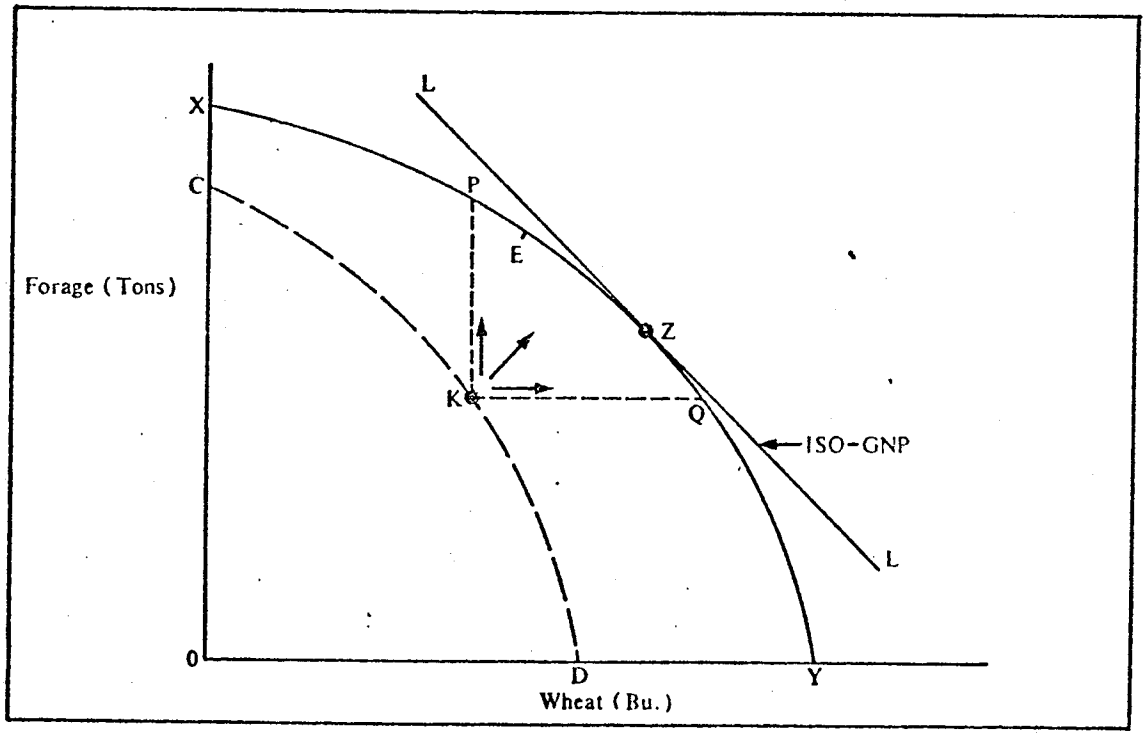

Figure 4.3 - Maximizing GNP

in the constrained locus is, of course, dependent on the design or the level of drainage improvement provided by the project. If other factors which generally contribute to inefficient production, such as management, are improved, it is theoretically possible to shift CD to become coincident with the frontier XY.

From the above discussion all that can be concluded is that on the simple assumption that society will be better off with more of one or both goods then an economy cannot be Pareto optimal unless it is productively efficient (Dorfman and Dorfman, 1972:XXVI). If it is now assumed that prices truly reflect consumer satisfaction or utility then the project scale which provides consumers with commodities they value most highly, in dollar and cents terms, is providing them with the most utility. Welfare is therefore maximized when the efficient output mix corresponds to the tangency of the production possibility frontier (XY) and the ISO-GNP line (LL)—that is, point Z. Of course, it cannot be overstated that the validity of the above is based on the assumptions that prices reflect benefits or utility and that income distribution is equitable or acceptable.

While a necessary condition for maximizing welfare using the GNP criterion is the attainment of productive-efficiency in the economy the nature of the problems considered in benefit-cost analysis can often be adequately studied within a simplified partial equilibrium framework.

The analytical problem in this study involves the determination of whether the drainage project yields a net welfare gain and if such is the case, to select from a number of alternatives the project scale which

maximizes the gains in social welfare. Using the GNP criterion, the above calls for an estimation of all benefits (increased value of production) and all resources used in the development of the watershed (costs). To the extent that disbenefits or 'spillover' effects result from the project these must be included in the benefit-cost accounting framework.

Projects which produce both benefits and disbenefits do not qualify as being desirable according to the strict Paretian definition. However, according to Mishan (1971:316), such changes are potential Pareto improvements and as such are desirable if net benefits are positive. Mishan argues that allocation theory is concerned with the latter which he defines "as an arrangement in which the gains can be so distributed so as to make everyone in the community better off."[6]

MICRO-ECONOMIC ADJUSTMENTS TO DRAINAGE DEVELOPMENT

The response in agricultural production to drainage development in a watershed and the manner in which likely benefits will be generated can be shown by considering, once more, the production possibility curves. Figure 4.4 shows two possibility curves--P.P. which represents a constrained frontier, reflecting the current state of inefficient production in the watershed, and P_2P_2 which is the production possibility frontier, reflecting efficient production or the situation when the

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6 On a theoretical level the question as to whether or not compensation can be made and yet confer a net gain to society has been extensively debated and has resulted in various criteria for welfare compensation tests such as those proposed by Kaldor, Scitorsky, Hicks and Samuelson. See Mishan (1960:218-235).

excess moisture problem is alleviated. Under current conditions GNP is maximized by producing an output mix[7] indicated by (x). But as drainage development improves productive-efficiency, it can be assumed that production on the efficient locus, P_2P_2, is attainable. A higher level of GNP such as that represented by MM is now possible. The gross benefit to society is therefore the change in GNP because of efficiency gains induced by the project. The use of resources for project construction results in a reduction in welfare since alternative activities in the economy (consumption or investment) must be foregone. These resources used by the project constitute the costs of the project. Feasibility is established if the project generates a net increase in GNP or, in other words, a net gain in social welfare.[8]

The net gain to the community from drainage development is the aggregate effect of adjustments which each producer makes when better drainage and consequently, more productive lands are available. The micro-economic aspects of these adjustments are discussed in this section.

In an area where the problem of excess moisture is significant, agricultural production is subject to even greater variability than

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[7] This is in fact determined from the marginality condition—marginal rate of product transformation between forage and wheat (in the example cited) and the inverse of their price ratios (assuming elastic demand for the region's output. See Henderson and Quandt (1958:6-8).

[8] According to Heady (1952:704) the marginal condition for maximum physical output of the farm with limited resources becomes the marginal conditions for attaining maximum efficiency in society if prices represent consumer choice and input price reflect the value of service.

would otherwise obtain. For such areas excess moisture is often the major factor causing production variability. The uncertainty associated

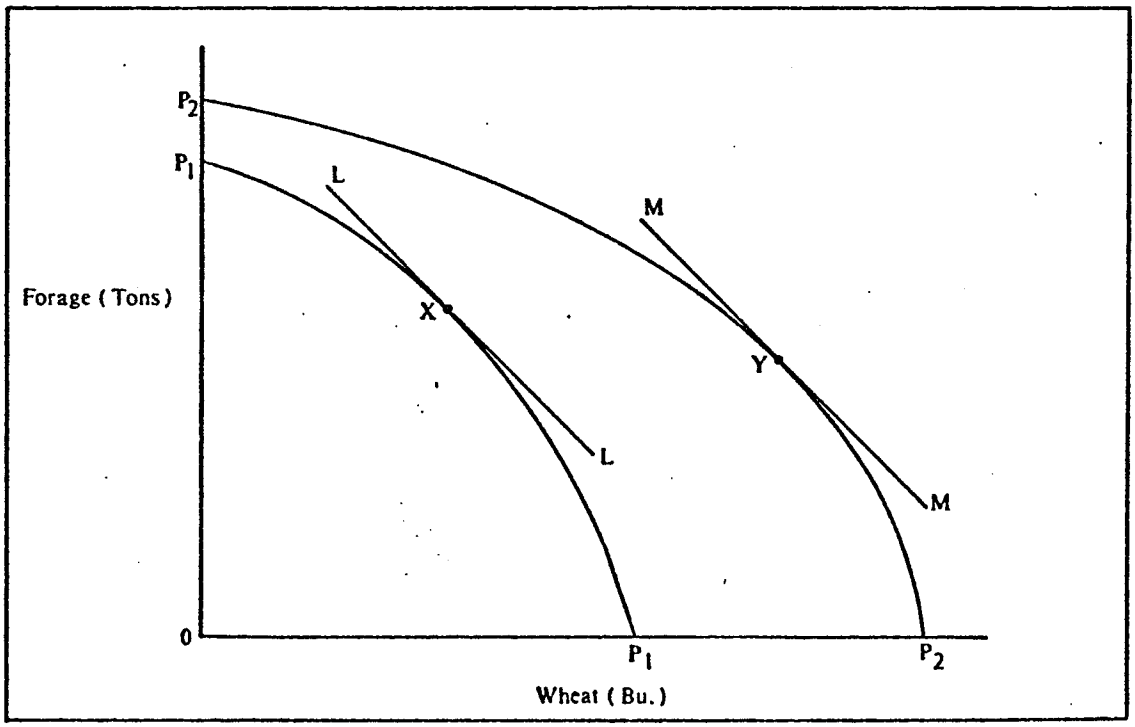

Figure 4.4
Shift in the Production Possibility Frontier from Drainage Improvement

with the problem affects farm planning, imposing a real efficiency cost. With improved drainage crops are better protected against storm events thus reducing the magnitude of the moisture excess problem. It improves productivity and exerts a stabilizing effect on production. The consequences of uncertain outcomes with respect to agricultural production are less significant after drainage development. It should be noted that while drainage development tends to reduce production variability, income may yet fluctuate since it is influenced by economic variables which are exogenously determined.

To develop the argument showing the efficiency cost associated

with the excess moisture problem consider, as an example, the production function for wheat and assume the use of one variable input—fertilizer. Also, assume that producers wish to maximize profit, prices are constant and there are no capital restrictions. For those years when the excess moisture problem is significant crop yields will be depressed; but in years when growing conditions are more favorable productivity increases. This situation may be viewed as an upward shift in the production function. We may consider such a shift as non-neutral—that is, marginal productivities change for various input levels. This suggests that for increases in productivity, optimal production requires higher levels of variable input to the fixed land resource. The optimal level of input is determined from the condition whereby the marginal value product of fertilizer application in the production of wheat equals the price of fertilizer. It can be assumed that producers, in some intuitive fashion, perceive their production functions on the basis of observed yields over a number of years for certain fields or soil groups. If drainage is inadequate a high density of lower level yields are observed. A producer tends to plan his production based on the expected production function, shown as F, in Figure 4.5. Maximizing behavior will result in an application of X_1 fertilizer giving an expected output of Y_1. If excess moisture conditions do not occur in a given production period, the production function shifts to F_2. But since production plans were based on function F_1 with fertilizer level X_1, the realized yield will be Y_2— which is less than the optimal amount. Optimum input application would have required X_2 fertilizer giving a yield of Y_2'. The efficiency cost,

in this example, due to uncertainty is equal to Y_2Y_2' bushels of wheat less the cost of additional input (X_1X_2).

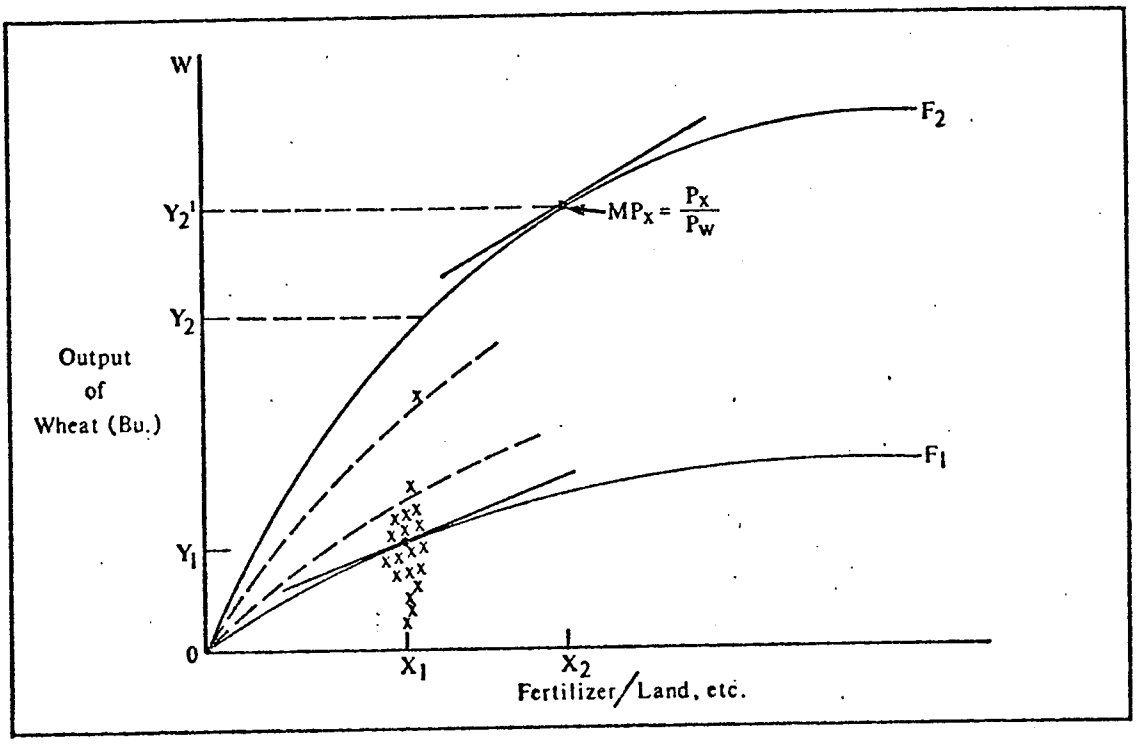

Figure 4.5
Production Conditions When Excess Moisture Problems are Frequent

When drainage protection is increased for the crops grown, the density of observations shifts upward resulting in an expected production function such as Y_2 (Figure 4.6). Additionally, excessive crop damage will now be avoided thus resulting in less deviation in realized output. As an example, Figure 4.6 shows that the production functions will now fluctuate between Y_1 and Y_3. A producer will plan his production based on the function Y_2. If, however, moisture excess conditions cause Y_1, or Y_3 to be realized, the efficiency cost resulting

from incorrect production planning will now be smaller than for the case illustrated in Figure 4.5.

Crop production records for the selected study area show that the level of fertilizer application is generally low. Two likely factors accounting for this are: (i) limited capital resource of farm operators; and (ii) production plans based on low level production functions such as Y_1 in Figure 4.5.

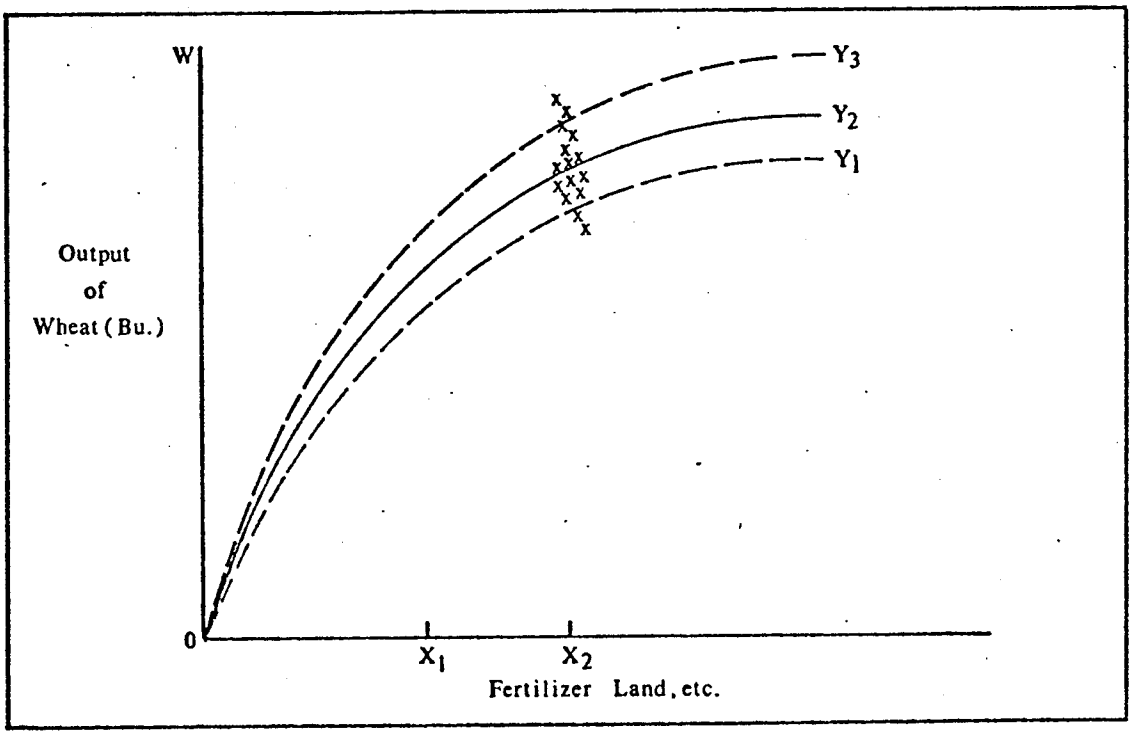

Figure 4.6
Production Conditions When Excess Moisture Problems are Reduced

Another adjustment which is likely to be induced by drainage development is the shift in relative factor intensities. As land becomes more productive there would be the tendency to substitute other inputs, such as seed quality, fertilizer, herbicides, labor and

machinery for land. Such a shift in resource intensity is shown in Figure 4.7 where q_1 represents an isoquant under current production conditions. As land productivity is enhanced by drainage development higher levels of output are now possible from given quantities of land (assumed variable) thus resulting in isoquants typified by q_2. Assuming no limitation on capital, factor intensities will shift from F_1 to F_2 where F equals the fertilizer to land ratio.

Drainage improvement works can also indure land use adjustments. As land productivity is enhanced it is possible that production of grains may now become the most profitable land use in some soil groups

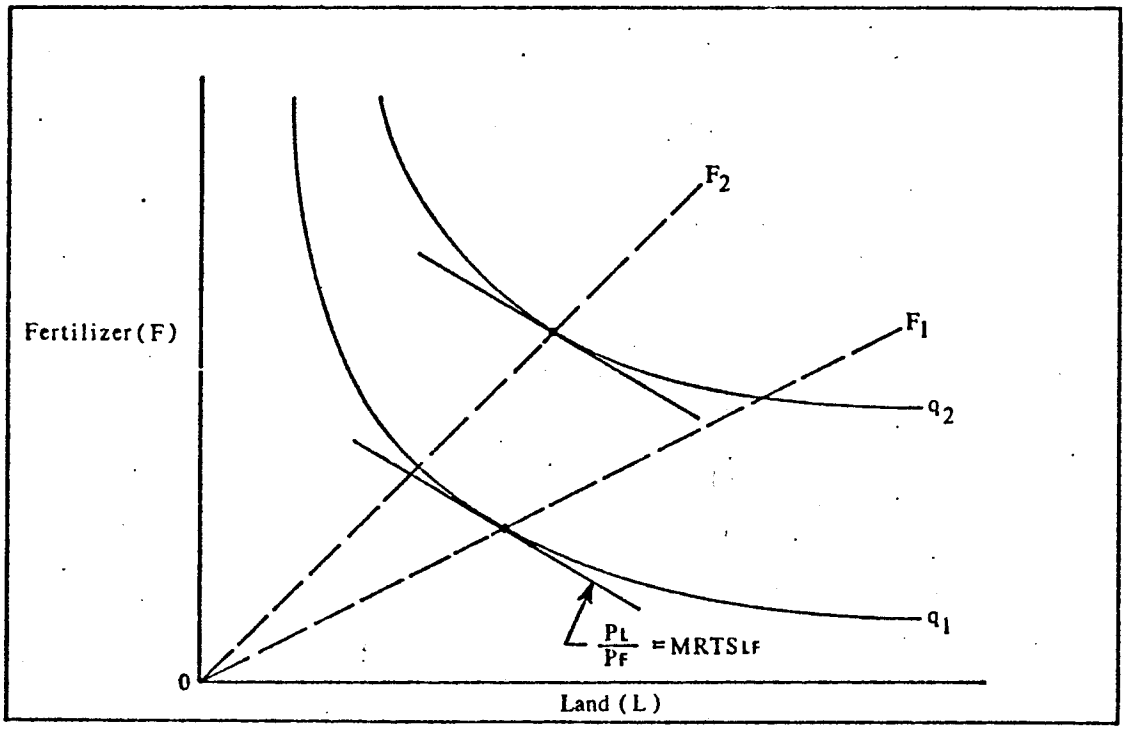

Figure 4.7
The Effect of Drainage Improvement on Factor Intensity

where previous levels of excess moisture resulted in forage or native grassland being the most profitable use. This can be attributed to the relative sensitivities of various crops to excess moisture in the different soil groups. Cereal grains are generally the most susceptible to damage from excess moisture. Cultivated forage can withstand slightly greater periods of exposure to excess moisture. Native grassland is little affected. For these reasons relative profitability of crops can change when drainage protection is improved.

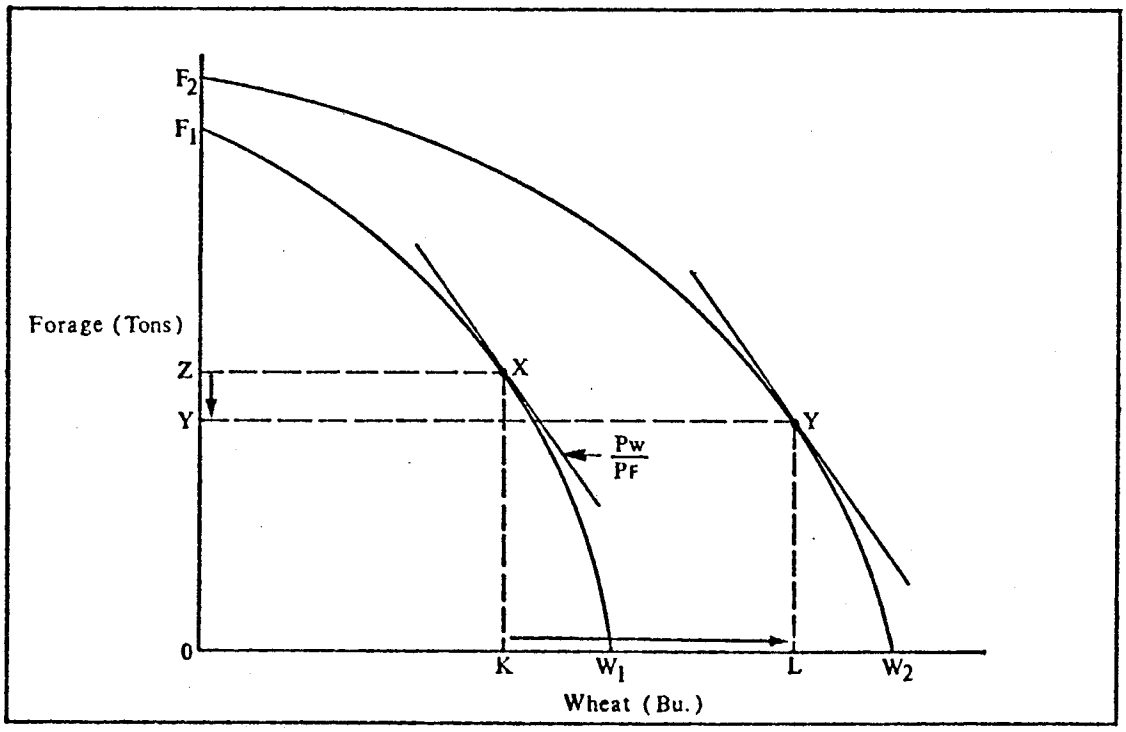

Figure 4.8

The Effect of Drainage Improvement on Output Combination

This effect of improved drainage on production can be explained by the outward shifts in the production possibility curve. Consider the case shown in Figure 4.8, where only two crops—wheat and forage--are grown and assume perfect divisibility. Also, assume that there is a greater proportionate improvement in the productivity of wheat relative to forage. Before drainage improvement, efficient output mix is identified by the tangency of the price line and the production possibility curve (F_1W_1)--that is, point (x), which requires OK units of wheat and OZ units of forage. After drainage development (assuming constant prices) the new efficient output combination is represented by point Y—that is, OL units of wheat and OY units of forage. As a consequence, farm operators must make production adjustments if they wish to maintain a profit maximizing position. The example illustrated calls for a reduction in the production of forage by YZ units and an increase in wheat production by KL units.

SUMMARY

If we assume an economy with no market imperfections (that is, there exists perfect competition) and no market failures then welfare economic theory provides decision rules for maximizing social welfare. But these are based on concepts such as utilities and social welfare which firstly, are reliant on value judgments, and secondly, are not quantifiable. In addition, the Pareto optimality conditions for attaining economic efficiency are based on a general equilibrium framework. The conditions are onerous to satisfy when resource

allocation decisions are to be made for development projects. Further, many such projects are small relative to the total economy. Adequate resource allocation decision rules can generally be formulated by viewing the problem within a partial equilibrium framework, thus ignoring elements which are not significantly affected by the economic changes. Applied studies have therefore relied on the GNP economic criterion for making resource allocation decisions. Its appeal lies in the fact that quantifiable magnitudes are used to choose among alternatives. It, nonetheless is based on rather strong assumptions about the acceptability of the prevailing income distribution and the suitability of market prices as a measure of value or benefit. The GNP criterion was therefore used to evaluate project feasibility in this study.

The basic assumption behind drainage development is that it confers benefits on individuals in the watershed. It was appropriate therefore to show in this chapter the theoretical validity of such an assumption. It was shown how GNP increases when the production possibility locus shifts towards the frontier and the benefits from reduced chance of crop losses. The micro-economic adjustments in factor intensity and cropping activities, which were discussed, will also improve efficiency.

Chapter 5

CONSTRUCTION OF THE THEORETICAL MODEL

INTRODUCTION

In the discussion of the conceptual framework the various forms of direct and indirect benefits and costs resulting from the project were discussed. There it was indicated that the analysis concentrated on the measurement of the major primary benefits (that is, the value of increased agricultural production) induced by drainage development. In this chapter the theoretical basis for a selected approach to estimate benefits is discussed. Conceptual difficulties in estimating costs are also discussed. Given that drainage projects provide improved protection for crops, benefits will be realized whenever protection is warranted--that is, whenever storm events (of magnitudes which can cause crop damage) occur. With respect to costs, large capital expenditures are incurred in the initial years whereas recurrent maintenance costs occur over the project life. The theoretical basis for selecting a project life and a discount rate is also discussed in this chapter. The final section of this chapter presents the theoretical model for identifying the efficient project scale.

BENEFITS

The analysis in this study focused on efficiency benefits. Such benefits may accrue to consumers from the consumption of the project's output or to producers because of increased returns from farming. Net benefits from the consumption of a certain quantity of a

good is defined as consumers' surplus. For example, if OX of a good is consumed (as shown in Figure 5.1) then consumers' surplus equals the area LMN. Total benefit derived from consumption of OX is OLNX. However, OMNX resources were used to acquire the goods and thus net benefit or consumers' surplus is LMN.

It should be noted that the use of the demand curve to measure consumer benefit when non-marginal changes are involved (such as XK in Figure 5.1) is premised on the fact that marginal utility of money is roughly constant (Millward, 1971:67). This condition ensures that the benefits so measured are in fact the maximum amount which the consumer will pay for the extra good or approximately the benefits measure from the compensated demand curve. The assumption that the marginal utility of money is constant is generally satisfied if the change is small relative to the consumer's budget. This point is made by Marglin (Mass, 1962:37) with respect to project's output which are consumer goods.

Under the conditions stated above if the project causes a change in consumption of XK units (Figure 5.1) then the consumer benefits of the project equal the increase in consumers' surplus, PMNR. Producers may also benefit from improved efficiency. The project can cause an increase in output or reduction in costs or a combination of both these factors. Such changes in production will tend to shift the producer's supply function to the right thus increasing the returns to the producer. This type of economic benefit is referred to as producers' surplus, which is the excess of price over the marginal valuation of successive units of output. The possible inaccuracy in measuring

producers' surplus from the supply function is symmetrical to that encountered in the demand curve measure of consumers' surplus. If it cannot be assured that price changes have a small impact on the producer's budget, then it is necessary to bear in mind that economic rent will be underestimated by the supply function. The area KMNJ in Figure 5.2 represents producers' surplus from OL units of output. This benefit is comprised of two components: (i) the area KMQJ, which results from lower marginal costs on OX units of output, and (ii) MNQ which is the producers' surplus from the production of an additional XL units of output. Improvements in productive-efficiency results in benefit accrual to the producer since he can now attain a higher level of consumer satisfaction because more resources are available to acquire

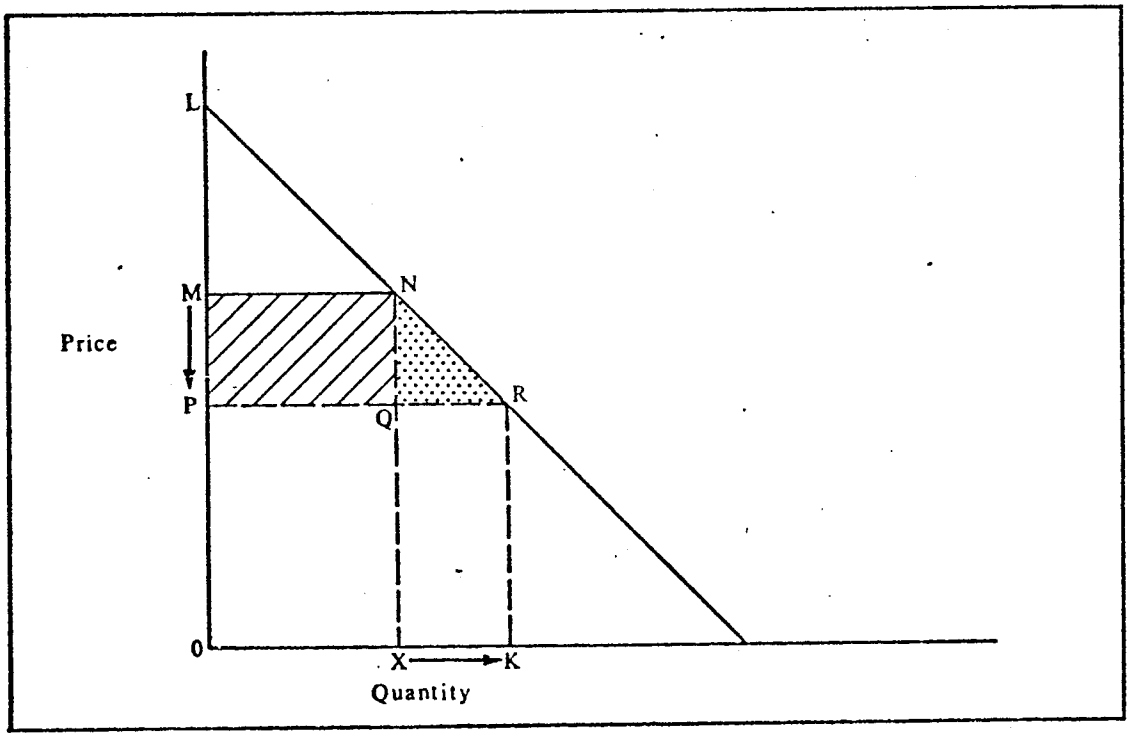

Figure 5.1

Increased Consumer's Surplus Induced by a Project's Output

goods and services.

Many public projects, such as recreation facilities, health and education, provide goods which go into direct consumption and are generally not priced in the market place. Evaluating the benefits from such projects is a difficult task, calling for the use of shadow pricing technique.[1] Fortunately, drainage projects belong to a class of public projects whose outputs are intermediate goods which are valued in the marketplace. Consequently, the increased volumes of agricultural

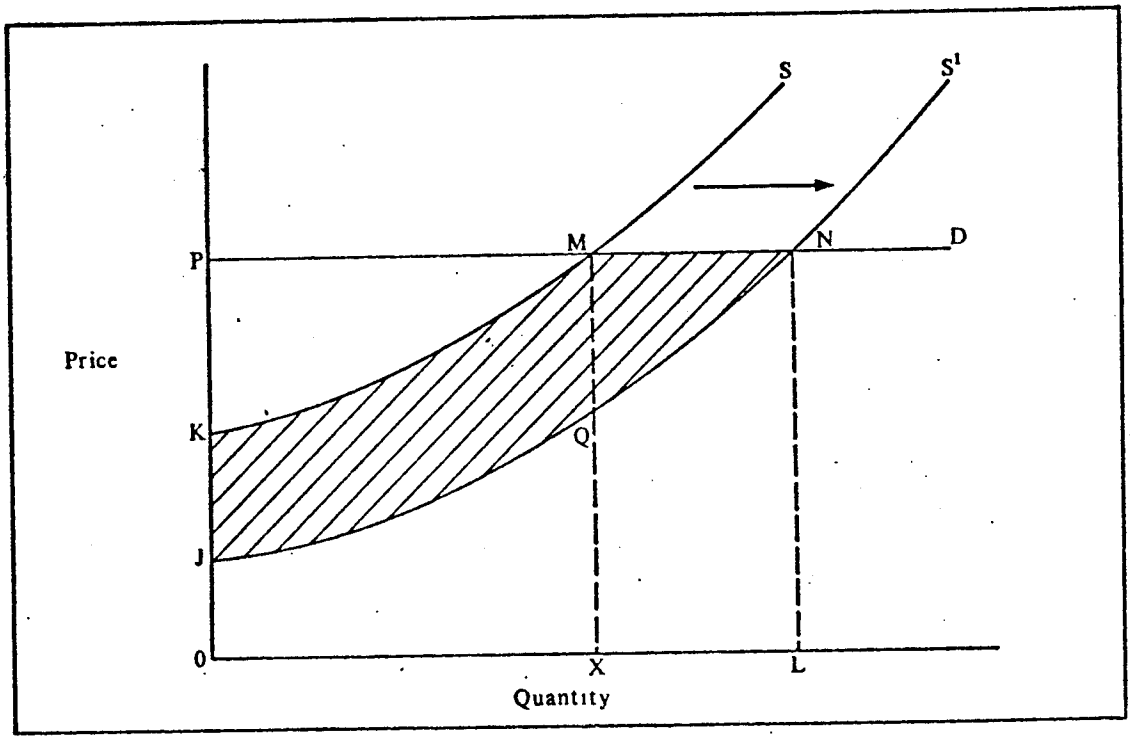

Figure 5.2

Increased Producer's Surplus Induced by a Project's Output

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[1] A 'shadow' or 'accounting' price is the price assigned to a good or service for the purpose of economic evaluation since it is felt that market prices do not truly reflect the economic worth or value of the good. The shadow price is intended to better reflect value. See Mishan (1971:79-89).

commodities (induced by the project) valued at market prices[2] provide an estimate of the benefits. If the output generated by a project significantly alters the market volume, prices will be lowered causing an increase in consumers' surplus. But if, relatively, there is no appreciable change in market supply then prices will not be affected and consequently consumers' surplus will not change.

The main agricultural products for the selected study area are wheat, oats and barley. Smaller amounts of cultivated forage are also found in this watershed. Commodities such as cereal grains enter the international market, which is a large market such that the increased output from relatively small projects, such as the one considered here, cannot affect prices. Also, changes in forage production are not expected to significantly affect prices. As a result of the foregoing, the demand functions for the project's output can be considered highly elastic showing almost no price response to changes in output. Benefits in the form of consumers' surplus are therefore expected to be negligible. All project benefits accrue via producers' rent. Figure 5.2 illustrates this case. Improved agricultural productivity causes the supply function for outputs to shift to the right thus generating a net increase in producer rent equivalent to the area KMNJ. For drainage projects it is likely that the additional production XL results primarily from increased productivity on acreages currently in

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[2] It is assumed that markets are competitive and that the demand for the project's output is elastic. These conditions ensure that market prices are good reflection of the value of these goods.

production. It is also possible that some portion of XL may result from new acreages (previously not economically viable for production) or from changes in land use.

Drainage development is expected to result in labor, machinery and other input economies and consequently a lower production cost per acre. But these changes are difficult to quantify and since, relative to the benefits from increased production, these are likely to be small, they have been excluded from the analysis. It is therefore assumed that total per acre costs of production are unchanged by drainage improvement, although unit output costs fall when productivity increases. On the basis of the foregoing, if it is assumed that OL units of output as shown in Figure 5.2 is produced on current acreages then the total costs are unchanged and area OKMX equals OJNL. In this situation benefits equal the value of additional output (XL) that is, benefits equal the area XMNL.

When the additional output comes from both current acreages and new acreages (reflecting land use changes) the accrued producers' surplus is not simply the value of the additional output. Costs associated with the new acreages must now be included in the analysis. These are production costs and, if necessary, development cost. Also, for acreages representing land use modifications output type changes. Because of the above factors benefits in this study must be evaluated on the basis of improvements in net returns rather than simply the value of additional output. This is the approach adopted in the analysis.

COSTS

Project cost equals the most valuable alternative foregone by the use of resources for project construction. It also includes the reduction in production or consumption activities as a consequence of adverse effects of the project. In this study the costs include the value of resources used in actual construction of drainage channels, rights-of-way, bridges and gradient-control structures. It also includes any loss in agricultural production which may result from downstream flooding within the watershed. Further, if flooding were to occur downstream from the watershed the effects which are external to the watershed (in the physical sense) should be internalized in the economic analysis since evaluation is conducted from the provincial viewpoint. Costs are also incurred for the recurrent maintenance work necessary.

MARKET PRICES AND THE EVALUATION OF BENEFITS AND COSTS

If market prices truly reflect marginal valuations of goods by consumers or producers (inputs) then these are appropriate measures of social value.[3] When the economy (or the relevant sector) is characterized by idle resources (at least those required by the project) and market imperfections such as immobility of resources, monopolistic market elements, price support programs and externality effects, prices

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[3] Consideration should also be given to the effect of output on market prices. This point was discussed in a preceding section. Howe (1971: 47) discusses this case in greater detail and suggests a method of handling it in benefit-cost analysis.

may not truly reflect social values of goods and services. Howe (1971: 53) suggests that prices are good measures of social values if the following holds:

(i) there is a high degree of competitiveness in the economy;

(ii) there is a high degree of use of the economy's labor resources and productive capacity;

(iii) There are no external benefits and costs.

The commodities produced in the selected study area enter competitive markets. Project inputs such as earthwork lumber and culverts can also be assumed to be derived from reasonably competitive markets. Drainage projects are not labor intensive and thus in the present study it is assumed that idle labor resources will not significantly affect the evaluation. Generally, it is felt that these conditions would not be violated to any appreciable degree and thus market prices are appropriate for the valuation of benefits and costs.

Because price movements will be expected over time it becomes necessary to select a suitable price to evaluate benefits and costs. Two possible situations can be conceived (Howe, 1971:55):

(i) there may be a general movement in all prices in the economy. Consequently the value of both inputs and outputs are changing at similar rates.

(ii) Prices of the project's inputs and outputs may change at rates different from the general price movements.

Prices of agricultural commodities are difficult to predict since short-run fluctuations in market forces are very common

occurrences. On the other hand, drainage construction costs have shown relatively stable upward movement over the years. With commodity prices, the variability exhibited over the short-run does not surface when considering average movement over the life of the project. It is not unreasonable, therefore, to assume that prices will move similarly over the project life. If this condition holds then benefits and costs can be evaluated using construction period prices and there will be no need for the discount rate to include an inflation component.[4] Because of short-run price fluctuations it is desirable to use an average or normalized price in constant dollars over a number of years as suggested by James and Lee (1971:209).

When inflation rates for project prices vary with general price movements valuation of future benefits and costs should be based on projected prices for the respective years. In such cases it is necessary to include a component for inflation in the discount rate.

DISCOUNT RATE

Drainage development projects are characterized by high capital expenditures in the initial years. Expectations are that benefits induced in subsequent years by these investments will, at the very least, compensate for economic opportunities foregone by the withdrawal of capital to facilitate construction or maintenance of the drainage system.

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[4] A proof of the validity of this conclusion is given by Howe (1971:81).

In an attempt to ascertain the foregoing it becomes necessary to aggregate the benefits and costs which accrue over the entire project life. But because monetary units accruing in different time periods have different values relative to the value of money at any given point in time, benefits and costs must therefore be converted to a commensurable unit—normally, construction period value. To accomplish this an appropriate discount factor must be found.

Theoretically, the selected discount factor should reflect both the marginal efficiency of private investment over time and social time preference for present versus future consumption. In an idealized economic system where there are no market imperfections, mobility of resources, no taxes or subsidies, perfect knowledge and no risk, it is possible to conceive an equilibrium situation between the marginal efficiency of investment and marginal social time preference, as shown in Figure 5.3. This provides a unique discount rate, r. However, the present structure of economies does not permit the attainment of the above equilibrium. Moreover, social time preference is not readily quantified. On a more practical note, the discount rate generally employed is one which represents the opportunity cost of resources used to finance the project. It is necessary, therefore, to determine what investments and/or consumption are foregone when resources are withdrawn by the project. In Manitoba, drainage projects are likely to be financed with general tax revenues. Consequently, some production and consumption activities will be curtailed. It is a difficult task determining the weighted average rate of return from these sources.

Haveman (1969:947-957) estimated that for the U.S. in 1966 the average rate was 7.3 percent. Howe (1971:67) suggests that in 1971 this would have been about 10 or 11 percent. One approach commonly found in the literature and which seems appropriate is the use of the effective yield[5] on bonds of long maturity. This is a risk free discount rate and seems suitable for the current study.

PROJECT LIFE

In project evaluation it is necessary to determine the economically useful life of the structures provided. This defines the period over which benefits and costs should be aggregated. Specifically,

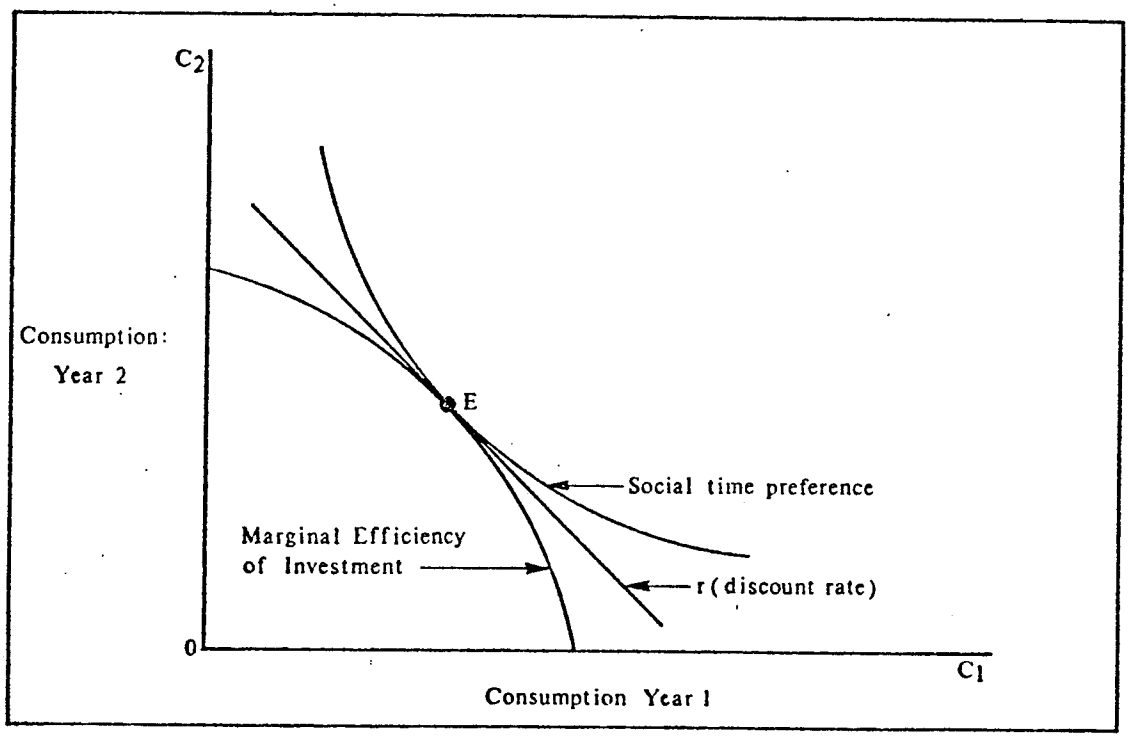

Figure 5.3 Discount Rate in an Idealized System

[5] Effective yield is defined as annual interest payment divided by the current market price of the bond.

benefits from drainage projects are expected to accrue as long as channels function efficiently. Infrastructures such as bridges and culverts form part of the drainage system. These have a useful life of 15 years. As a result, it is desirable to limit the project life to this period. However, during this period frequent maintenance is needed to ensure that channels function efficiently.

Limiting the life of the project to 15 years does not significantly affect the results. Sensitivity analysis by Rigaux and Singh (1975, Vol. 3, p. 138) for an agricultural drainage project showed that extensions of the project life beyond 15 years produced relatively small changes to the benefit/cost ratios.

SOCIAL OPTIMUM

When selecting a project scale it is not only desirable to ensure that net benefits are positive but they are maximized. Economic efficiency is attained by a particular project design if it maximizes social surplus or net benefits. From a study of the marginal benefits and marginal costs for different project scales the efficient drainage design can be identified. Assuming divisibility in project scale, the economic optimum is identified as that scale for which marginal social benefits equal marginal social cost. This is illustrated by point X in Figure 5.4. This point is most efficient since for further increases in scale the marginal increase in benefits is less than the marginal increase in costs. Similarly, project scales below OX are not the most efficient since marginal cost is less than marginal benefit. The

efficient project scale can also be identified from the incremental benefit/cost ratio. A value of one for this ratio indicates that the corresponding project scale is the optimum.

The marginal functions shown in Figure 5.4 are derived from the aggregation of marginal benefits and costs for all producers in the watershed.[6] For example:

$$MB_L = \sum_i mb_{i(L)}$$

where MB = marginal benefit from the project scale L

mb_i = marginal benefit to each producer (i) from project scale L.

This relationship results primarily from the fact that drainage service has public good characteristics and specifically, 'non-rival' consumption

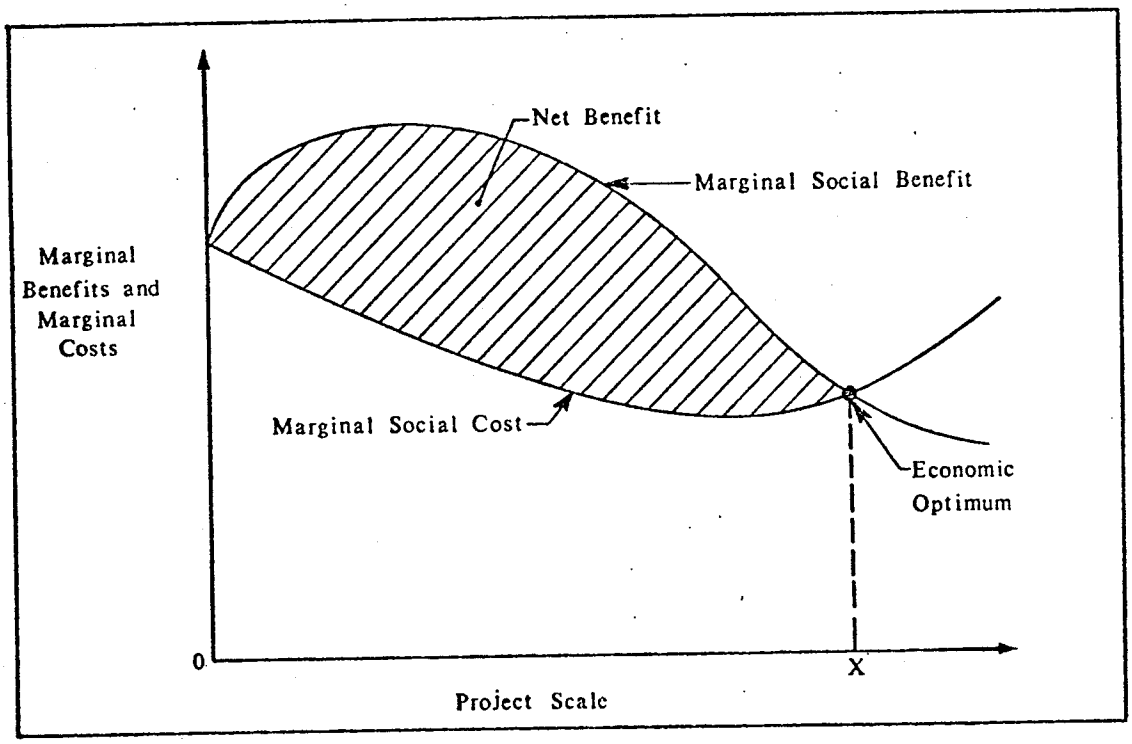

Figure 5.4 Economic Optimum

[6] Marginal costs will also include costs incurred by the public sector for provision of public drainage channels.

characteristics. For example, if a portion of the system is developed to a specific level, then that level of service is available to all occupants or farm operators in the area. Consequently, the economic benefits (or marginal benefit) associated with a given level of drainage service (or project scale) is the aggregate of benefits (or marginal benefits) derived by all users. The demand for various levels of drainage service is therefore the sum of the marginal benefits accruing to farm operators.

Chapter 6

ANALYTICAL MODEL

INTRODUCTION

The benefit-cost analysis framework in this study essentially involves the comparison of the drainage development and maintenance costs with the stream of agricultural benefits which are likely to be generated over time by a project providing improved agricultural drainage protection. The primary policy variable, therefore, is drainage service to agricultural lands. The objective is to assess the economic impact of alternative development plans and from a number of discrete cases attempt to locate the optimum project scale.

The stream of benefits generated is profoundly influenced by variables which are stochastic and dynamic in nature. The most important are the storm magnitude variable and the economic variables, such as crop prices and costs of production. As an example, consider the possible extreme outcomes of storm events over the project life. The storm events over the project life can be of magnitudes and frequencies which warrant no additional drainage protection. In such a case no benefits would have been derived from expenditure on an improved system. Alternatively, the frequencies and magnitudes of storm events may be such that high demands are made on the drainage system and consequently the likely benefits to improvement works are quite large. With respect to the economic variables, prices and costs which are used to evaluate

benefits fluctuate over time in response to market forces exogenous to the system being studied. It is obvious then, that levels of net benefits and consequently project feasibility can show great variations depending on the movement of economic variables over the project life.

Therefore, it follows that decisions based on single-valued estimates of benefits, costs and drainage optimum are indeed risky because of the uncertainty as to what values these important exogenous variables will assume over the useful life of the project. Drainage projects have high costs and so in evaluating the feasibility of public expenditures in these projects it is important to fully consider the sensitivity of benefits to the stochastic behaviour of this storm variable and the economic variables. Stability measures or confidence limits of these impact variables call for their explicit inclusion in a stochastic simulation model.

In addition to the factors outlined above which stress the need for a simulation method of analysis, there is also the fact that an integral part of this model deals with the hydrologic component measuring the runoff from various parts of the watershed. It is convenient to trace runoff through the various subwatersheds of the system using a simulation procedure.

These considerations together with the general complexity of the analysis makes analytical solutions impractical. The problem situation therefore seemed well suited to a numerical solution approach such as simulation.

The analysis proceeds in two steps. Firstly, the economic impact of alternative levels of drainage service was evaluated with the use of a deterministic simulation model. The stability characteristics of the results obtained in the deterministic analysis and the sensitivity of certain endogenous variables to selected economic variables was subsequently investigated with the use of a stochastic simulation model. These steps in the analysis were introduced with the primary objective of avoiding excessive computer costs.

Because there are some basic differences in these models resulting from the introduction of probability distribution to characterize the random behaviour of certain variables and in the treatment of the time variable, they will be discussed separately.

General Characteristics of Computer Simulation Models

Naylor (1966: 20) describes simulation as a "a numerical technique for conducting experiments on a digital computer which involves certain types of mathematical and logical models that describe the behaviour of a business or economic system over extended periods of real life". In this particular study, the economic entity is the Province. It is desirable to try out various development alternatives (with respect to land drainage) for a specific watershed and to monitor the effects in terms of increased economic efficiency. Because of the nature of the developments considered, the impacts are primarily confined to the watershed being developed. Thus, although the accounting stance is from the

Provincial viewpoint, which is the primary source of project financing, the system is basically the watershed entity.

The decision to perform the analysis with a simulation model arises from the complexity of the relationships which does not readily permit an analytical solution. This is especially so when stochastic processes are introduced in the model since it will be a tedious task to describe analytically, how they will jointly perform.

While in general, simulation models can be used for predicting or control of a system, its use in this particular problem situation is basically one of prediction. Drainage development requires substantial resource cost and thus ex-ante economic analysis is needed to provide proper guidance on expenditure decisions before they are made. It is necessary, therefore, to realistically describe the system so that by experimentation the impact of various alternative plans can be considered so that the best may be chosen.

Simulation models contain the following elements:

1. components
2. variables
3. parameters
4. functional relationships.

The components are the various entities which form the system. Those variables whose values are generated by changes within the system are referred to as ENDOGENOUS, whereas those whose values are determined outside the system are EXOGENOUS variables. Exogenous variables may be

either deterministic or stochastic in nature. They may also be controllable such as the case with policy variables or they may be generated by the environment and thus NON-CONTROLLABLE. In addition to the endogenous and exogenous variables there are also STATUS variables which define the state of the system.

The relationship among parts of the system are presented by the mathematical relationships. The interaction among variables according to the specified mathematical relationship and logical relationships which are referred to as the system's 'operating characteristics' generate the behaviour of the system. The parameters of the model are derived by statistical inference.

One of the necessary steps in the use of a simulation model is the validation of the model. This need arises from the fact that in many simulation models, parts of the system have been described with the use of hypothetical functions and contrived data. Examples are the choice of statistical probability distributions or parameters by the analyst based only on his knowledge of the system. Such models, if they are not subjected to empirical validation, are void of meaning (Naylor and Finger in Naylor, 1971: 153). In many cases the validity of the model has been based on its predictive ability, the approach of the positive economist. Naylor and Finger suggest a Multistage Validation approach for computer simulation which incorporates the methodologies of rationalism, empiricism and positive economics[1].

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[1] Naylor, T. H. and J. M. Finger in (Naylor, 1971: 153)

In the first stage, the behaviour of the system, which includes specification of the components, the variables and functional relationships, must be described by a set of postulates. These are tentative hypotheses about the system. An attempt is made to validate these in the second stage. But as the authors suggest, "in economics we often find that many of our postulates are either impossible to falsify by empirical evidence or extremely difficult to subject to empirical testing[2]" and so we may choose either to abandon the postulates or still retain them as tentative postulates. In the third stage, the final decision concerning validation of the model is made. This is accomplished by testing the ability of the model to predict the outcome of the system.

In this particular study, the economic outcomes resulting from various development alternatives are difficult to subject to Naylor and Finger's third stage validation test since no corresponding historical series exist to provide a satisfactory basis for predictive tests.

The validation of the model in this study will therefore follow the procedure outlined below. Firstly, the realism of the set of postulates proposed will be judged on the basis of: 1) the existing state of knowledge which appear in the literature, 2) previous related research and 3) the expertise of individuals working in some of the disciplines such as agronomy, hydrology and soil physics. In the second stage validation of the model, many of the relationships within the various components can be analyzed separately and the results tested for goodness of

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[2] Naylor, T. H. and J. M. Finger in (Naylor, 1971: 153)

fit to known historical values or the reasonableness can be checked against: 1) other known methods which are similar; 2) observation or experience; 3) apriori expectations.

The final predictions or values of the endogenous variables generated by the model can be evaluated on the basis of apriori expectation formed from conditions (physical and economic) which generated the results. These are, however, short of the validation proposed by Naylor and Finger, but given that the various relationships have been shown to be satisfactory (and realistic) they may be considered acceptable.

In the section which follows, a brief survey of the logic of the model is presented so that the main interrelationships, primarily among components, can be highlighted. It also serves to generally indicate the main differences between the deterministic and stochastic versions of the model. After this brief overview, the deterministic version of the model is discussed in greater detail. In chapter 7, the stochastic version is presented.

SURVEY OF THE LOGIC OF THE MODEL

Simulating the impact of various development plans calls for adequate and realistic representation of the system. The components which are the primary structural blocks of the model must be identified. These are expected to be consistent with the existing body of knowledge as argued in both the conceptual framework and the theoretical framework. The realism and completeness of the model can better be judged from a review of the logic of interrelationships among variables and parts of the system. Such a procedure takes place in the discussions of the model. However, before venturing to discuss the model in detail, prior knowledge of the perspective of the various parts with respect to the entire system will certainly facilitate its understanding. The main purpose of the following discussion is to fulfill this role by presenting an overview of the logic of the model.

The model can logically be separated into three stages, reflecting the nature of the underlying relationships. In the first stage the stimulus to the entire system, the storm event, is examined. Because the impact of this factor embodies interdependent hydrologic relationships among parts of the watershed, it is necessary in this first stage to base the analysis on the entire watershed. Having fully considered hydrologic interdependency among subwatersheds, the economic evaluation of the development plans for individual subwatersheds

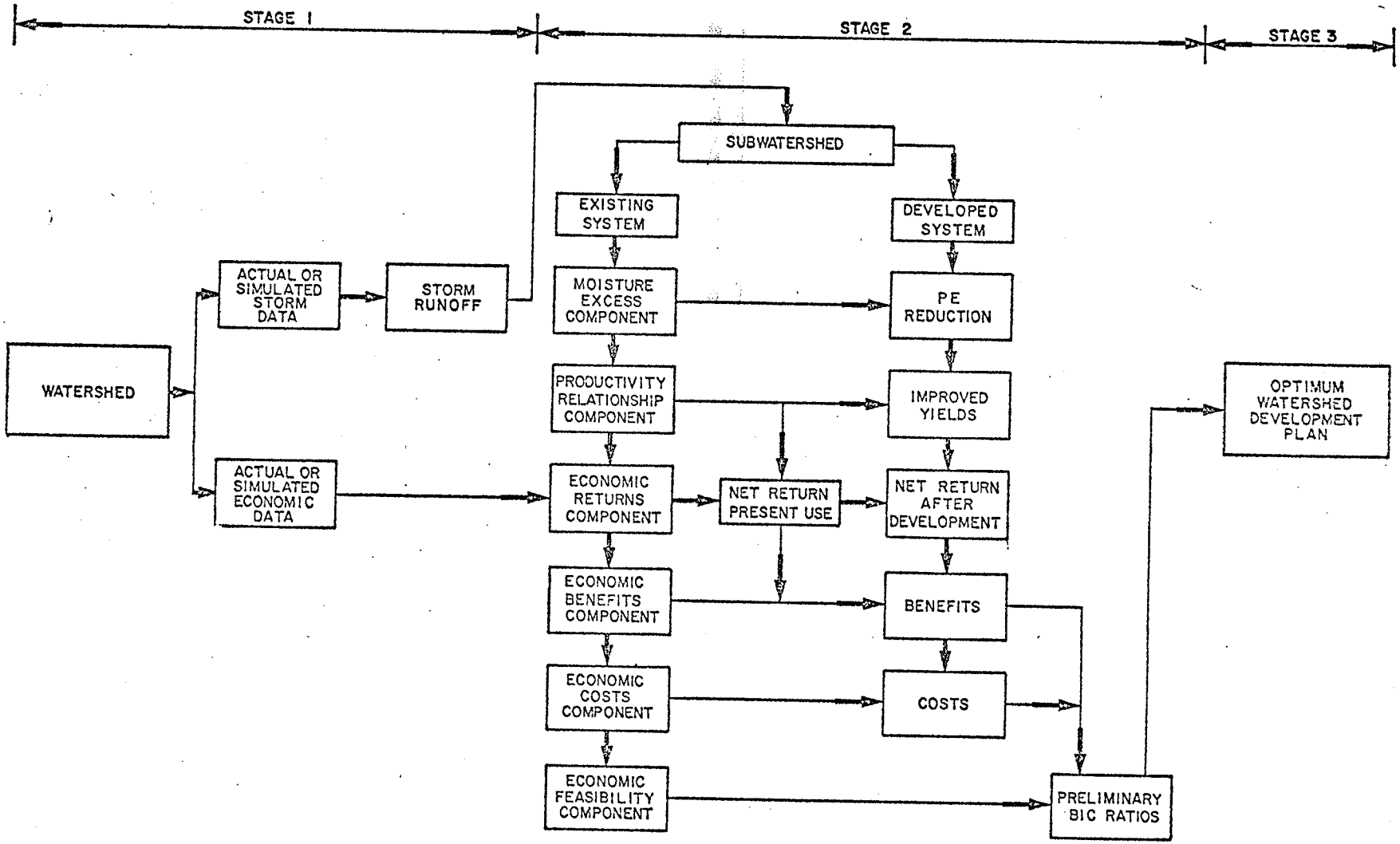


Figure 6.1

Generalized Flow Diagram of the Analytical Model

can then proceed in the second stage under the assumption of economic independence. In the second stage the unit of analysis is therefore the subwatershed. Because developments in one subwatershed are likely to have impacts on downstream locations of the watershed, the economic interdependence among units must be considered. These considerations constitute the focus of the analysis in the third stage of the model.

The generalized flow diagram of the model in Figure 6.1 shows the important relationships among parts of the system. The diagram indicates that storm data, the simulation of runoff and economic variables are the main concerns of the first stage of the model. Storm events provide the stimulus to the system in this study. They constitute one of the primary factors influencing the economic performance of the system being simulated. To evaluate the impact of this component on the remaining system it is desirable to have information on the occurrence of daily storm events over the planning period. When only point observations are available then the spatial distribution of these events over the watershed must be determined. In the deterministic version of the model the observed daily precipitation for the watershed over the last 15 years was used for the evaluation since it was shown to be a normal period with respect to storm events. The appropriate statistical tests are given in the discussion of the data. In the stochastic version of the model storm events are randomly generated.

The storm data together with the data describing the hydrologic properties of the watershed are used to simulate total discharge and

peak flows through the system. The occurrence of a storm event initiates a hydrologic process in which water infiltrates into the soil, ponding and depressional storage takes place, and depending on rainfall excess, surface flows are observed. Surface flows together with subsurface flows enter drainage channels which move the water through the system to the outlet of the watershed. The complexity of this process is in the simultaneous flows which occur along the different tributaries which enter the main watercourse at different junctures. The volume of discharge from various parts of the watershed also varies significantly. To describe the above process realistically, runoff must be simulated along the tributaries and main stem of the drainage system. This is the task of the runoff simulation component. The analysis in this component provides estimates of the important output variables of this part of the model - total discharges at points along the entire drainage system resulting from specific storm events.

Having identified the storm events for a given day and traced the runoff generated through the system, the analysis then proceeds to repeat this procedure for the entire planning period. The period selected is 15 years. While the model assumes that economic benefits are realized only from protection in the months of June, July and August, runoff is estimated for the months April to September. Data for April and May provide information on antecedent moisture conditions, whereas September's data give some idea of moisture buildup for the following spring.

The true significance of precipitation and runoff must be judged in relationship to its adverse effect on agricultural production and the economic returns to production in the watershed. The concepts involved in a study of crop damage from excess moisture were discussed in an earlier section, at which time the duration dimension of excess moisture was cited as being the factor in this type of crop damage. The estimation of excess moisture duration in this study is accomplished with a synthetic hydrograph model. This model is considered valid for application to relatively small areas of up to about 10 square miles. For this reason it was convenient to initially base the economic analysis on relatively small hydrologic units or subwatersheds. Subsequently, the watershed was considered in its entirety.

The flow diagram shows that after runoffs for the watershed are estimated, the analysis proceeds to the second stage where development proposals for subwatersheds are examined for feasibility. The economic feasibility of alternative development plans in this study is based on the concept of induced economic returns. This approach therefore calls for an examination of the improvement in net returns from the pre-development to the post-development status of the subwatershed. Firstly, the flow diagram shows that precipitation excess for the existing system is estimated. PE for various storm events is a function of the peak discharge (obtained from the runoff component), drain capacity at the outlet of the subwatershed and other hydrologic variables such as length of drainage area and the difference in elevation. Subsequently,

alternative development plans are introduced and their improved drainage efficiency are examined. This is measured by the reduction in the duration of excess moisture relative to what obtains under the present conditions. The proposed development (shown on the right side of the diagram) and the existing system (shown on the left) together provide estimates of PE reduction.

Associated with the development plans are costs. This is comprised of drainage development cost for the total system - the on-farm drains, collection drains and the main channels. The cost component shown in the flow chart include drain excavation costs, erosion control structures, and bridges, culverts and rights-of-way.

The flow diagram shows that the reduction in PE from storms because of development can be translated in productivity gains. What this means is that without development (under the existing status of drainage service) agricultural lands in the subwatershed would have had longer exposures to excess moisture. Consequently, for the crops grown yields would have been lower and inefficient land and resource use would have resulted. The economic losses resulting from this situation may be partially or completely averted by providing improved drainage protection to the cultivated crops.

Because the improvement in productivity is not uniform for all soils on account of their non-homogenous characteristics, the evaluation of the impact of drainage development requires that first, the soils in the subwatershed must be grouped into homogenous units. The modifica-

tion of the land resource by drainage may result in various soil groups being better suited for uses other than what currently exists. In this model it is assumed that the highest use, given certain constraints, will be made of the land after development takes place. Thus, in the productivity component the potential improvement to alternative uses must be determined before the highest use can be identified for each soil group. The highest use is defined as the net return after development and inclusive of (amortized) land development and on-farm drainage costs. This is shown in the flow diagram. From the highest use for the various soil groups, the net returns are aggregated to obtain the economic returns for the subwatershed.

The economic impact of drainage development is estimated by the increase in net returns as generated above (after development) over the returns obtained under the assumption of present land use and no change in drainage protection. This increase constitutes the benefits or returns to drainage.

The drainage costs include the development cost for the entire drainage system - that is, the main channel, lateral drain, on-farm drains, bridges, culverts and right-of-way costs.

The final step in this portion of the model is the feasibility test where benefits and costs accruing over the project life are compared. A preliminary estimate of the best plan (optimum) is obtained.

The analysis of all subwatersheds provides the necessary data required for assessment of optimum development for the entire watershed.

As shown in the diagram, this is the last step in the analysis. Thus far benefits and costs were evaluated for each subwatershed assuming that there were no adverse effects on downstream locations because of upstream drainage works. In this stage of the analysis the effects of drainage improvements on downstream reaches must be studied so that such costs are internalized to the subwatersheds producing the adverse effects. A basic premise of this study is that the level of service to be provided in any given reach should not be less than the current level of protection. To the extent that the level of protection in downstream reaches deteriorates because of larger peak flows or greater discharge induced by upstream developments then the drainage should be modified to maintain current protection. This external cost for drainage should be internalized to the subwatershed(s) inducing the change. Introduction of these costs (or benefits) in this stage of the analysis are expected to lead to the identification of the true optimum.

THE DETERMINISTIC AND STOCHASTIC MODELS COMPARED

The above discussion outlines the logic of the model in a general way. There are significant differences between the stochastic version of the model and the deterministic version and these are briefly reviewed in this section.

Firstly, as it was indicated earlier, in the stochastic model the storm data is simulated for the entire project life. The basic

approach of the deterministic analysis is to use the mean values of exogenous variables as input into the model. The observed precipitation for the Big Grass Watershed over the last 15 years is approximately normal and thus it is used as input in this version of the model.

In computing the economic benefits from drainage the analysis in the deterministic model is based on average annual net returns. Accordingly, the average annual net returns under the existing system is computed on the basis of average prices for crops and average costs of production. Returns after improvement are also annual averages. The reduced precipitation excess acruing over the project life because of development were averaged to annual amounts for each of the relevant months. These were then used with average prices and costs to obtain the average annual return. The above estimates of net return in the deterministic model give the average annual benefits to drainage.

The stochastic version of the model simulates prices annually for the entire project life. These are used to compute net returns for each year of the project. The analysis of the system produces a stream of benefits over time. These are expected to fluctuate significantly reflecting the underlying stochastic behaviour of the input variables.

Both models assume the same development plans. However, the analysis of the stochastic model takes as given the highest land use identified in the deterministic model for the various soil groups.

THE DETERMINISTIC SIMULATION MODEL

This version of the model is used to evaluate the economic impact of various levels of drainage improvements. Variables which normally are stochastic in nature are constrained to their historical means or values approximating the means and thus the algorithm for this model is consequently less costly for computation than the stochastic version. In this chapter the specific interrelationships among variables and components are discussed. A list of variables is given in Table 6.1 at the end of this section. The flow chart in Figure 6.2 identifies the three logical stages of the model. The discussion in this section follows this sequence.

Stage One: Storm Precipitation and Storm Runoff Components

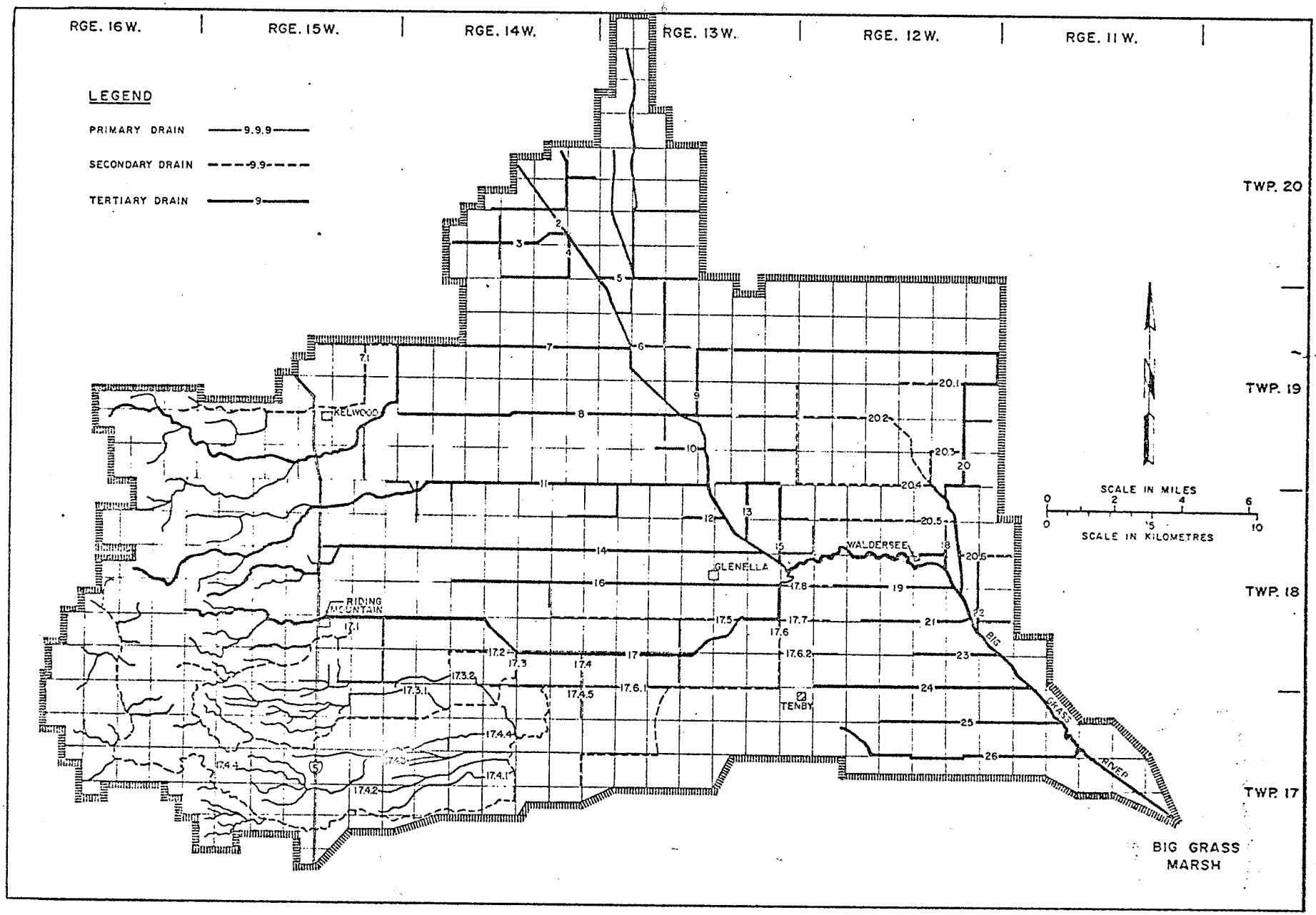
The first stage of the model is primarily concerned with precipitation and the runoff generated from various parts of the watershed. The relationships involved were conveniently grouped into two components - the STORM COMPONENT and the STORM RUNOFF COMPONENT. Since the deterministic model uses historical precipitation data, the storm component here is mainly concerned with the estimation of the areal distribution of precipitation from the point observations of daily precipitation. The precipitation data are used in the storm runoff component to estimate runoff and the latter is fed as input in the synthetic hydrograph model.

The relationships embodied in the runoff component requires that runoff measured at any point along the system explicitly consider

the discharge from the entire contributing drainage area. Since interest is to obtain estimates of storm runoff at various points along the drainage system, specifically at the outlet of the various subwatersheds, it was necessary to aggregate runoff from the various subwatersheds following the logical hydrologic sequence of events. The runoff generated by a particular storm event is estimated by beginning with upstream points, having the smaller drainage areas, and gradually extending to points downstream which correspond to larger drainage areas. Following this approach the hydrologic interdependency among subwatersheds can be explicitly considered in a convenient fashion.

To facilitate the procedure outlined above, the tributaries of the drainage system have been numbered and identified as primary, secondary, tertiary and the main river (Map 6.1). Runoff is first estimated for subwatersheds along all primary tributaries. Estimates of discharge along the secondary, tertiary and main river follow in that order since the outflow from primary tributaries becomes the inflow into secondary and similarly the outflow from the secondary tributaries becomes the inflow into the tertiary, etc.

The analytical process for this first stage of the model begins with the selection of a subwatershed according to the procedure outlined above wherein the most upstream subwatershed along a primary tributary is selected. Based on the available precipitation data and the distances of the subwatershed from the various precipitation recording stations a weighted estimate of precipitation for the first day of the project life is made for the subwatershed. It is assumed that the



Map 6.1 - Drainage Channels in the Big Grass Watershed

precipitation distribution over parts of the watershed is inversely related to the distances from the precipitation recording stations. Weighted precipitation is computed using equation (1):

$$PREC = \left[\frac{1}{1/D_1 + 1/D_2 + 1/D_3}\right]\left[\sum_{i=1}^{3} \frac{1}{D_i} PREC(i)\right] \quad \ldots\ldots 1$$

Where D_1, D_2, D_3 = distances of subwatershed from stations 1, 2, and 3, respectively

PREC (i) = point estimate of daily precipitation for station i

PREC = weighted daily precipitation for the subwatershed

Having estimated the precipitation for a subwatershed for a selected day, the flow chart (Figure 6.2) shows that this information is fed into the runoff component, where the runoff from the storm is estimated. This estimate of runoff refers to local discharge. For the most upstream subwatersheds where total drainage area equals subwatershed area, local discharge constitutes total runoff. For subwatersheds located downstream, the total discharge leaving the subwatershed is comprised of both local runoff and upstream runoff and is referred to as drainage area runoff. In this study, a storm was defined as an event where precipitation is greater than 0.1 inches. Accordingly, if the analysis in the storm component produced a precipitation for the subwatershed which is less than or equal to 0.1, then local discharge is assumed to be zero for the selected day. However, drainage area runoff may yet be non-zero for subwatersheds that do have upstream contributing drainage areas, since discharge may be received from such areas.

If the subwatershed's precipitation is greater than 0.1 inches, then the model proceeds to estimate runoff. The volume of runoff which is generated by a storm is determined endogenously by factors other than storm size and storm characteristics. These include the topography, land use, hydrologic soil characteristics and soil moisture in the subwatershed. The interrelationships among these factors were discussed in the conceptual framework. Together they have been used quantatively by the U.S. Department of Agriculture, Soil Conservation Service (S.C.S.) in the National Engineering Handbook to derive an index which reflects the amount of runoff generated by a storm event. This index is referred to as the runoff curve numbers or CN value in the section on data preparation. The S.C.S. Handbook provides three alternative values of CN for each soil-cover complex, the suitability of each depends on the level of antecedent soil moisture (API). From CN values the S index is estimated. The latter indicates the potential maximum moisture retention[4] by the soil from the total moisture generated by a storm. While three S values are derived for each soil-cover condition and these correspond to the three API levels, the following discontinuous function is constructed, given by equations 2.1 to 2.4, to relate S and API:

$$S = S3; \quad \text{when} \quad API > 1.10 \qquad \text{.....2.1}$$

$$S = S2 - \left[(S2-S3) * \frac{API-0.80}{0.30}\right] \quad ; \text{ when } 0.80 < API \leq 1.10 \qquad \text{.....2.2}$$

$$S = S1 - \left[(S1-S2) * \frac{API-0.30}{0.50}\right] \quad ; \text{ when } 0.30 < API \leq 0.80 \qquad \text{.....2.3}$$

$$S = S1; \quad \text{when} \quad API \leq 0.30 \qquad \text{.....2.4}$$

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[4] U.S.D.A., Soil Conservation Service. National Engineering Handbook Section 14, Hydrology

Where: S1, S2 and S3 are the indices provided by the S.C.S. Handbook and are respectively applicable when antecedent soil moisture is low (dry), moderately wet and saturated. These are estimated as follows:

$$S(i) = \left[\frac{1000}{CN(i)} - 10\right] \quad \text{for } i = 1, 2, 3 \qquad \ldots\ldots 3$$

The Antecedent soil moisture index (API) is estimated from antecedent precipitation according to equation 4:

$$API(t) = 0.84 \left[PREC(t-1) + API(t-1)\right] \qquad \ldots\ldots 4$$

Where: t = day

Antecedent moisture levels are determined in this study using the antecedent precipitation index (API) whereas the index given in the S.C.S. Handbook is equivalent to the total precipitation over the 5 - day period prior to the storm event. As a result the range of antecedent moisture levels (given in the equations above) which are used to establish whether soils are dry, moderately wet or saturated differs from the S.C.S. recommendations.

Runoff is estimated in the S.C.S. Handbook using the empirical relationship:

$$R = \frac{(PREC - 0.2S)^2}{(PREC + 0.8S)}$$

Where: R = runoff in inches

In the Rigaux-Singh study (1975, Vol. 1: 23) it was found that runoff prediction by this function was at great variance with actual observed runoff and precipitation data for watersheds in Manitoba. Consequently,

runoff functions were estimated in that study using data on precipitation, runoff and hydrologic variables for 29 watersheds in Manitoba. The functions estimated were linear functions which generally gave good predictions within the range of values from which they were estimated. Outside of this range predictions were poor. Because the general curvilinear shape of the S.C.S. runoff equation seems more realistic, numerical analysis was used in this study to modify its parameters so that the predictions of runoff correspond more closely to that observed. The resulting equation is:

$$R = \frac{(PREC - 0.10S)^{1.5}}{(PREC + 0.90S)} \qquad \ldots\ldots 5$$

which is used to predict runoff in the present study.

The hydrologic characteristics of an area are defined by the status variables (defining the state of the entity) - topography, land use, and soil characteristics. As the flow diagram shows, these variables (or their input in the estimation of (S)) together with the magnitude of the storm (PREC) are used to estimate the runoff from a subwatershed.

The final step in the relationships outlined for the runoff component is the estimation of drainage area runoff. The first subwatershed chosen for analysis was the most upstream along a first order tributary and so the drainage area runoff and local runoff are equivalent. The results obtained are kept in storage and identified by subwatershed and day. The model advances time (t) by one day and re-computes storm precipitation and runoff for the subwatershed for day (t + 1). This

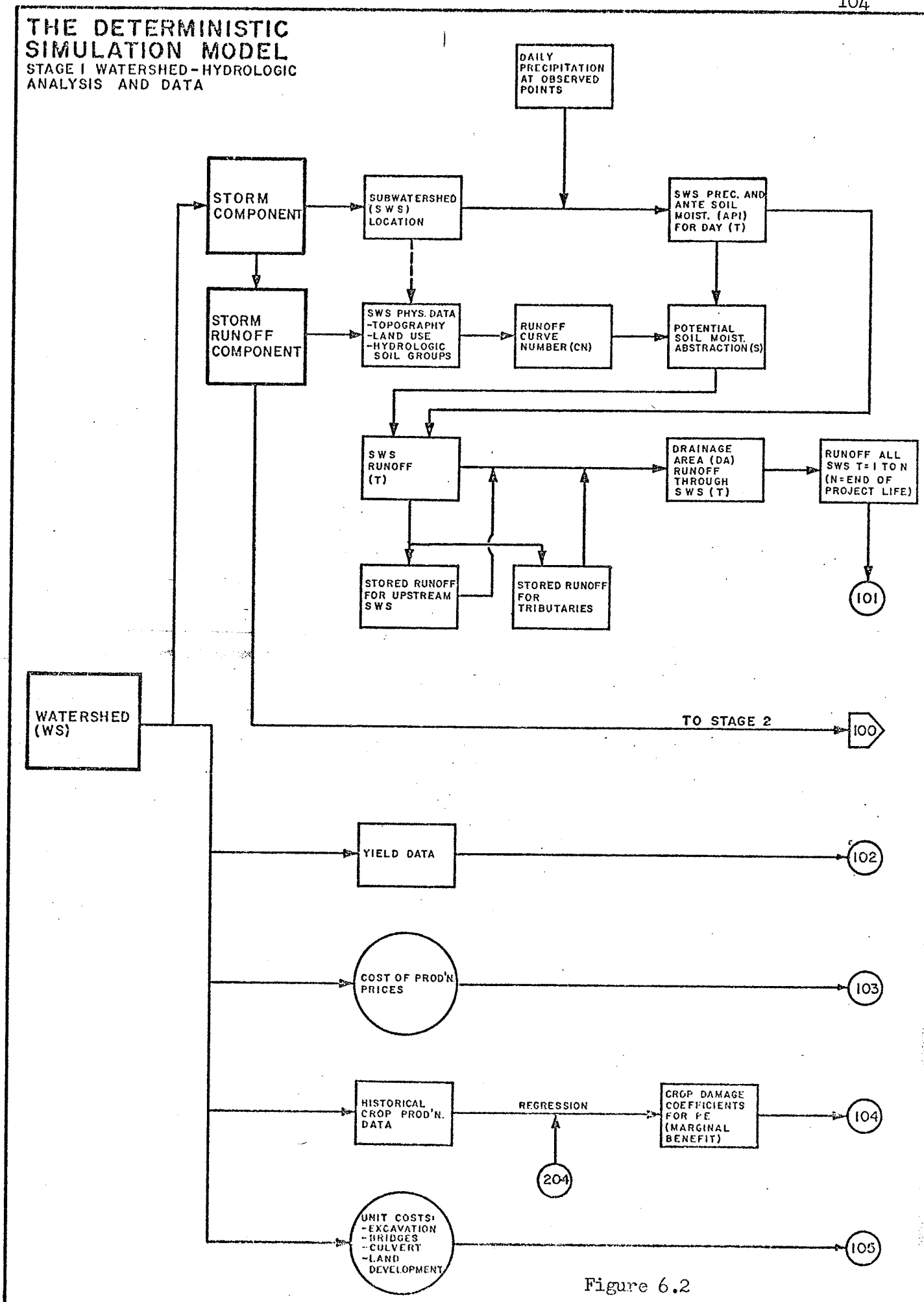
THE DETERMINISTIC SIMULATION MODEL
STAGE I WATERSHED-HYDROLOGIC ANALYSIS AND DATA
DAILY PRECIPITATION AT OBSERVED POINTS
STORM COMPONENT
SUBWATERSHED (SWS) LOCATION
SWS PREC. AND ANTE SOIL MOIST. (API) FOR DAY (T)
STORM RUNOFF COMPONENT
SWS PHYS. DATA -TOPOGRAPHY -LAND USE -HYDROLOGIC SOIL GROUPS
RUNOFF CURVE NUMBER (CN)
POTENTIAL SOIL MOIST. ABSTRACTION (S)
SWS RUNOFF (T)
DRAINAGE AREA (DA) RUNOFF THROUGH SWS (T)
RUNOFF ALL SWS T=1 TO N (N=END OF PROJECT LIFE)
STORED RUNOFF FOR UPSTREAM SWS
STORED RUNOFF FOR TRIBUTARIES
101
WATERSHED (WS)
TO STAGE 2
100
YIELD DATA
102
COST OF PROD'N. PRICES
103
HISTORICAL CROP PROD'N. DATA
REGRESSION
CROP DAMAGE COEFFICIENTS FOR PE (MARGINAL BENEFIT)
104
204
UNIT COSTS: -EXCAVATION -BRIDGES -CULVERT -LAND DEVELOPMENT
105

Figure 6.2

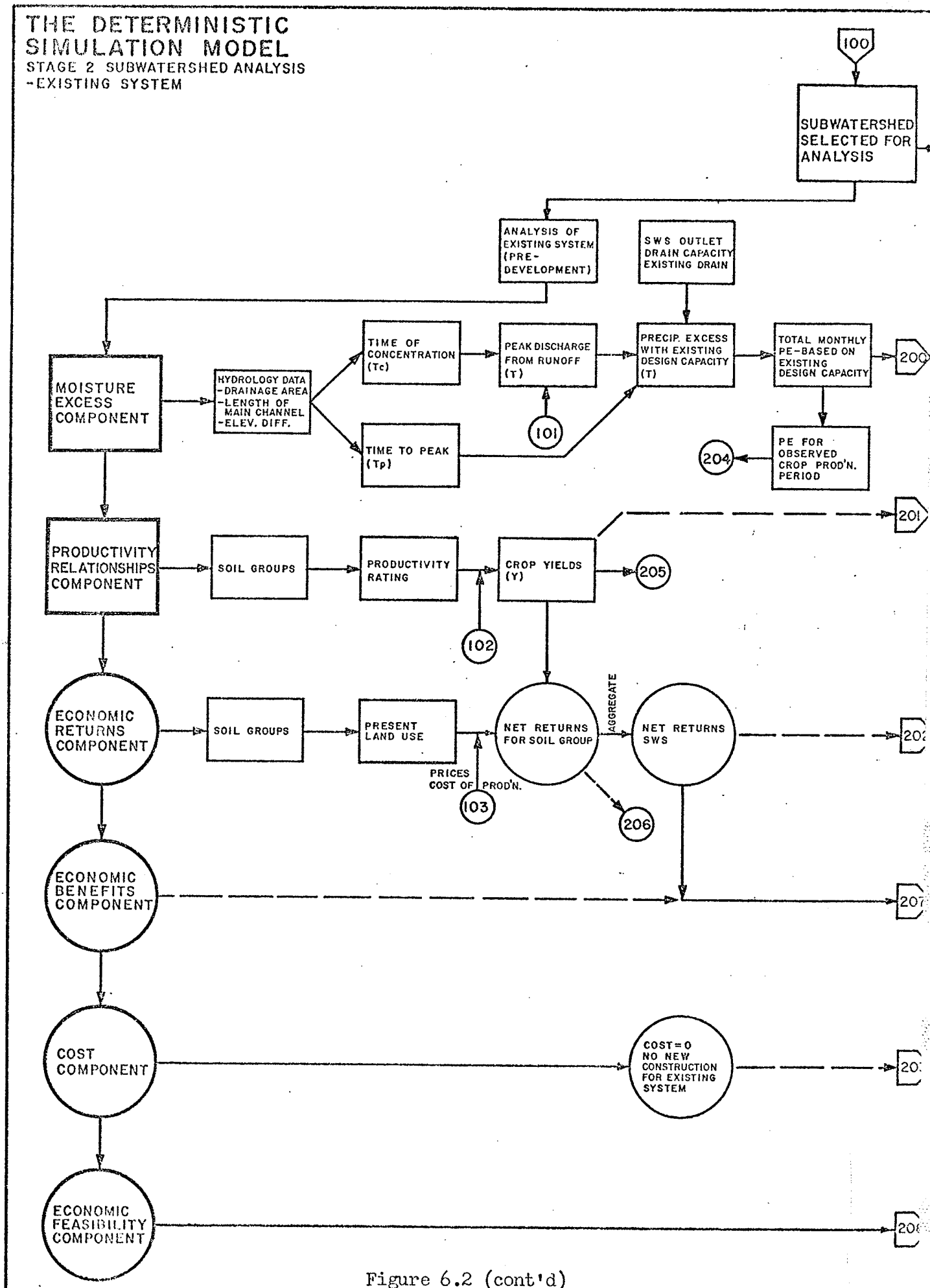

Figure 6.2 (cont'd)

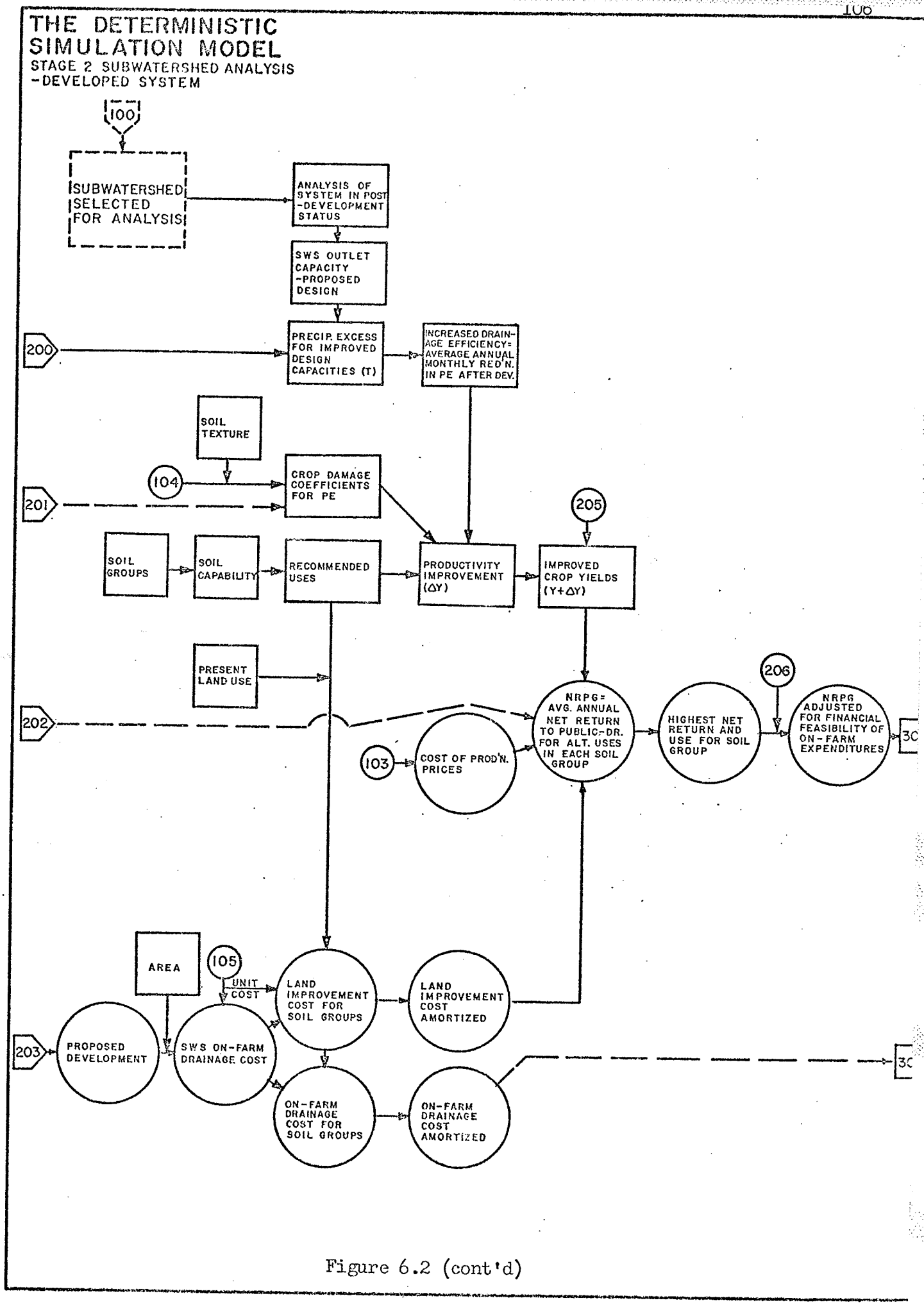

Figure 6.2 (cont'd)

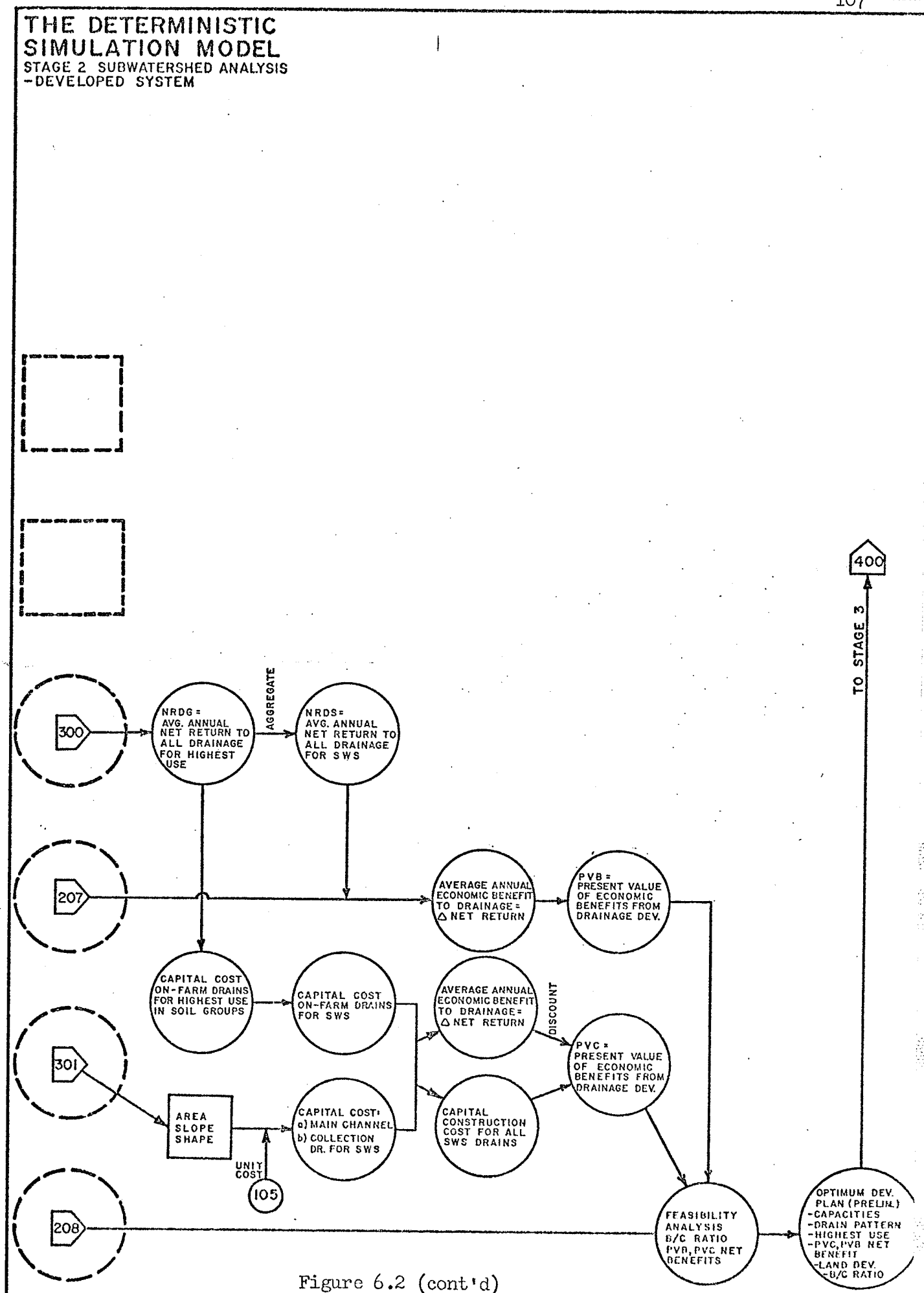

Figure 6.2 (cont'd)

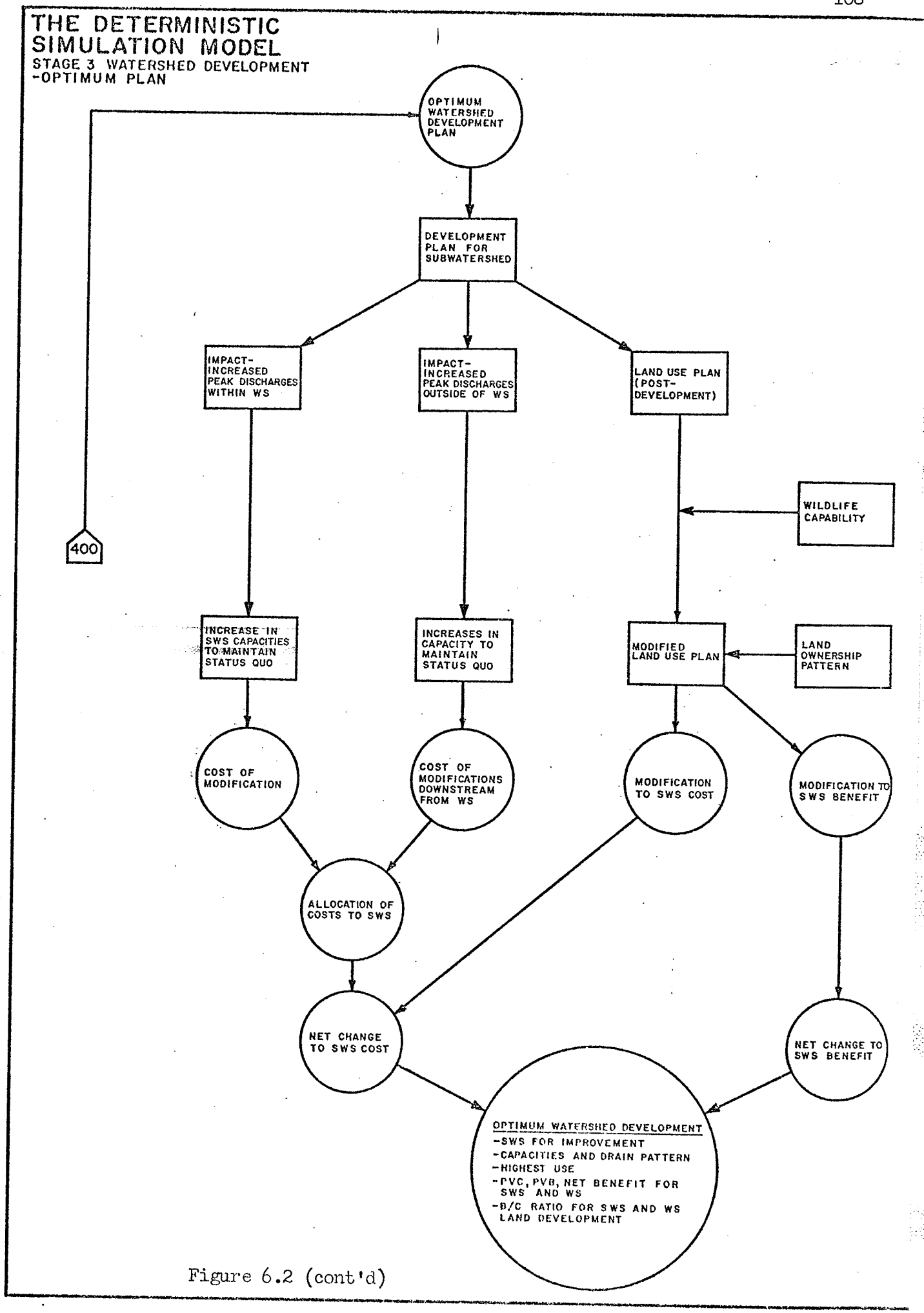

Figure 6.2 (cont'd)

process is repeated for the entire life of the project before analysis of the next subwatershed begins. Project life is 15 years and the relevant months in this component are April to September inclusive. At the end of the runoff analysis for a subwatershed, the results held in storage form a matrix of drainage area runoff for a particular location in the drainage system.

The simulation of runoff continues for other subwatersheds within the system. It should be noted that along the primary tributaries, upstream runoff can only be generated from subwatersheds which are located upstream along the same tributary. For higher order tributaries upstream runoff can be generated from inflowing (lower order) tributaries and/or subwatersheds located upstream along the same tributary.

General Watershed Data

Before proceeding to the other components of the model, some of the data used in the evaluation of drainage development impact for all parts of the watershed are indicated at the start of the flow chart. These are primarily derived from historical data which are generally applicable to the entire watershed.

The first variable of interest is the yield information for crop production. This information is used in the latter stages of the model to estimate net returns under the present state of the system and the improved yields in the post-development period. Yield data for this watershed, like most areas, show variability among fields and over time

Differences in management, which includes cultural practice and input usage, can account for a significant proportion of the cross-sectional variations in yields. Other important factors which account for cross-sectional variability are the productivity potential of the soils and drainage conditions. Variability in yields over time can result from factors which include weather conditions and the effects of disease and insects. The source of crop production data is the Manitoba Crop Insurance Corporation (MCIC). Because of the absence of data on management and cultural practice and the general scarcity of yield data for many areas of the watershed it is difficult to evaluate the influence of these factors on yield. However, the MCIC data (which begins from 1966) does show significant differences in the average yield for the various soil productivity groups. In the economic evaluation of returns, the soil productivity grouping for various soils is used to establish the average yield.

In this portion of the model, the analysis points to the need to determine the crop damage factors (the marginal effect of excess moisture on yields) for the various production conditions which exist in the selected watershed. Historical crop production and precipitation excess data are used in a regression analysis to estimate the effect of moisture excess on yields. At a subsequent stage in the model precipitation excess data are estimated for specific periods of interest and locations in the watershed, assuming the current level of the drainage protection. The estimated coefficients or damage factors together with estimates of

damage factors from a previous study (Rigaux and Singh, 1975, Vol. 2) are used in the evaluation of economic benefits.

In addition to the above, the levels of the economic variables - crop prices and costs of production, are assumed constant for the entire watershed. Prices used in the deterministic version of the model are the average normalized farm prices in Manitoba estimated from data for the period 1970 - 76. Cost of production are computed to reflect differences among crops but constancy for all parts of the watershed.

The foregoing completes the discussion of the first stage of the model. The next section discusses the second stage in which the ultimate objective is the assessment of the economic impact of drainage development in each subwatershed. The unit of analysis is therefore the subwatershed.

Stage Two: Subwatershed Analysis

In its second stage, the model concentrates on the economic impact of drainage development plans. As previously outlined in the discussion of the logic of the model, this assessment can be reduced to a comparison of economic output from the subwatershed under the existing drainage design with that obtained after development. Derivation of these estimates calls for prior assessment of the improvement in drainage efficiency and the resulting improvement in agricultural productivity. The relationships involved in this part of the model have been grouped into the following components: moisture excess, productivity,

economic returns, economic benefits, economic cost and economic feasibility. These are shown on the left side of the flow diagram in the order (top to bottom) in which the analysis proceeds. The flow chart also separates the relationships of the existing system from the developed system. The former relationships are shown on the left side of the chart whereas the latter are indicated on the right.

Moisture excess component. In this component, the objective is to evaluate the increase in drainage efficiency[5] when that portion of the system within a subwatershed is improved. To accomplish this, it is appropriate to first consider the existing system and the extent of precipitation excess which can result from the various storm events. The results obtained are then compared to precipitation excess estimated from the same storm events and under the improved drainage conditions. The reduction in precipitation excess brought about by the drainage improvement provides the measure of increased efficiency referred to here.

Given a certain level of drainage service, the inadequacy of local drains within the subwatershed and/or the inadequate capacity of the main channel to receive both upstream and local flows results in excess moisture detention on the land. By an improvement in the system within a particular subwatershed in terms of extended drainage channels to service agricultural lands and more efficient (larger) capacities, the detention period of excess moisture can be reduced. This

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[5] This reference is with respect to technical efficiency and not economic efficiency which is the main objective of the study.

is precisely the objective in developing the system. While the volume of discharge may remain unchanged or increase slightly, the major effect of development is in the reduction of the excess moisture period. Drainage development plans therefore constitute the instrumental exogenous variable or the policy variable in this study. Efficiency in the removal of excess moisture results from: (i) the shorter time requirements for overland flow because on-farm drains are either newly introduced or increased in density per unit area; (ii) the reduction in channel resistance to flows because of new design and construction; and (iii) the larger capacities to accomodate larger flows.

The most suitable hydrologic model found thus far for estimating PE is the one developed in a previous drainage study[6]. It is based on the concept of a synthetic triangular hydrograph. Essentially, this model uses hydrologic data for a drainage area to derive the parameters of the synthetic triangular hydrographs which can be used to represent the inflow hydrograph[7] for the area. The inflowing volume of runoff from a storm is then translated into an outflow hydrograph in which the capacity constraint of the channel is introduced. The result is that outflows are prolonged when the peaks of the inflow hydrograph exceed the drain capacity at the outlets of the subwatershed. This produced moisture excess conditions.

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[6] Rigaux and Singh, (1975: Vol. 1)

[7] These concepts are adopted from: V.T. Chow (ed), Handbook of Applied Hydrology, (Toronto: McGraw-Hill Book Co. Inc., 1964), Section 21, pp. 41-46. They are described in terms of the present application in Rigaux-Singh (1975: Vol 1).

The parameters of the synthetic triangular hydrograph which are derived from the hydrologic data are the time of concentration (Tc) and the time to peak (Tp). The former is an estimate of the time it takes for a particle of water to travel from the most distant part of the drainage area to the subwatershed's outlet, whereas the time to peak (Tp) is the time required for discharge at the outlet to reach a maximmum (peak) flow.

In the moisture excess component PE is first estimated for the existing system. As the flow diagram shows the input data which are required in this component to estimate the hydrograph characteristics for a specific drainage area are:

(i) the length of the main watercourse from the distant ridge to the particular subwatershed outlet (LT)

(ii) the difference in elevation between the highest point in the most distant part of the drainage area and the subwatershed's outlet (HT)

(iii) the surface area being drained - that is the total contributing drainage area (DA)

The time of concentration, which is constant for the drainage area, fixes the base time for the synthetic hydrograph[8]. Accordingly, in this model all hydrographs generated for a particular drainage area are assumed to have constant base time. Different volumes of run-off will therefore be shown by triangular hydrographs with the same base, but peaks

[8] Chow found that the base of the hydrograph was roughly constant for a particular watershed. Storm magnitude did not significantly affect the base of the inflow hydrograph.

of different heights. The computation of time of concentration is given by:

$$Tc = (1.3 \times 10^{-4}) * (_{LT}1.15/_{HT}\ 0.38) \quad \ldots.6$$

Having established the base for the synthetic hydrographs in the subwatershed being analyzed, the analysis proceeds to estimate peak discharges of the inflow hydrographs which are generated by the volume of runoff previously estimated in the runoff component for the selected subwatershed. Time is initialized to the first day of the project life (t=1). The estimated volume of discharge is retrieved from storage and is used to compute peak discharge. In Figure 4.2, this outflow hydrograph is represented by the triangle, ACE. Peak discharge is computed by equation (7):

$$Qp = \frac{484\ (DA)*(R)}{Tc^{.5} + 0.6Tc} \quad \ldots..7$$

Where: Qp = peak discharge in cubic feet per second, and other variables are as previously defined.

The outflow hydrograph from the subwatershed takes on a trapezoid shape because of the restrictive channel capacity. This is shown by the area, ABGF. The channel capacity at the outlet is (Q) and is assumed to be representative of the level of protection which obtains in the remainder of the subwatershed. This assumption constitutes the primary reason for the selection of relatively small hydrologic units or subwatersheds. It should be noted that the displacement from the inflow hydrograph (BCD , which is the volume above the capacity level) equals the extended area in the outflow hydrograph, DGFE.

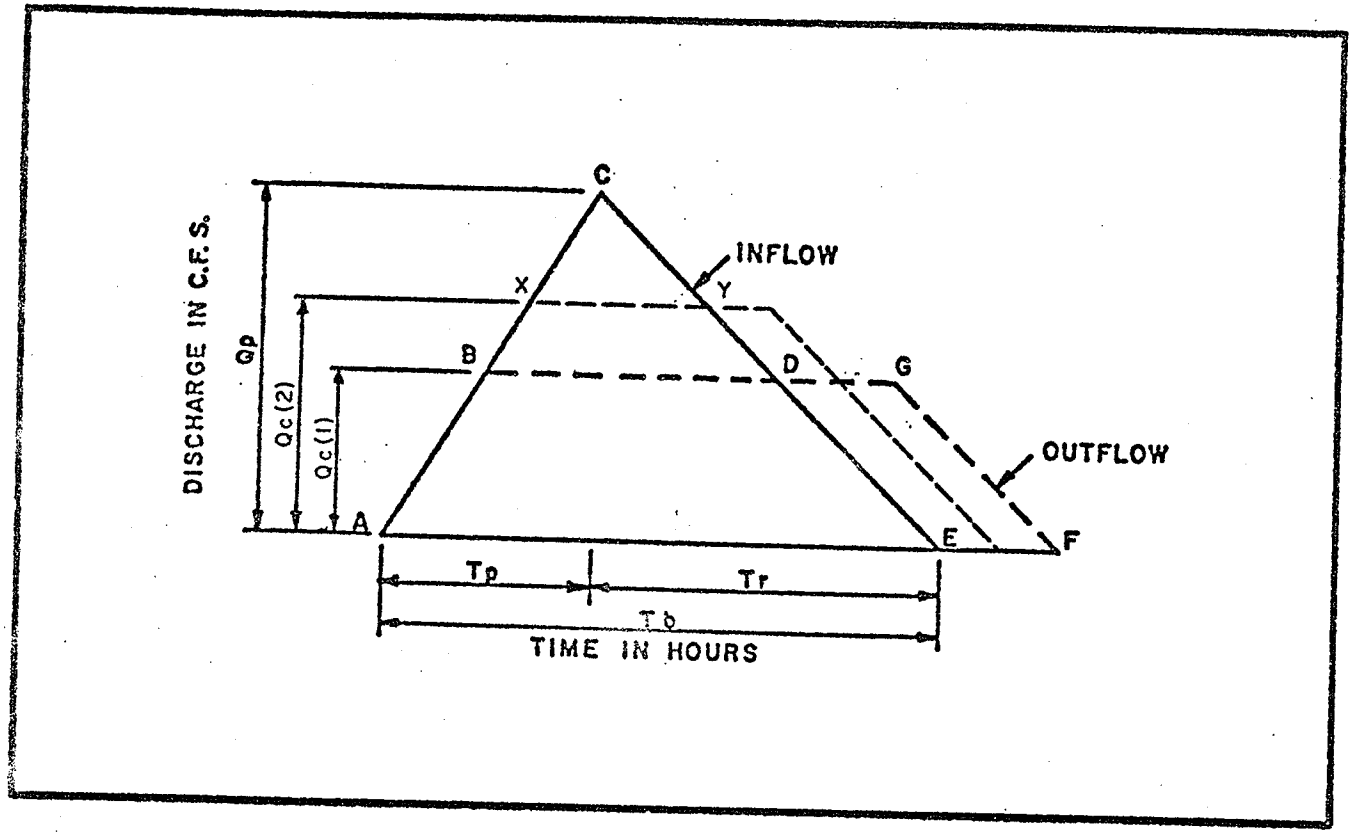

Figure 6.3

The Synthetic Inflow and Outflow Hydrographs

The efficiency of the drainage system is measured by the duration of excess moisture (PE). In this model the PE resulting from a storm event is defined as the duration of time over which the outflow hydrograph is at maximum channel capacity, as measured below prairie elevation[9]. Water detention on the land is assumed to exist for at least this time period. In Figure 6.3, PE is defined by the time BG.

PE can be estimated if the peak discharge of the inflow hydrograph, the time to peak and the effective outlet capacity are known. Time to peak is computed from the catchment area data as follows:

$$Tp = Tc^{0.5} + 0.6\ Tc \qquad \ldots.8$$

Where: Tp = time to peak for the hydrograph in hours.

In earlier discussions it was indicated that drainage improvement causes both an improvement in drainage effectiveness and in drainage efficiency. The former results from the fact that areas which were not serviced by drains are now provided with this facility. The latter refers to larger channels which have the capacity to remove a greater volume of water in the same time period.

When drainage effectiveness is increased the distance for overland travel of runoff before entering the drainage channel is shortened. The most significant improvement in drainage effectiveness in the Big Grass Watershed results from on-farm drain installation. Travel time for overland flow is reduced and thus the average duration of crop ex-

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[9] Capacity is measured relative to prairie elevation (which is the elevation of the lands adjacent to the channel) because water levels exceeding prairie elevation, such as at dyked elevation, does not allow effective drainage to the lands around.

posure to excess moisture (PE) is also reduced by an amount which equals one-half of the reduction in overland travel time. The effect of on-farm drain installation in reducing PE because of improved effectiveness is discussed more fully in Appendix E.

The duration of excess moisture is also reduced when drainage efficiency is increased since the larger capacities now facilitate the removal of excess moisture from the land in a shorter time period. Precipitation excess resulting from inefficient drainage is defined as the time period when the channel flow is at maximum discharge capacity at prairie elevation.

PE from both these factors is estimated from the equation[10]:

$$PE = KG^{-0.25} + 1.335\,Tp\,(Qp / Q - Q / Qp) \quad \ldots.9$$

Where: PE = precipitation excess in hours

K = constant reflecting overland travel time;

= 0.35, for level 1 drain design

= 0.11, for levels 2, 3, 4

Q = the effective outlet capacity for the subwatershed in cubic feet per second and other variables are as previously defined.

The first component in equation (9) estimates the PE which results from overland flow. The second component results from the capacity constraints of the channel.

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[10] The values of K are derived in Appendix E. Equation 9 can also be expressed in the following alternate form:

$$PE = KG^{-0.25} + 2.67\,Tp\,(1 - Q / Qp)\,(Qp / 2Q + 0.5)$$

After PE is estimated for the first day under the existing system, time is advanced to the second day (t + 1) and PE is estimated once more for the volume of runoff recorded for day (t + 1). By advancing time on a daily basis the model estimates PE for all runoff volumes which were previously estimated. Many of the elements of the matrix storing runoff values would have been zeros since not all storms produce runoff, nor are there storms for each of the days. Similarly, many runoff values would have been too small to produce measurable PE.

As previously indicated, the hydrologic analysis - that is, the estimation of precipitation, runoff and PE was conducted for the period April 1 to September 30 to obtain information on moisture levels at times other than when direct agricultural benefits are derived from drainage protection. The model computes agricultural benefits from improved drainage from the protection of crops against PE over the period June 1 to August 30. Accordingly, any PE over this period is directly used by the model to estimate benefits.

From the matrix of PE values estimated for the subwatershed under the existing level of drainage service, the monthly values for June, July and August are aggregated for each of the years. For the analysis in the moisture excess component the annual monthly PE estimates are averaged to give an annual equivalent for each month. This is consistent with the methodology of the deterministic model of using the mean values of variables for analysis.

As the flow chart indicates, the next step in the analysis is

the estimation of PE after development. The status variables (DA, HT, LT) for the subwatershed are unchanged; so too are the runoff values. The estimation of PE for the developed system therefore involves a repeat of the process outlined for the existing system. The only change being channel capacity which is assigned the value given by the development plan.

The reduction in PE due to improved drainage efficiency can be demonstrated with the use of the synthetic inflow and outflow hydrographs given in Figure 4.2. Assuming an existing drain capacity Q(1) and a storm which generates a peak discharge Qp for the inflow hydrograph the volume of runoff corresponding to the area CBD under the hydrograph is displaced resulting in an extended period of time (BG) when the channel flow is a maximum prairie elevation capacity. BG is defined as the PE. If drainage improvement works increase the channel capacity to Q(2) then a smaller volume of runoff is displaced and PE is reduced to XY. This is the effect desired from drainage capacity improvements.

The reduction in PE which results from drainage development is the measure of improved drainage efficiency and effectiveness. This is estimated from annual monthly average PE determined for the subwatershed in its pre-development status. As shown in the flow chart this estimate of improved efficiency, which was endogenously determined, is fed back into the model in the next component.

Productivity relationship component. In this study the econ-

omic impact of development will be assessed on the basis of the improvement in net economic returns generated by the system in its developed state over the returns resulting from existing (pre-development) state. The interrelationships among parts of the system in the productivity component are therefore directed towards both the identification of the current productivity level and the enhanced productivity after development.

Previous discussion suggested that average yields were determined from the MCIC productivity rating for soil groups. In the economic analysis of drainage development, the land area within a subwatershed was divided into homogenous soil groups to facilitate the analysis. Homogeneity was defined with respect to the following characteristics:

(i) agricultural capability class

(ii) productivity group

(iii) soil texture

(iv) hydrologic soil grouping

The agricultural capability class[11] identifies the alternative uses for which the land is physically suited, whereas the productivity group identifies the average yields associated with the recommended alternatives. Soil texture was cited in the discussion of the conceptual framework as an important factor affecting productivity response of soils to better drainage. Clays are the most responsive, whereas coarse textured sands showed little need for further drainage works. The hydrologic soil class-

[11] See Jenkins (1973)

ification reflects internal drainage characteristics of the soil, and thus the influence of soils on the proportion of runoff from storm events. This characteristic is important in the analysis of the runoff component.

Productivity rating of the soil groups is useful in estimating net return from the current land use under the existing drainage. Productivity rating, soil capability and texture are useful in estimating the improved yields to the alternative uses for each soil group in the post-development state.

Consistent with the above rationale, the analysis in this component of the model is based on the soil groups. The chart shows that for the existing system, the productivity rating for each group identifies the average yields from the matrix of MCIC average yield data. This provides yield data input for estimating net returns to present land use in the next component.

The next relationships in the productivity component are those which attempt to derive the improved productivity after drainage development. This procedure calls for the identification of the alternative uses to which each soil group is suited and the estimation of increased yields which are likely to be observed.

That portion of the flow diagram dealing with the developed system shows that soil capability class for a soil group determines the uses for which the lands within the soil group are suited. The estimates of improvement in yields are based on:

(i) the reduction in annual average monthly PE - determined from the moisture excess component

(ii) the marginal physical benefit or marginal gain in productivity with respect to PE reduction ($\delta Y / \delta PE$). This is shown in the flow diagram as being derived from the regression analysis submodel.

The discussion in the conceptual framework established that crop damage from excess moisture is dependent on the texture of the soils on which production takes place. Appropriately, the flow chart indicates that the choice of marginal gain function (or crop damage function) is based on the texture of the soil group being analyzed.

The model indicates that a soil group is selected and for the first use identified, the improved productivity resulting from more efficient drainage is computed as follows:

$$DY\ (soil, crop) = \left[DYDPE\ 6\ (crop) * ADPE\ (6)\right] + \left[DYDPE\ 7\ (crop) * ADPE\ (7)\right] + \left[DYDPE\ 8\ (crop) * ADPE\ (8)\right] \quad ...10$$

Where: DYDPE 6 (crop) = damage factor or marginal gain in productivity per unit reduction in PE for the month of June and for the specific crop indicated.

DYDPE 7 (crop), DYDPE 8 (crop) = similar to the above; these refer to the months of July and August, respectively.

ADPE (6) = average annual monthly reduction in PE for June.

ADPE (7), ADPE (8) = similar to the above; these refer to July and August respectively.

DY (soil, crop) = improved productivity for the specific crop and soil texture indicated (yield per acre).

The model then proceeds to the estimation of the improved yields for the specific soil group and the crops which were recommended above. The improved yield is equivalent to the sum of improved productivity (DY) and the average yield (Y) which was identified for the soil group at the beginning of this component. The improved yields for other land use alternatives are subsequently estimated by the same method.

The estimates of this endogenous variable are used in the analysis of the economic returns component which is discussed next. Before proceeding to do so, there is one additional point with respect to this component of the model. Some of the alternative land uses will obviously differ from present land use. As land is made more productive and becomes better suited for other uses, the need may arise to develop the land to accomodate the new uses. Such will be the case when unimproved land or pasture is to be used for forage or grain, or unimproved land is to be used for pasture. The diagram shows that information on the present land use and the alternative uses provide input data into the cost component. These are used to determine land development and on-farm drainage costs.

Economic returns component. The evaluation of net returns in this component is based on the soil group as the unit of analysis. The procedure followed in the model is to first estimate net returns for the soil groups under the existing drainage. Here, net returns are defined as

the returns to land, labour and capital after other production costs are deducted[12]. Subsequently, net returns are computed for agricultural production after drainage development occurs. This estimate of returns after drainage development differs from the foregoing in that gross returns are higher while the deductions are also greater because they include the costs of on-farm modifications which induced the higher gross returns. These costs are for on-farm drains and for land development.

For agricultural production after drainage development two different estimates of net returns are made. The first is the returns to the factors cited above (land, labour and capital) and to public drainage, net of other costs. The latter includes both the other production costs (referred to above) and the amortized costs for land development and on-farm drainage. As a result this estimate of net return is referred to as the net return to public drainage (NRPG for soil groups and MRPS for the subwatershed). The second estimate is the returns to land, labour, capital, public drainage and on-farm drains and net of other production costs and the amortized cost of only land development. This measure is referred to as net returns to all drainage (NRDG for soil groups, and NRDS for the subwatershed). The relevance of the various computations of net return will become apparent when the appropriate parts of the model are discussed.

The relationships which are first encountered in this compon-

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[12] The items which are included in the estimates of production costs are given in Table C3 in the Appendix.

ent deal with the estimation of net returns from agricultural production under the existing drainage system. The model assumes that land use is unchanged for the existing system and so net returns computations are based on the present land use, the average yields identified in the productivity component and crop prices and costs of production which were identified in stage one of the model. The computation of net returns for the existing system is given in equations (11 to 15):

$$NRPG = NRA + NRP + NRK \quad \ldots 11$$

$$NRA = NRO1 + NRO2 + NRO3 \quad \ldots 12$$

$$NR(i) = \left[Y\ (i, PROD) * PR(i) - CP(i)\right] \left[ACA * FC(i)\right] \quad \ldots 13$$

$$NRP = \left[Y\ (P, PROD) * PR(P) - CP(P)\right] \left[ACP\right] \quad \ldots 14$$

$$NRK = \left[Y\ (K, PROD) * PR(K) - CP(K)\right] \left[ACK\right] \quad \ldots 15$$

where: NRPG = net return to soil groups (for the existing system, NRPG = NRDG, since no development takes place),

NRA = net return from field crops

NRP = net return from forage production

NRK = net return from native grassland usage

i = 01, 02, 03 where: 01 = wheat; 02 = oats; 03 = barley.

PR (i) = price of crop i

CP (i) = cost of production of crop i

FC (i) = fraction of cereal product in crop i

ACA = acreage of land in the soil group used for cropland

ACP = acreage of land in the soil group used for forage

ACK = acreage of land in the soil group used for native grassland

PROD = soil productivity rating

CP (k) = cost of production of native hay

CP (p) = cost of production of tame hay

The estimation of net returns is repeated for all soil groups and the results kept in storage for use at a later stage in the analysis. Before proceeding to the analysis after development the net returns for the entire subwatershed are obtained by aggregating the net returns for all groups. This is shown by equation (16):

$$NRPS = \sum_{g=1}^{L} NRPG\ (g) \qquad \ldots 16$$

where: NRPS = net return for the subwatershed under the existing drainage. (Since there is no drainage improvement at the existing level, NRPS and NRDS are equal).

g = 1,. . . , L, are the soil groups in the subwatershed

Having estimated the returns from agricultural production under the existing drainage, the model next considers the net returns generated after drainage development. First, the net returns to public drainage is computed for the alternative uses recommended for the various soil groups. From these the highest use is selected.

To determine the highest land use for a soil group at a particular level of drainage protection a comparison must be made of the net returns from alternative uses. This estimate of net returns is computed by subtracting both the production costs (given in Table C3 in the Appendix) and the amortized on-farm cost (that is, land development and on-farm drainage). This was previously referred to as the net return to public drainage (NRPG). The above criterion is the basis for choosing the

highest use since farm operators will tend to adopt the land use alternative which produces the highest financial net returns. This means that private costs, which consist of production, on-farm drainage and land development must be deducted from gross returns. It was on account of this need to determine the highest land use that the measure of net return to public drainage was introduced in the model.

While the analysis does not consider the effect of resource limitation of individual farm operators on the adoption of the highest use there are nonetheless other constraints on production which must be observed. Firstly, the land use adopted should satisfy traditional crop rotation practices which usually reflect farm operators' desire to diversify, to control disease, to improve fertility and to satisfy marketing quotas or restrictions. Apart from this is the limited market for certain output such as forage. Thus, even though a particular activity may produce the highest NRPG in many soil groups in a subwatershed, if the aggregate production for the subwatershed exceeds the probable market potential then the level of such an activity must be scaled downwards. That is, the choice of highest land use is constrained by economic and other restrictions.

But given that the unconstrained choice of highest land use results in the violation of certain restrictions it then becomes necessary to select the next highest use, providing that this results in constraints being satisfied. The model uses an optimization subroutine

to make land use adjustments so that the highest use which enters the solution satisfies the various constraints. The highest land use solution in this model is in fact a constrained solution

The flow chart identifies the various factors which determine the net returns. Firstly, the higher yields which are likely to result after development were determined in the productivity component. Secondly, crop prices and cost of production are obtained from stage one and finally, the amortized costs for land development and on-farm drains are generated by the cost component. The amortized costs were estimated from the land use information, the soil group area and unit costs. The net return to public drainage for the alternative uses of the various soil groups are computed according to equations (17 - 20):

(i) if the use = cereal crop production:

$$NRPG = [(NRO1 + NRO2 + NRO3) - AOFC\ (A)] \quad \ldots 17.1$$

$$NR(i) = \left\{[Y\ (i, PROD) + DY(i)] * PR(i) - CP(i)\right\} * [AC(g) * FC(i)] \quad \ldots 17.2$$

where: NRPG = net returns to public drainage for the soil group.

AOFC = amortized on-farm costs (land development + on-farm drainage) for cereal production.

AC(g) = acreage of land in soil group (g).

(Y + DY) = improved yield after development

Other variables are as previously defined.

(ii) If use = forage production:

$$NRPG = [NRP - AOFC\ (P)\ ] \qquad \ldots 18.1$$

$$NRP = \left\{[Y\ \ (P, PROD)\ +\ DY\ (P)\ ] * PR(P) - CP(P)\right\} * [AC\ (g)\ ] \qquad \ldots 18.2$$

where: AOFC (K) = amortized on-farm costs when use = forage

(iii) if use = native grassland:

$$NRPG = [NRK - AOFC\ (K)\ ] \qquad \ldots 19.1$$

$$NRK = \left\{[Y\ \ (K\ , PROD) + DY\ (K)\ ] * PR(K) - CP(K)\right\} * [AC\ (g)] \qquad \ldots 19.2$$

where: AOFC (K) = amortized on-farm costs when use is native grassland

(iv) if no economic use:

$$NRPG = 0 \qquad \ldots 20$$

Following the above procedure, the net returns to public drainage for alternative uses for each soil group in the subwatershed are computed and the highest use identified.

If the drainage system is improved it is possible that the incremental costs for on-farm drainage and land improvement which are likely to be incurred by farm operators may exceed the increase in gross returns or gross benefits for the highest use at the particular level. That is, on-farm costs can be sufficiently high to result in lower net returns to public drainage after improvement of the system. If this situation holds for some of the soil groups it is unlikely that farm operators will undertake the necessary on-farm modifications when public drains are developed. Net returns and land use will remain unchanged from the present, and so there will be no on-farm costs associated with the specific soil groups.

It is therefore necessary at this step in the model to conduct a financial feasibility test to ensure that for each soil group the change in the net return to public drainage resulting from development is positive. Thus if

NRPG (developed system) - NRPG (existing system) < 0 ...21.1

then:

(i) highest use after development = present use ...21.2

(ii) on-farm costs = \$0 ...21.3

(iii) NRPG (developed) = NRPG (existing) ...21.4

Based on the above procedure, the financial feasibility test and appropriate adjustments are made for all soil groups thus ensuring realism in the choice of highest use.

Because net returns to all drainage is computed from the gross returns by deducting all costs except drainage improvement costs for both the public and on-farm drains (that is, production costs and land development costs are deducted) then any increase in net returns to all drainage which is induced by drainage development expenditures constitutes the benefits of the project.

Accordingly, this version of net returns was introduced in the analysis to estimate benefits. The net returns to all drainage for each soil group (NRDG) are aggregated to obtain the net return to all drainage for the subwatershed (NRDS) and this estimate is used to derive the benefits.

The net returns to all drainage (rather than net returns to public drainage) is the definition of net returns which is used finally to determine whether: (1) drainage should be improved; and (2) whether the highest land use identified should be adopted. Net returns to public drainage is used in a financial feasibility test to identify the highest use. If the net returns to public drainage give estimates of benefits which show that drainage improvement is not feasible then the highest economic use requires no drainage improvement and no change in land use. That is the highest land use identified is not compatible with the highest economic use. If however the benefits estimated showed that drainage development was feasible then the highest land use identified in the financial test is consistent with the highest economic use.

Economic benefit component. Drainage development programs can affect farm incomes and the economy of a region in a number of different ways. These favourable effects or benefits were enumerated in the discussion of the conceptual framework but the practical difficulties involved in quantifying these were indicated in the benefit-cost analysis framework. Accordingly, it was decided that for analytical purposes, the economic impact of drainage development should be measured in terms of the major primary benefit - the net increase in the value of agricultural production which is induced by the improvement in the level of agricultural drainage protection.

The flow diagram shows that the inputs for this component were

estimated in the economic returns component. The first input quantity is the net returns for the subwatershed from agricultural production under the existing status of the drains. This is in fact the net returns to land, labour and capital. The second input is the net returns for the subwatershed under the improved drainage. It is the net returns to land, labour, capital and to all drainage expenditures (that is, for main channel, the collection drains and the on-farm drains). These estimates of net returns are the average annual amounts and thus the benefit to drainage computed is the average annual benefit. Benefits are computed according to equation (22):

$$AB = [NRDS \text{ (Dev. system)} - NRDS \text{ (Exist. system)}] \quad \ldots 22$$

where: AB = average annual benefit

Because benefits accrue at different points in time over the life of the project it is necessary to convert them to a constant dollar value before they can be aggregated. In this study benefits accruing at various points in time are discounted to their present value equivalent. The discounting formula is given by equation (23):

$$PVB = AB \left[1 - (1 + r)^{-n} \right] / r \quad \ldots 23$$

where: PVB = present value of benefits

n = project life

r = discount rate

Economic cost component. The costs for the project are the costs associated with drainage development. These consists of both the capital costs and the cost of maintaining the system. Capital expen-

ditures are incurred for the construction of the main channels, lateral drains and on-farm drains, for the various structures such as bridges, culverts and gradient-control structures and for right-of-way.

Field surveys of the existing drainage system provided the cross-section and drain profile data which were used to design the drains of the system to the levels selected for analysis and to estimate the cost of drainage development.

On-farm drainage costs were initially estimated for all lands within the subwatershed. As indicated by the flow diagram on-farm drainage costs were subsequently adjusted downwards to reflect the actual land use. That is, if the highest land use solution shows that certain parts of a subwatershed are not to be used for field crop or tame hay then on-farm drainage costs are pro-rated to reflect this lesser amount of on-farm drainage in the subwatershed.

However, before on-farm drainage cost for the subwatershed is adjusted, the model calls for an estimate of both the land development cost and on-farm drainage cost for each of the alternative uses associated with the soil groups. The land development cost is dependent on both the amount and type of development which is required by the existing land base so as to facilitate new usage, and the unit cost of various types of developments. Since present land use may be comprised of various proportions of cereal crops, tame hay, native grassland and unimproved land, then development costs for alternative uses can be estimated as follows:

1. If the new use = field crop (A), then development is required to transform pasture and unimproved land to make them suitable for field crop cultivation. The cost is:

$$DCA = [\, AC(K) * DCKA \,] + [\, AC(T) * DCTA \,] \quad ...24.1$$

where: DCA = land development cost for field crop usage

DCKA = unit cost per acre of developing land used for pasture (native grassland) for field crops

DCTA = unit cost per acre of developing unimproved land for field crops

2. If the new use = forage (P), then the improvements are similar to that above, and thus cost is:

$$DCP = [\, AC(K) * DCKA \,] + [\, AC(T) * DCTA \,] \quad ...24.2$$

where: DCP = land development cost for forage usage

3. If use = K, then the only improvement required is clearing of heavy brush and trees and thus the cost is estimated as follows:

$$DCK = [\, AC(T) * DCTK \,] \quad ...24.3$$

where: DCK = land development cost for pasture usage.

DCTK = unit cost per acre of developing unimproved land to native grassland use.

4. If use = T, then no costs are incurred:

$$DCT = 0 \quad ...24.4$$

where: DCT = land development cost for no economic usage.

Recall that the economic returns component required amortized land development cost to compute net return to public drainage. The am-

ortization of cost is based on equation (25):

$$ADC = DC\left[\frac{i}{1-(1+i)^{n}}\right] \qquad \ldots 25$$

where: ADC = amortized land development cost

DC = capital cost of land development

i = interest rate

n = project life

The computation of net returns for alternative land uses also required estimates of amortized on-farm drainage costs. It is assumed in this model that field crops, and native grassland are provided with the same level of on-farm drainage service. This is the level which is consistent with the improved protection in the public drains of the subwatershed. Unimproved land are not provided with on-farm drains. The estimate of on-farm costs for each soil group is based on equation (26):

1. If use = A, P or K

$$OFCG = \left[\frac{AC(A) + AC(P) + AC(K)}{AREA}\right]\left[FCSW\right] \qquad \ldots 26.1$$

2. If use = T

$$OFCG = 0 \qquad \ldots 26.2$$

where: AC (A), AC (P), AC (K) = are as previously defined

OFCG = on-farm drainage cost for a soil group

AREA = area of subwatershed in acres

FCSW = on-farm drainage cost assuming on-farm drainage for entire subwatershed

The amortization of on-farm drainage costs is the same as that given by equation (25).

These estimates of on-farm drainage costs and land development cost assist in the identification of the highest land use and in the estimation of the net returns to all drainage. Only after these steps are completed (which includes the financial feasibility test) are the final estimates of on-farm drainage costs obtained for the soil groups. This is shown in the cost component section of the flow diagram. The cost for all groups are then aggregated to obtain total on-farm costs for the subwatershed. Below this element in the flow diagram are the costs for the main channel and collection drains which were previously estimated.

The cost of maintaining the drains, when expressed as a percentage of capital cost, varies among the types of drains in the system. Generally, it has been found that smaller drains, such as on-farm and collection, require greater maintenance than the larger channels. The computations of maintenance costs are given in equations (28 - 30):

$$AMCF = [MCCF * CCOF] \quad ...28$$

$$AMCM = [MCCM\ (cfs) * CCM] \quad ...29$$

$$AMCC = [MCCC * CCC] \quad ...30$$

where: AMCF = annual maintenance cost of farm drains in the subwatershed

AMCM = annual maintenance cost of main channel in the subwatershed

AMCC = annual maintenance cost of collection drains in the subwatershed

MCCF, MCCM, MCCC = the maintenance cost coefficients

(maintenance cost as a fraction of capital cost) for farm drains, main channel and collection drains, respectively. Note that MCCM is a function of discharge capacity.

CCOF, CCM, CCC = capital costs of farm drains, main channel and collection drains, respectively, for the subwatershed.

From the above equations the annual maintenance costs for drains within the subwatershed can be estimated. Because these are incurred over the life of the projects they must be discounted to the present value equivalent. Total cost is therefore the sum of the latter and capital construction costs (equations 31 - 33):

$$AMCT = AMCF + AMCC + AMCM \quad \ldots 31$$

$$CCT = CCC + CCM + CCOF \quad \ldots 32$$

$$PVC = CCT + AMCT \left[1 - (1 + r)^{-n}\right] / r \quad \ldots 33$$

where: AMCT = total annual maintenance cost

CCT = total capital expenditure

PVC = present value of all costs

Thus far the model has generated estimates of benefits and costs for the various development plans which were chosen for analysis. These output variables constitute the measures of economic impact as defined in this study. It now remains for the feasibility of the various development plans to be assessed. This is the task of the next component.

Economic feasibility component. The model in this study examines the impact of various drainage development plans so as to assess their economic feasibility. Subsequently, and more importantly, it is desirable to locate the optimum scale of drainage development. Feasibility is evaluated on the basis of the economic efficiency criterion which implies that net benefits must be positive or alternatively, the benefit/cost ratio should be greater than or equal to one. In order to establish the economic optimum with respect to the level of drainage protection, it is ideally desirable to have output data for benefits and costs for the complete range (up to some reasonable upper bound) of drainage design levels. To do this would involve considerable time and costs. Accordingly, in this study an attempt is made to derive the optimum from an analysis of the economic output data generated by the system for three alternative development plans. The procedure followed is based on a graphical analysis whereby the data generated from the system (benefits and costs) are used as reference points for interpolating intermediate results in the construction of the benefit and cost functions. Of course, there is little doubt that the optimum identified by this procedure will at best be only an approximation to the true optimum. From a practical viewpoint these results obtained are adequate since final allocative decisions are likely to be based on both the single-valued estimates obtained here and the confidence range generated from the stochastic simulation version of the model.

The procedure outlined above assumes that the expenditure bud-

get for the project does not constrain the optimum. This assumption is plausible since decision-makers are primarily interested in the knowledge of the location of the unconstrained optimum. Whenever capital (public sector) expenditure associated with the optimum exceed the budget, it is unlikely that the project will be undertaken at the constrained optimum. The problem is more likely to be resolved by one of the following:

(i) phasing construction along various reaches

(ii) phasing construction on parts of the system - for example, main channels first, then collection drains and finally on-farm drains

(iii) delay the entire project but maintain those parts of the system where drainage service has deteriorated significantly.

The flow diagram shows that benefits and costs are the input data into the feasibility component. Before the economic optimum can be determined the impact of alternative plans must be evaluated. This does not require a re-evaluation of the entire model, but instead the re-entry point is in the moisture excess component where the capacities of proposed designs enter the model. This procedure ensures that storm data, run-off, economic data, crop damage factors and present land use are held constant for the various development plans.

The analysis of the impact of various policy alternatives for the subwatershed are expected to provide the following information:

(i) optimum drain design capacities and drain pattern

(ii) the present value of benefits and costs resulting from optimum development

(iii) the highest land use and land use pattern

(iv) land development which are necessary to facilitate highest use

It should be noted that these findings are only preliminary since adjustments are likely when both the economic interdependency among subwatersheds and the externality impact outside the watershed (downstream) are considered in stage three.

The impact of development in other subwatersheds is assessed similarly. The re-entry point is at the initial point in stage two - the identification of subwatershed for analysis. The results obtained from stage one are held constant.

Having evaluated drainage improvement feasibility in all subwatersheds the flow chart shows that the results are fed into stage three. This last stage of the model is now discussed.

Stage Three: Optimum Watershed Development

In this stage of the model, the assumption of economic independence among subwatersheds is relaxed. The resulting effects from development are incorporated into the analysis to modify the preliminary results of the second stage. In addition to the above, possible downstream effects and land use conflicts are considered.

Improvements in the drainage system efficiency will tend to modify hydrographs, producing a shorter base and consequently higher peaks from the various storms. When drainage improvement takes place

in a subwatershed, the hydrograph modifications are greatest in the reach immediately downstream. As one travels away from the developed area towards the outlet of the watershed the changes in peaks become more moderate, eventually becoming negligible at some distance away. In this study a basic constraint imposed on construction of the system is that the status quo of the drainage system with respect to the level of protection will at least be maintained. This implies that if changes in the level of drainage are warranted for a subwatershed, but not for the subwatershed immediately downstream from it, then to the extent that the changes proposed modify the hydrographs observed in the downstream unit, a reduction in the level of protection will result. To at least maintain the drainage status in the lower reach, the main channel must be upgraded.

The flow diagram shows that output data from stage two of the model identifies the subwatersheds for which improvements are feasible. The economic effects of developing these subwatersheds at their optima are then estimated. Both the effects within the watershed and downstream from the watershed are considered. The model proceeds to allocate these costs to the subwatershed which are to be developed and which have induced the problem. Allocation of costs is on the basis of: (i) the extent of the modification; and (ii) the subwatershed's area. These costs are then used to modify the preliminary feasibility results for various subwatersheds.

The analysis in this component also looks at the compatibility of the land use plan originating from the economic model with the non-economic wildlife uses. Where conflicts appear in terms of a high wildlife capability area being used for agricultural production, an attempt will be made to resolve the problem by examing land ownership. If a relatively high wildlife capability area is owned by the crown, then land use will be changed from agricultural production to wildlife. If the land is privately owned then it is likely that it will be used for agriculture and thus no change is warranted. If a change in land use occurs then benefits and costs in the respective subwatersheds must be adjusted accordingly. This further need for cost adjustment results from the fact that such areas will no longer need onfarm drains and possibly collection drains.

These final modifications may not be significant. To the extent that they are, the adjusted benefits and costs will be used to locate the final optimum drainage development plan. The output from the model will therefore comprise of the following:

(i) a comprehensive drainage development scheme for the watershed indicating optimum design capacities and pattern of the drainage network

(ii) the land use plan which is generally consistent with the concept of highest use given certain constraints

(iii) the aggregate benefits and costs for the watershed resulting from development

(iv) the aggregate net benefits

(v) the ratio of total benefits to total costs at the optimum for all subwatersheds to be developed

These results are therefore expected to represent the average or the mean impacts which are likely to result from development. No measures of the confidence interval for the important endogenous (output) variables were obtained since a deterministic model does not have the structure to readily provide this information.

The purpose of the stochastic version of the model is precisely to fill this gap. It will be employed to measure the output characteristics for one of the subwatersheds. The next chapter discusses the stochastic model.

Table 6.1

List of Variables

VARIABLE	DEFINITION
Exogenous	
PREC	Daily precipitation in inches
API	Antecedent precipitation index
PR	Crop price
CP	Cost of production
r	Discount rate
n	Project life
DCKA	Unit cost of land development - posture to cereal crops
DCTA	" " - trees to cereal crops
DCTK	" " - trees to posture
i	Rate of interest
MCCM	Maintenance cost coefficient for main channel
MCCC	" " " " collection drains
MCCF	" " " " on-farm drains
FIPI	Farm input price index
Z	Standard normal variate
CPD	Deflated cost of production
PRD	Deflated crop price
PRSD	Standard deviation of deflated crop prices
U	Random number
V	Random normal variate
Status	
D	Distance of a sub-watershed from a precipitation station
G	Average land gradient in feet per mile
Tc	Time of concentration in hours
Tp	Time to peak in hours

Table 6.1 (continued)

List of Variables

VARIABLE	DEFINITION
DA	Run-off contributing drainage area
Q	Sub-watershed outlet capacity
HT	Elevation difference between the sub-watershed outlet and most distant ridge
LT	Length of drainage channel from the sub-watershed outlet to the most distant ridge
PROD	Soil productivity rating
CAP	Soil capability
HSG	Hydrologic soil grouping
SOIL	Soil texture
Y	Crop yields
ACA	Acreage of a sub-watershed in cereal crops
ACP	" " in forage
ACK	" " in native grassland
ACT	" " in trees or unimproved
FC	Proportion of cereal acreage in various crops
AC	Area of a soil group in acres
AREA	Area of a sub-watershed in acres
t	Time in days
T	time in years
M	Months (1, ..., 12)
Endogenous	
CN	Run-off curve number
S	Potential soil moisture abstraction index
R	Run-off in inches

Table 6.1 (Continued)

List of Variables

VARIABLE	DEFINITION
Qp	Peak discharge
PE	Precipitation excess
DY	Change in yields - improved productivity
DYDPE 6	Marginal crop damage for PE in June
DYDPE 7	" " " " July
DYDPE 8	" " " " August
NRPG	Net return to public drainage for soil groups
ADPE 6	Average annual PE reduction for the month of June
ADPE 7	" " " " July
ADPE 8	" " " " August
NRA	Net returns for soil groups from cereal production
NRP	" " forage "
NRK	" " native grassland production
NRO1	" " wheat "
NRO2	" " oats "
NRO3	" " barley "
NRPS	Net return to public drainage for the sub-watershed
AOFC	Amortized on-farm costs (on-farm drainage and land development) for soil groups
AB	Average annual benefit
PVB(	Present value of benefits
NRDS	Net return to all drainage for a sub-watershed
DCA	Land development cost for soil groups from cereal production usage
DCP	" " forage usage
DCK	" " pasture usage
DCT	" " non-use

Table 6.1 (Continued)

List of Variables

VARIABLE	DEFINITION
OFCG	Capital on-farm costs for soil groups
FCSW	Capital cost of on-farm drains for sub-watersheds
AMCF	Annual maintenance cost of farm drains
AMCM	" " main channel
AMCC	" " collection drains
AMCT	" " total system
CCM	Capital cost of main channel (sws)
CCC	" collection drains (sws)
CCOF	" farm drains (sws)
CCT	" total system (sws)
PVC	Present value of all drainage costs
B/C	Benefit-cost ratio
DPE	Reduction in PE for specific years (monthly)
B	Annual benefit

Chapter 7

THE STOCHASTIC SIMULATION MODEL

AN OVERVIEW OF THE MODEL

This version of the model is included in the study for the purpose of providing decision-making information in addition to that given by the deterministic simulation model. Specifically, the stochastic version provides sample estimates of the output variables rather than the single-valued estimates which are generated by the deterministic model. Because the stochastic and dynamic behaviour of certain variables are explicitely allowed for in the analysis, the current version of the model produces estimates of each output variable according to its statistical distribution. Thus the stochastic model is useful for obtaining decision-making information on the statistical distribution and the dispersion or confidence limit for the important output variables. For the analytical framework in this study it was assumed that the stochastic and dynamic properties of the storm precipitation, crop prices and cost of production variables were such that they exerted the strongest influence on the output of the system. Other stochastic variables in the model are assumed to have random properties which exert a much lesser influence on the outcome of the system. These are introduced into the analysis at their mean values.

The major differences, therefore, between this version of the model and the deterministic are the STORM SIMULATION and the ECONOMIC

VARIABLES SIMULATION COMPONENTS and the treatment of time. The relationships in the other components are similar to those presented in the earlier version. In presenting the stochastic model, greater emphasis is placed on those aspects which are different from version already disussed. For those relationships which were previously discussed, the treatment will be brief.

Because of the computer cost of running the stochastic version of the model, its use will be restricted to the evaluation of drainage impact in one of the subwatersheds which was found to be economically feasible for development in the deterministic analysis. The model therefore uses as input some of the intermediate results generated from the deterministic analysis for the particular subwatershed being investigated. The components of the stochastic model are:

1. Storm simulation component
2. Storm runoff component
3. Economic variables simulation component
4. Moisture excess component
5. Productivity relationships component
6. Economic returns component
7. Economic benefits component
8. Economic cost component
9. Confidence tests component

There are two time variables in the model; (t) which refers to days and (T) which refers to the years. The project life is 15 years

and thus (T) takes on the values one to 15. The days within each year or period which are of interest for the hydrologic analysis are April 1 to September 30 and thus the values of (t) are one to 183. At certain points in the model the specific months within each period need to be identified and so the variable (M) is used, where M takes on the values four (4) to nine (9) for the months of April to September, respectively.

Generally, the model begins with the simulation of storm data for the precipitation stations for the first day. This precipitation for (t) is used to estimate runoff. In the runoff component it is necessary to simulate runoff from all upstream areas (or subwatersheds) which contribute to the discharge moving through the subwatershed selected for economic analysis. The runoff estimated for day (t) is fed into the moisture excess component where the reduction in precipitation excess resulting from drainage development is computed. Before proceeding further in the model, similar data are generated for the remaining days in period (T) - that is, from (t) equals one to 183.

Simultaneously, the model simulates economic variables which are the average annual values. Thus for each period (T) one set of crop prices and costs of production is generated. The data from this component enter the model as input in the Economic Returns Component.

The PE reductions computed for the various months in period (T) are then used in the computation of benefits according to the procedure outlined in the deterministic model. Also, corresponding to the development are the costs of drainage. For similar development plans

these are assumed to be the same as those used in the deterministic model. The output from the model which have been discussed thus far are the benefits and costs for (T = 1). The entire analysis is repeated for the remaining years of the project. This analysis produces the data for estimating the benefit/cost ratio for one of the development plans. Repeating the above analysis from the point at which the new drainage designs are introduced will similarly produce estimates of benefit/cost ratios for other plans. This constitutes one simulation run for the entire model. To obtain adequate data for the estimation of statistical distribution and confidence limits the above simulation is re-evaluated at least thirty times. For each simulation run the input information into the system which are likely to change or enter at new levels are the daily storm data, agricultural prices and cost of production. These in turn will affect the various output variables.

It will be observed that the plans evaluated in this version of the model are identical to those considered in the deterministic analysis. For this reason the capital cost of public drains, the on-farm drainage costs, the land development costs, the maintenance cost of drains and the highest land uses are the same as those used or generated by the previous model. The discussion now focuses on the components of the stochastic model.

THE STORM SIMULATION COMPONENT

This component generates point estimates of daily precipitation for selected stations within the watershed's environment. For analytical purposes the joint probability of storm events of various magnitudes between the different stations must first be known. The particular method followed in generating storm data is to select one of the stations as a prior station for which precipitation is generated. Having generated a storm event for the prior station, storm data can then be generated for the other stations (referred to as conditional stations) using the posterior or conditional probability density functions.

Of course, the questions which remain are which stations should be selected as prior and how to generate data for this station? The prior station should be the one for which a long period of historical records is available. Failing this, the choice should be for the station whose long-term storm frequency and storm pattern are expected to be similar to those of any other station in the region with a well establised series of historical records. The prior station in such a case will assume the frequencies of the station for a long period of observation.

If storm occurrences were completely random, then data can readily be generated for the prior and conditional stations using the statistical distributions. But storm events are not entirely random. Firstly, in certain months storms occur with greater frequencies than in others. Secondly, when precipitation occurs on one day the probability

of precipitation on the following day generally seems greater than if no precipitation had occurred on the first day. With respect to the first situation, the variability in storm frequencies among months was explicitly incorporated into the model by having individual storm frequencies (prior and joint) for each of the months, April to September. However, with respect to the second point, it is difficult to quantify the climatological factors that cause the non-random pattern of storms. A pattern refers to occurrence or non-occurrence of daily precipitation (in chronological order) over a period of a year. The problem of determining the storm pattern was resolved by using the historical storm patterns observed for the station with long-term records. This provided the sample from which random selection (where a selection constitutes the pattern for one year) were made.

The method of generating storm data for the watershed can now be followed from the flow diagram. The diagram shows that the prior station is first identified and the model is initialized to the first period ($T = 1$). For the first period, it is necessary to determine what pattern of storms exist for the prior station. In this study, the long-term precipitation for Brandon provided an 80 - year pattern sample. One of these is randomly selected and the pattern data indicates whether precipitation is zero or whether it should be generated (that is some positive quantity) for the prior station for each of the days of the year. However, the model is concerned only with spring and summer months (April to September) and thus time within the first period is initialized to

the day (t = 1) and month (M = 4). For this first day, the storm pattern is checked to determine whether day (t = 1) was a dry day or a wet day. If the former holds then precipitation equals zero. But, if the storm pattern had indicated day (t = 1) to be a wet day then storm data must be generated for this day. The model randomly generates a storm value for (t = 1) from the distribution of storm frequencies for the appropriate month. The precipitation generated (including assignment of zero value) for the prior station is then used to generate precipitation for the conditional stations given the precipitation at the prior station. As the flow diagram indicates, after generating the storm datum for the prior station, the first conditional station and its posterior probability distribution are selected to generate the storm magnitude for day (t = 1) in the month of April. This is randomly generated. If other conditional stations are present, their precipitation for day (t = 1) are generated similarly.

Thus far, the model has produced data on point precipitation for the selected stations for the first day of the first year. This provides the input for the storm runoff component. As computations in the rest of the model progresses to the point where further analysis requires input of storm data for the next day, time is advanced by one day (t = t + 1) and the analysis will re-enter the storm simulation component at step two. Here the pattern for (T = 1) is again checked for day (t + 1) and precipitation generated accordingly. As (t) advances the months eventually change and thus the monthly storm frequency distributions from which the

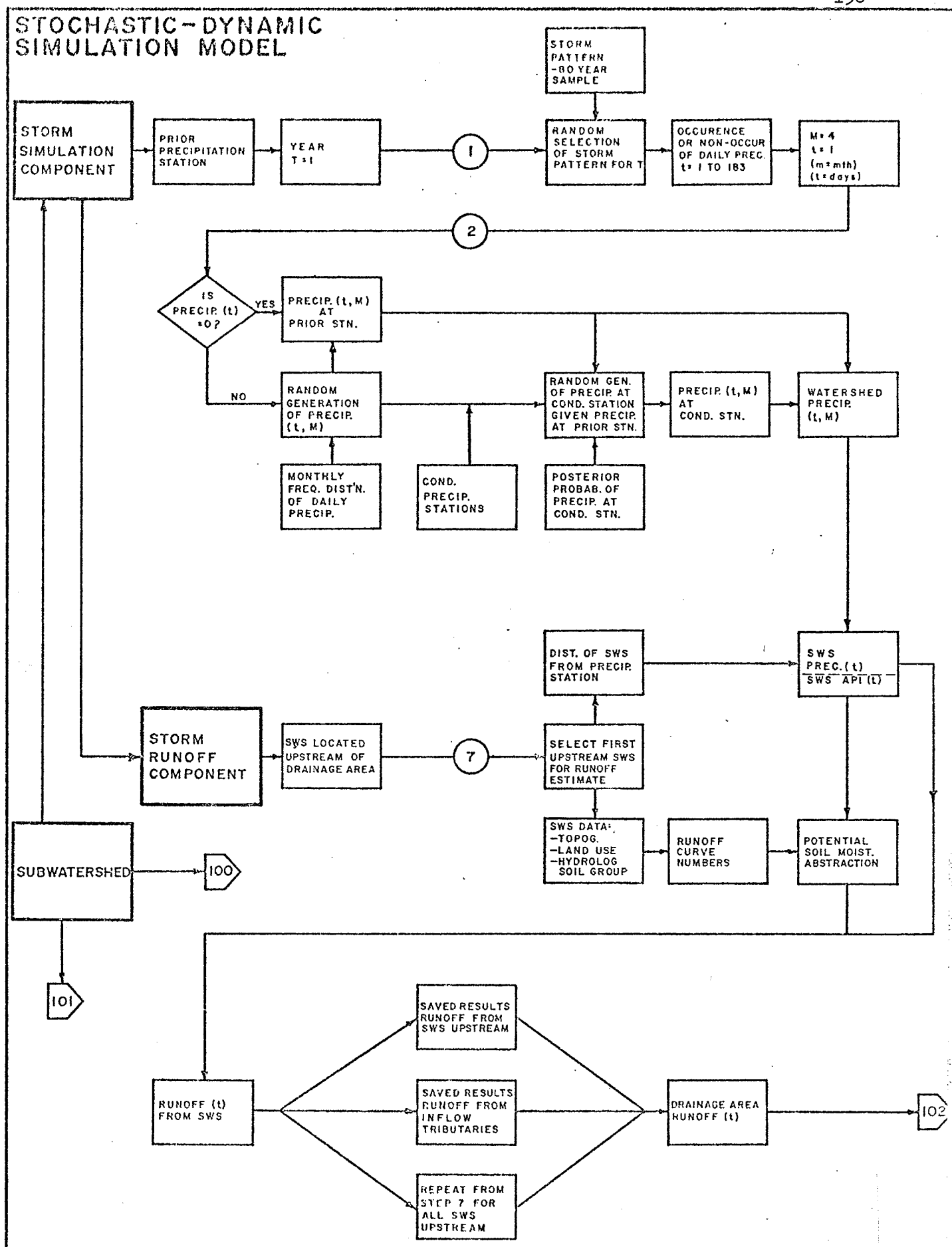
STOCHASTIC-DYNAMIC SIMULATION MODEL
STORM PATTERN -60 YEAR SAMPLE
STORM SIMULATION COMPONENT
PRIOR PRECIPITATION STATION
YEAR T=1
1
RANDOM SELECTION OF STORM PATTERN FOR T
OCCURENCE OR NON-OCCUR OF DAILY PREC. t= 1 TO 183
M=4 t=1 (m=mth) (t=days)
2
IS PRECIP. (t) =0?
YES
PRECIP. (t, M) AT PRIOR STN.
NO
RANDOM GENERATION OF PRECIP. (t, M)
MONTHLY FREQ. DIST'N. OF DAILY PRECIP.
COND. PRECIP. STATIONS
RANDOM GEN. OF PRECIP. AT COND. STATION GIVEN PRECIP. AT PRIOR STN.
POSTERIOR PROBAB. OF PRECIP. AT COND. STN.
PRECIP. (t, M) AT COND. STN.
WATERSHED PRECIP. (t, M)
DIST. OF SWS FROM PRECIP. STATION
SWS PREC. (t) / SWS API (t)
STORM RUNOFF COMPONENT
SWS LOCATED UPSTREAM OF DRAINAGE AREA
7
SELECT FIRST UPSTREAM SWS FOR RUNOFF ESTIMATE
SWS DATA: -TOPOG. -LAND USE -HYDROLOG SOIL GROUP
RUNOFF CURVE NUMBERS
POTENTIAL SOIL MOIST. ABSTRACTION
SUBWATERSHED
100
101
SAVED RESULTS RUNOFF FROM SWS UPSTREAM
RUNOFF (t) FROM SWS
SAVED RESULTS RUNOFF FROM INFLOW TRIBUTARIES
REPEAT FROM STEP 7 FOR ALL SWS UPSTREAM
DRAINAGE AREA RUNOFF (t)
102

Figure 7.1

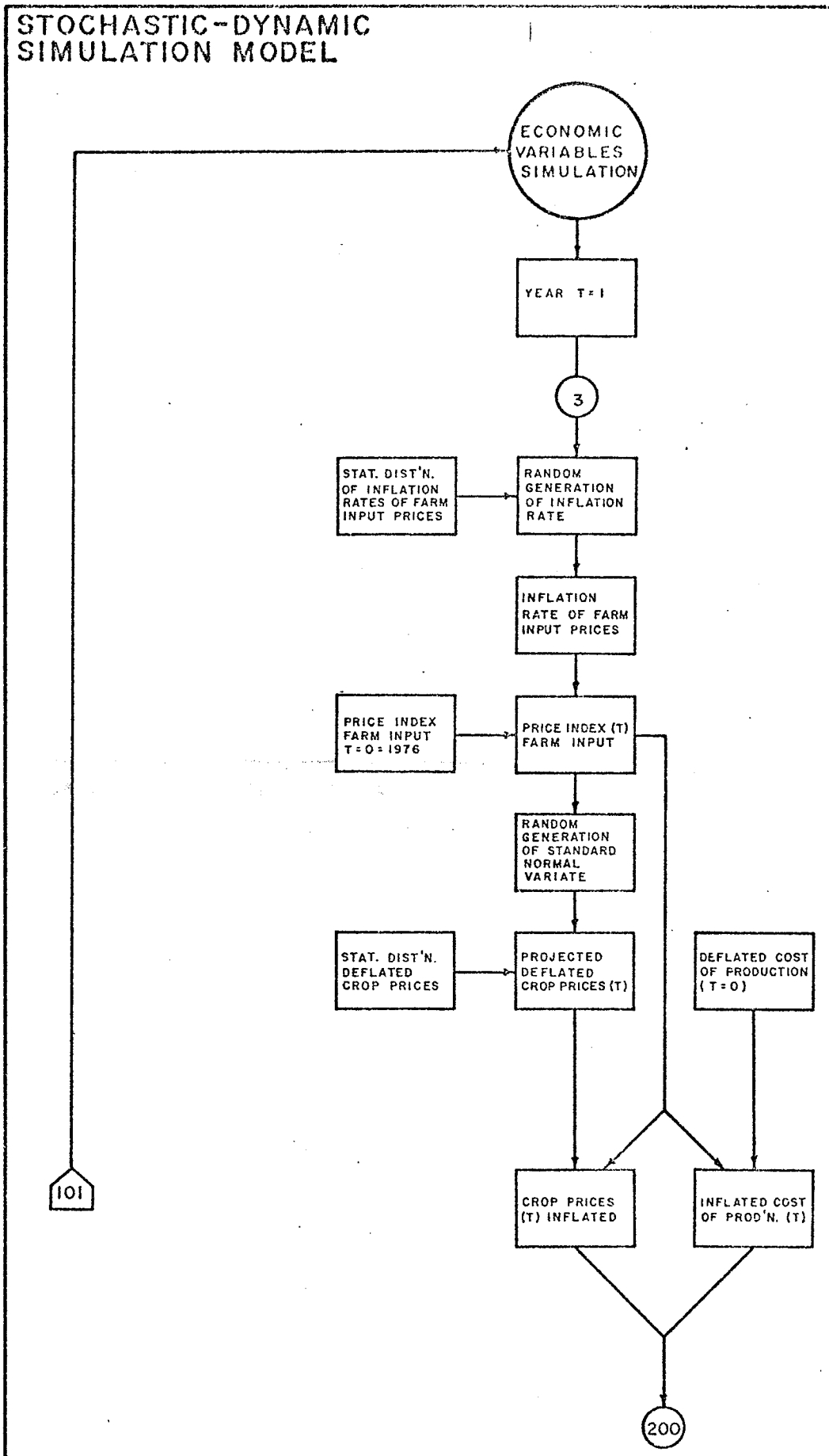

Figure 7.1 (cont'd)

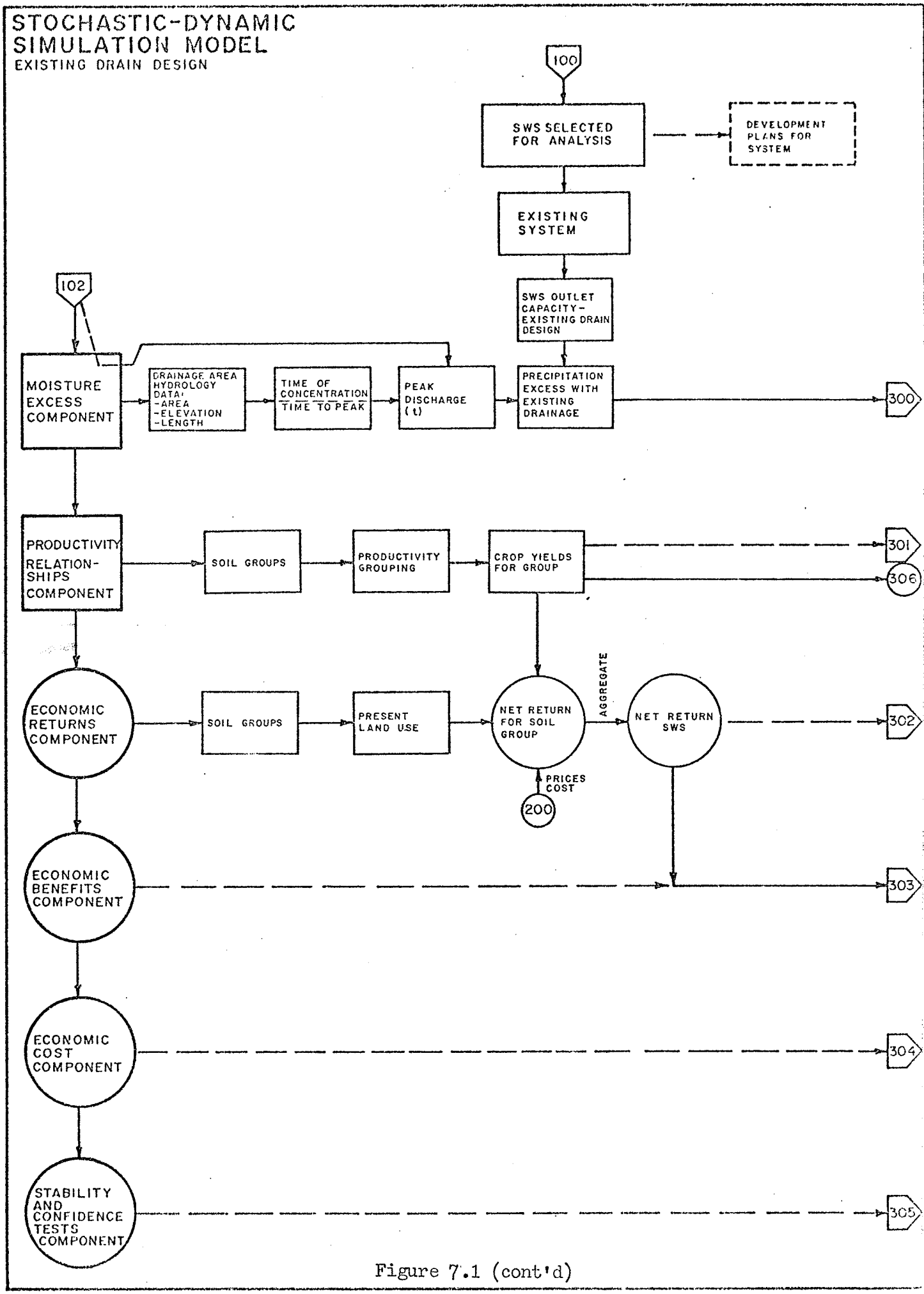

Figure 7.1 (cont'd)

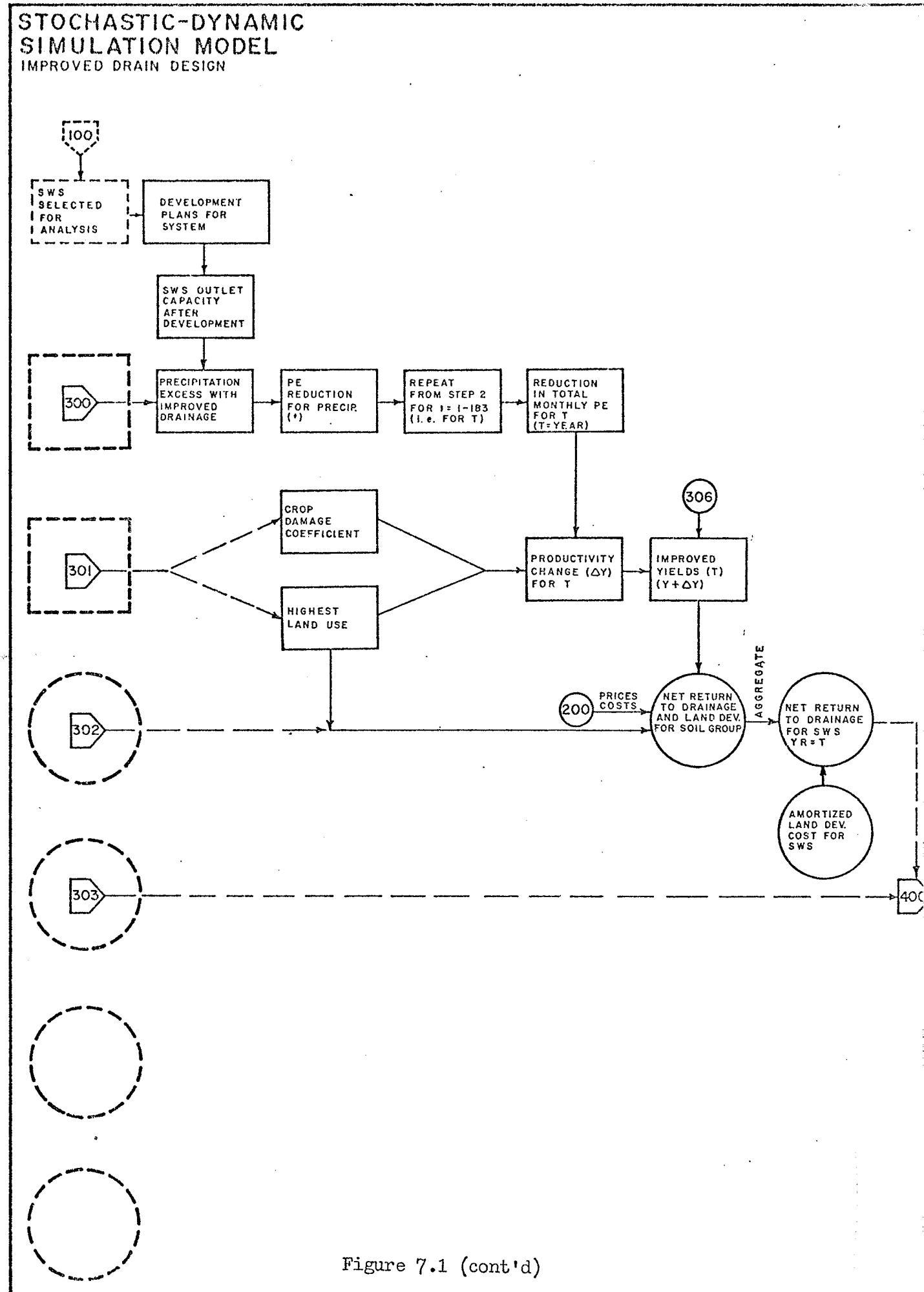

Figure 7.1 (cont'd)

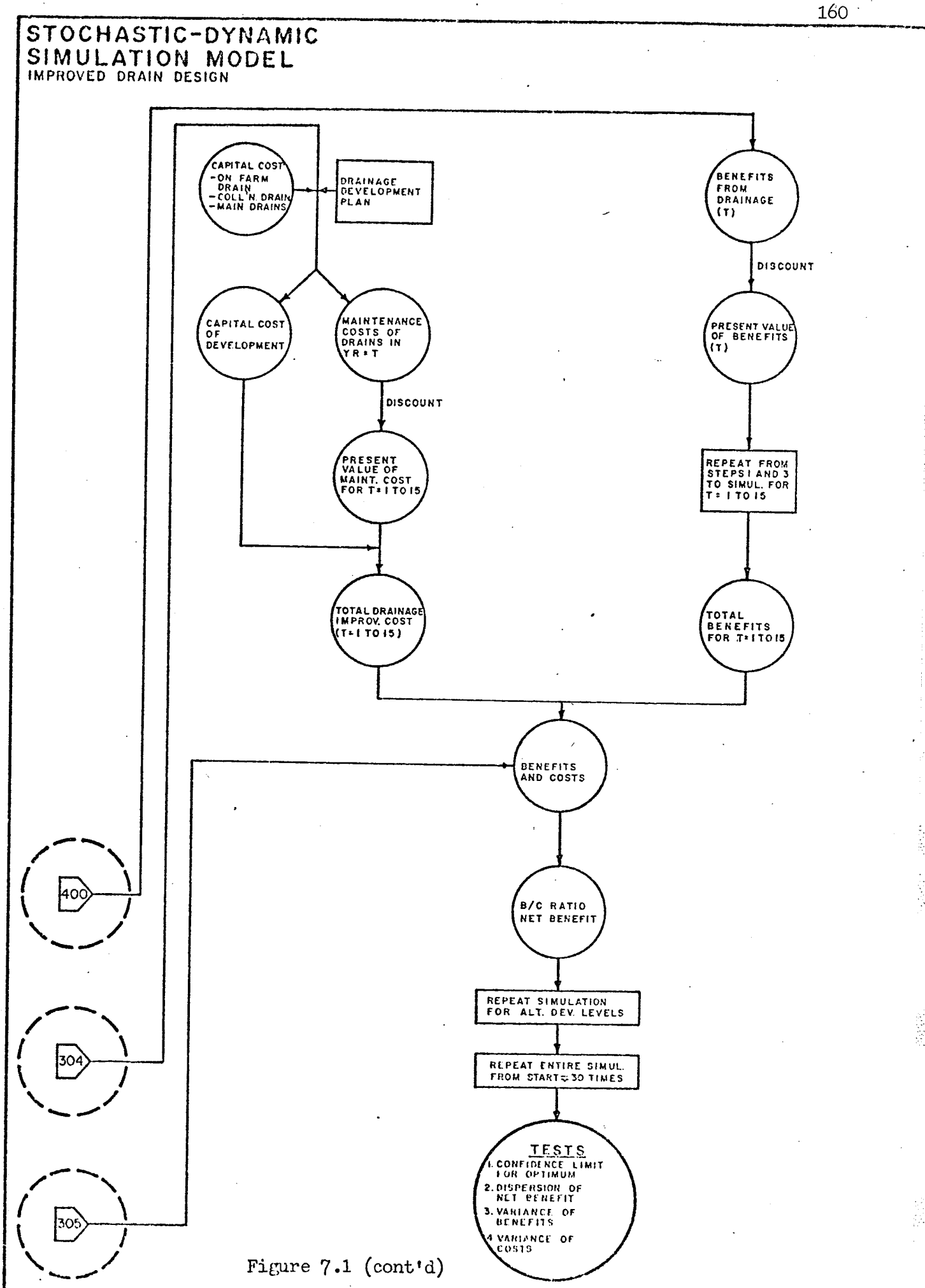

Figure 7.1 (cont'd)

storm data are generated should change to the appropriate month. When (t = 183), then an advance in time automatically shifts to a new period and so (T = T + 1). The analysis is re-entered at step one in the flow diagram which indicates that for the new period (T + 1) a new storm pattern is again randomly selected and this is used to generate precipitation for all (t) in period (T + 1). Thus (t) is initialized again to (1) and the storm data for the prior and conditional stations are generated for the days (t = 1 to 183) in period (T = T + 1). In this manner storm data is generated for the entire project life.

It is appropriate at this point to review the methods which were used to randomly select storm patterns and to generate storm data. Firstly, with respect to annual storm patterns the model assumes that the distribution is uniform with the following probability density function:

$$f_X(x) = \frac{1}{b-a} \; ; \quad \text{for } a<x<b \qquad \ldots.1$$

$$= o \; ; \quad \text{elsewhere}$$

where: x = random variable with an integer value

b = upper bound of the range

a = lower bound of the range

The storm patterns are identified by the numbers one through 80 and thus parameters 'a' and 'b' are 1 and 80, respectively. The random variable x is therefore the number of the storm pattern selected.

The random selection procedure is based on the cumulative probability function rather than the probability density function for the uniform distribution. This is expressed as follows:

$$F_X(x) = \int_a^x \left(\frac{du}{a-b}\right) = \left(\frac{x-a}{b-a}\right) \qquad \ldots.2$$

The procedure followed is to generate a random variable U which has the distribution— U(0,1). The value of U generated is assumed to represent the cumulative probability distribution of X and so it identifies the integer value X or the annual storm pattern selected.

$$X = a + (b-a)u \qquad \ldots.3$$

Where X is an integer value obtained by truncating the fractional component.

Secondly, with respect to the random generation of storm events the statistical distributions for both the prior and conditional stations are described by empirical distributions and so the procedures for random generation of storm data are similar. For analytical purposes the data were grouped into ranges and were arranged in ascending order of magnitude. The cumulative distribution function is defined as follows:

$$G(X) = \frac{1}{n} \sum_{j=1}^{n} I_{v(j-1),\,\infty}(X) \qquad \ldots.4$$

where: $I_{v(j-1),\,\infty}(X) = 1$ for $v(j-1) \leqslant x$

$= 0$ for $v(j-1) > x$

$v(j)$ for $j = 0, \ldots\ldots, n-1$ are the boundaries

To generate the storm data, the range is first generated and this is then assigned a storm magnitude equivalent to the median of the range. The procedure followed is to first compute the following cumulative probabilities:

$$G\,[\,v\,(j-1)\,] \quad \text{for} \quad j = 1, \ldots., n, \qquad \ldots.4.1$$

The random variable U is then generated and is used to identify the range (j*) such that:

$$G\ [\ v\ (j^* - 1)\ ]\ \leqslant\ U\ <\ G\ [\ v\ (j^*)\ ] \qquad \ldots.5$$

Finally, the median storm value for the range (j*) is the storm event generated.

While the procedure outlined above is applicable for generating storm data at both the prior and conditional stations since they both have empirical distributions, it should be noted that the particular storm probability distribution which is selected to generate storm data for a conditional station is conditional on the storm event generated for the given day at the prior station.

THE ECONOMIC SIMULATION COMPONENT

In this component, the model generates prices and costs of production for each period (T) over the project life. These are fed into the model in the Economic Returns Component where the value of production for both the existing and developed systems are computed.

A study of actual data indicated that simple linear projections of these variables would not give realistic values. While the past 25 years have shown a general upward trend in monetary prices, inflation rates for crop prices have not been constant. On the other hand, the farm input price index have shown a more constant upward movement over time

making it relatively easier to project. Additionally, when the farm input price index was used to deflate crop prices, the real prices obtained were found to approximate the normal distribution when subjected to the chi-square test.

On the basis of the above factors, the best procedure adopted for simulating crop prices and costs of production is as outlined below:

1. Randomly generate an inflation rate for the change in farm input prices from period (T) to (T + 1).
2. Compute the farm input price index for (T + 1) by adding the projected inflation rate to the farm input prices index for (T).
3. Randomly generate values for real crop prices in period (T + 1).
4. Use the farm input prices index for (T + 1) to inflate the real crop price to the monetary value for period (T + 1).
5. Costs of production were projected by using the farm input price index for period (T) to inflate the initial period (T = 0) deflated production costs to the monetary value in (T).

Because the prices for the crops considered in this study showed similar movement over time (although oats prices seemed to lag those for wheat and barley slightly) it was necessary to use this interrelationship in the projection model. Accordingly, a standard normal variate was randomly generated and this value was subsequently used to project all prices. The variate generated is assumed to represent the change in deflated crop prices in terms of standard deviation units. Thus all prices were projected on the assumption of having the same change in

standard deviation units.

Following the flow chart (Figure 7.1) outlining the simulation procedure for the economic variables component, it will be observed that the model is first initialized to period one (T = 1) - that is, the first year of the project. After time is initialized, the model then randomly generates an inflation rate for (T = 1) for the farm input price index (FIPI). The statistical distribution for (FIPI) approximates the normal. The price index of farm inputs is then projected for the period (T = 1) by adding the randomly generated inflation rate to the FIPI for period (T = 0) which is the initial project year (1976). To demonstrate the computations thus far, assume that the normal distribution for the inflation rates is characterized by the following:

mean = $\bar{X}$

standard deviation = s

A pseudo-random number generator is used to generate a random normal variate (V) from a normal distribution with parameters $\bar{x}$ and s. This value (V) is used to compute the farm input price index for (T = 1):

$$FIPI\ (T) = [\ FIPI\ (T - 1)\ ] + [\ V\ (T)\ ] \qquad ....6$$

where: FIPI (o) = farm input price index for the year 1976.

The estimated FIPI for period T will be used to inflate the deflated costs of production and the deflated crop prices to the money equivalent for period T. First, the inflation rates for the costs of production are assumed to be the same as those shown by the farm input price index. The flow diagram shows that the deflated cost of production for (T = 0) is

known and is used to compute the inflated cost of production for period (T) as follows:

$$CP(T) = \left[DCP(T = 0) * \frac{FIPI(T)}{100} \right] \quad \ldots.7$$

where: CP (T) = inflated cost of production for period T

DCP (T = 0) = cost of production for the year (T = 0) and is a deflated value.

Equation (7) is used to compute the production costs for all crops for year (T).

Because crop prices are assumed to exhibit similar movement over time, the flow diagram indicates that a standard normal variate (Z) is randomly generated and then used to project the deflated prices of crops for period (T) as follows:

$$DPR(T, i) = [DPR(T = 0, i)] + [Z(T) * PRSD(i)] \quad ..8$$

where: DPR (T, i) = deflated price for crop i in period T

Z (T) = standard normal variate generated for period T

i.e. $[Z \approx N(0.1)]$

PRSD (i) = standard deviation of deflated prices for crop i

The model then proceeds to inflate these prices to the money value for year (T). Equation (9) shows the computation:

$$PR(T, i) = [DPR(T, i) * FIPI / 100] \quad \ldots.9$$

where: PR (T, i) = inflated price for crop i in period T

As time frame advances to another period (T = T + 1) in other parts of model, and specifically in the Economic Returns Component, the analysis will re-enter the Economic Variables Simulation Component at

step (3) to project prices and costs of production for the new period. In this manner values for these variables are generated for the entire project life.

The next logical step in the discussion of the stochastic simulation model is to the Storm Runoff Component. This is presented in the following section.

STORM RUNOFF COMPONENT

The relationships embodied in this component are identical with those previously discussed for the deterministic model. The major difference is that runoff is only estimated for some subwatersheds in this model, whereas runoff was previously estimated for the entire watershed. Here, the model evaluates the impact of improvements in one subwatershed and thus only those upstream subwatersheds which contribute to drainage area runoff through the subwatershed being evaluated are of interest. There is one additional aspect of the computational procedures which is different. In this version of the model, the runoff from precipitation on day (t) is traced through the relevant parts of the system to the specific subwatershed's outlet before proceeding to evaluate runoff from other storms. As a matter of fact, re-entry into the storm runoff component only occurs after the estimated runoff for (t) has been fed into the moisture excess component.

Tracing through the relationships in the flow chart for the storm runoff component it is seen that the upstream subwatersheds are first identified. The model then selects the most upstream subwatershed and proceeds to compute the weighted precipitation for day (t). From the hydrologic characteristics of this subwatershed, described to topographic, land use and hydrologic soil group data, the runoff curve numbers (CN) are identified. This together with the antecedent soil moisture index API) are used to estimate the maximum potential soil moisture abstraction (S). The runoff function uses the precipitation (t) and (S) to estimate runoff. This value is held in storage and the above procedure repeated consecutively for other subwatersheds by re-entering the model at step (7). Finally the runoff is traced and aggregated up to the outlet of the subwatershed being evaluated. This output is then fed into the moisture excess component to compute the peak discharge for the synthetic inflow hydrograph. After computing the reduction in PE resulting from the runoff generated by the storm event on day (t), time is advanced by one day (t +1) and the analysis re-enters the storm simulation component at step (2). The simulation of storm data for day (t + 1) is necessarily followed by an entry into the storm runoff component and once again runoff is estimated for the storm on day (t + 1). This is the procedure whereby runoff is estimated for all days within each period.

The specification of the storm run-off component in this version of the model is identical with that given for the deterministic version and was presented in equation (1 to 5).

The relationships which are discussed in the remainder of the model - the Moisture Excess Component, the Productivity Relationship Component, the Economic Returns Component, the Economic Benefits Component, the Economic Cost Component and the Stability and Confidence Test Component have been separated in the flow chart into two groups. On the left side of the flow diagram the relationships which apply to the existing system are shown and on the right are those which refer to the system after development. The top of the diagram shows that the subwatershed for analysis is identified and for it the data on existing drain capacity at the outlet is fed into the left side of the diagram, whereas on the right the development plans provide the data on improved capacities.

MOISTURE EXCESS COMPONENT

The relationships in the Moisture Excess Component are similar to those previously discussed for the deterministic model and so the treatment here will be brief. The flow diagram shows that following the analysis in the Storm Runoff Component the next logical step is the Moisture Excess Component. The analysis begins by computing the time of concentration (Tc) and time to peak (Tp) for the hydrographs. Having estimated the volume of drainage area runoff in the Storm Runoff Component, the peak discharge for the inflow hydrograph (Qp) is then computed using the (Tc) value to fix the base of the inflow hydrograph. The constraint

which may be imposed on the outflow hydrograph by the existing drain capacity is then evaluated in the synthetic hydrograph model to estimate agricultural drainage inefficiency for PE. The model proceeds to the re-estimation of PE after drainage development plans are introduced. The improved efficiency in drainage is reflected by the reduction in PE (t) - which is the PE resulting from the storm on day (t). The flow diagram indicates that PE reductions for other storms are similarly estimated by advancing time (t) by one day and returning to step (2) in the diagram. In this manner PE reductions for all storms in period (T) are estimated. Since agricultural benefits are estimated for drainage protection only in the months: June, July and August, the flow diagram shows that reductions in PE in period (T) are aggregated for these months.

The computation of PE is identical to the presentation in equations (7 - 9) in the discussion of the deterministic model. The reductions in PE (t) and the aggregations are according to equations (10, 11) below:

$$DPE\ (t) = PE\ (1, t) - PE\ (i, t) \qquad \ldots 10$$

$$DPE\ (M, T) = DPE\ (t) \qquad \ldots 11$$

where: DPE (t) = the reduction in PE for storm on day t

PE (1, t) = PE from the storm on day (t) under the existing drainage system.

PE (i, t) = PE from the storm on day (t) under the drainage system improved to level i

DPE (M, T) = monthly reduction in PE for period T and month M

These estimates of PE reductions for period (T) provide the measure of drainage efficiency due to development. They are used at a subsequent stage in the analysis to estimate benefits.

PRODUCTIVITY RELATIONSHIPS COMPONENT

In this component the improvements in productivity are evaluated for the individual soil groups within the subwatershed being studied. For the existing drainage system the net returns are computed and, as the flow diagram indicates, the improvements in productivity are evaluated when the new drainage designs are introduced in the model. The inputs which are used to determine improved productivity are the reductions in PE, the soil group characteristics, the crop damage coefficients and the highest land use. The first two mentioned are obtained from current version of the model. Whereas the latter two are derived from the deterministic version since they do not change values. The relationships for the Productivity Relationships Component are the same as those given by equation (10) in the deterministic model.

ECONOMIC RETURNS COMPONENT

In this component of the model, the current productivity levels for the various soil groups together with the information on present land use are used to compute the net returns on value of current production

for period (T). Of course, the values for the economic variables which are used in the computations were generated by Economic Variables Component. The aggregation of returns for all soil groups gives the estimate of the returns for the subwatershed in (T).

For the developed system, the higher productivity levels which are induced are first used to compute the net returns to all drainage and land development. These returns are then aggregated for all groups and from this amount the amortized land development cost for this subwatershed is subtracted to obtain the economic returns to all drainage for period (T), since it is this definition of net returns which is required by the benefit-cost analysis. The computations involved are similar to those previously presented for the deterministic model in equations (11 - 21).

ECONOMIC BENEFITS COMPONENT

The economic benefits which are induced by improved drainage efficiency and influenced by other stochastic variables are computed from the economic returns. The improvement in economic performance of the system with respect to the value of agricultural production constitues the benefits in this study. Thus for period (T) benefits are:

$$B(T) = NRDS(i, T) - NRDS(1, T) \qquad \ldots 12$$

where: $B(T)$ = benefits for period T

$NRDS(i, T)$ = net returns to all drainage for the subwatershed at development level i in period (T)

NRDS (1, T) = net returns from the present system (level 1) in period (T).

Benefits generated from the system for period (T) are discounted to the present value using the following function:

$$PVB\ (T) = \frac{B\ (T)}{(1 + i)^T} \qquad \ldots 13$$

where: PVB (T) = present value of benefits derived in period (T)

i = discount factor

As the flow diagram indicates, the computation of benefits for other periods of the project life (T = 1, ..., 15) requires the analysis to be repeated from step (1) in the storm simulation component and step (3) in the economic variables component. Aggregating all discounted benefits gives the present value of benefits over the life of the project (PVB):

$$PVB = \sum_{T=1}^{15} PVB\ (T) \qquad \ldots 14$$

ECONOMIC COST COMPONENT

In this component the capital costs for drainage improvement are identical to those provided in the analysis of the deterministic model for the same drainage design. Maintenance costs have been found to be relatively stable over time and expressed as a proportion of capital costs they are not expected to change significantly from the values used in the deterministic model. The total costs for drainage construction will therefore tend to remain unchanged from that estimated in the deter-

ministic model. The computations can be followed in equations (24-33) in the discussion of the previous model.

STATISTICAL CHARACTERISTICS OF THE SYSTEM'S OUTPUT

The purpose of the analysis in this component is to measure the stability of the optimum as stochastic influences are imposed on the system. The confidence limits for the optimum and the net benefits are to be evaluated.

To evaluate the impact of alternative plans the simulation is repeated according to the procedure outlined above. In doing this it is necessary to evaluate the new drainage design level using the same values for the economic variables and storm events as the first plan. This permits the comparison of various plans and can be achieved by using the same seed values for the random generator. The results from the various plans provide the data for estimating the optimum and the net benefits. The procedure described thus far completes one simulation run. To estimate confidence limits for the population it is necessary to repeat the entire simulation a number of times to obtain a sample of the output variables. In this study this number is taken to be about thirty.

These measures of the characteristics of the benefit/cost analysis results obtained for the subwatershed evaluated can be used to guide decision-making with respect to drainage development in other subwatersheds of the system which were previously found to be economically feasible for development in the analysis of the deterministic model.

Chapter 8

DRAINAGE DESIGN AND COSTS

INTRODUCTION

The type of development evaluated in this study is surface drainage improvement. Although the feasibility of improvement is examined for the entire drainage system below the escarpment, the hydrologic and physical soil characteristics make it desirable to consider non-uniform development for various parts of the system and to evaluate each subwatershed as a unit. To facilitate the benefit-cost analysis, alternative discrete drainage designs were evaluated. The level of drainage design for each subwatershed which were considered for analysis are determined from soil capability and the hydrologic characteristics. In designing the parts of the drainage system within a subwatershed the interdependencies among hydrologic units, specifically the hydrologic units which generate runoff through the particular subwatershed, are considered.

Drainage development involves the construction of both channels and associated structures. The latter includes culverts, bridges and gradient-control structures. The drainage system is comprised of on-farm drains which flow into collection or lateral drains and these discharge into the main channels.

There are basically three templates which are used for drain design in this study for the various components of the system--that is for the on-farm drains, for the collection or lateral drain and for the

main channel. The specific template used reflects the particular hydrologic function carried out by the component of the system. Designs also reflect cost-effectiveness with respect to both construction and maintenance of drains.

In this section the design of the components of the drainage system are discussed. Included in this discussion are the designs of structures. This section also outlines the procedures used to estimate costs for the drainage system. The data used and a summary of the estimated costs are given. The final portion of the section discusses the costs involved in maintaining the drainage system.

Design of On-Farm Drains

On-farm drains are designed to remove surface water from agricultural fields efficiently so as to minimize the adverse effects of excess moisture on crops. It is also desirable to design on-farm drains so that they do not hinder the operation of farm machinery nor result in the loss of valuable cultivated land. With these considerations in mind, the most suitable design is the 'V shaped' channel with side slopes of 8:1. The depth ranges from 9.5 inches to 1.25 feet. A typical cross-section of an on-farm drain is shown in Figure 8.1. The shallowness of this type of drain together with the gentle side gradient allows both the cultivation of the entire channel area and the unimpeded operation of farm machinery.

In order to effectively drain agricultural fields it is necessary that the drains be spaced sufficiently close so as to reduce

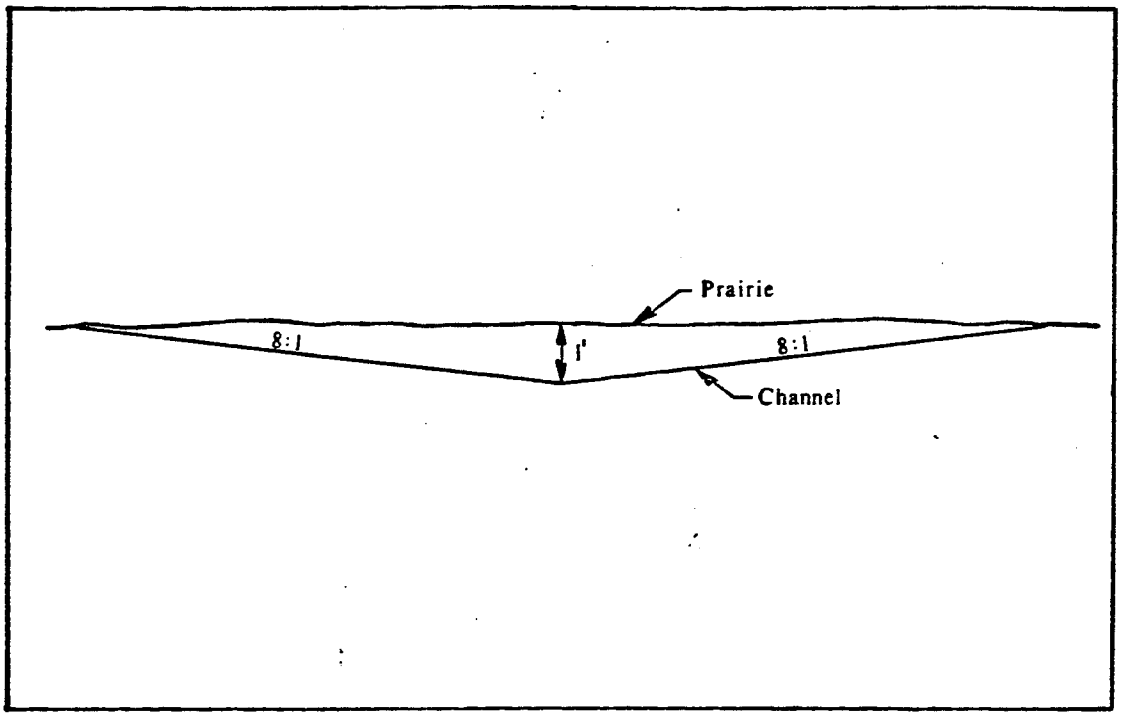

Figure 8.1 - On-Farm Drain Template

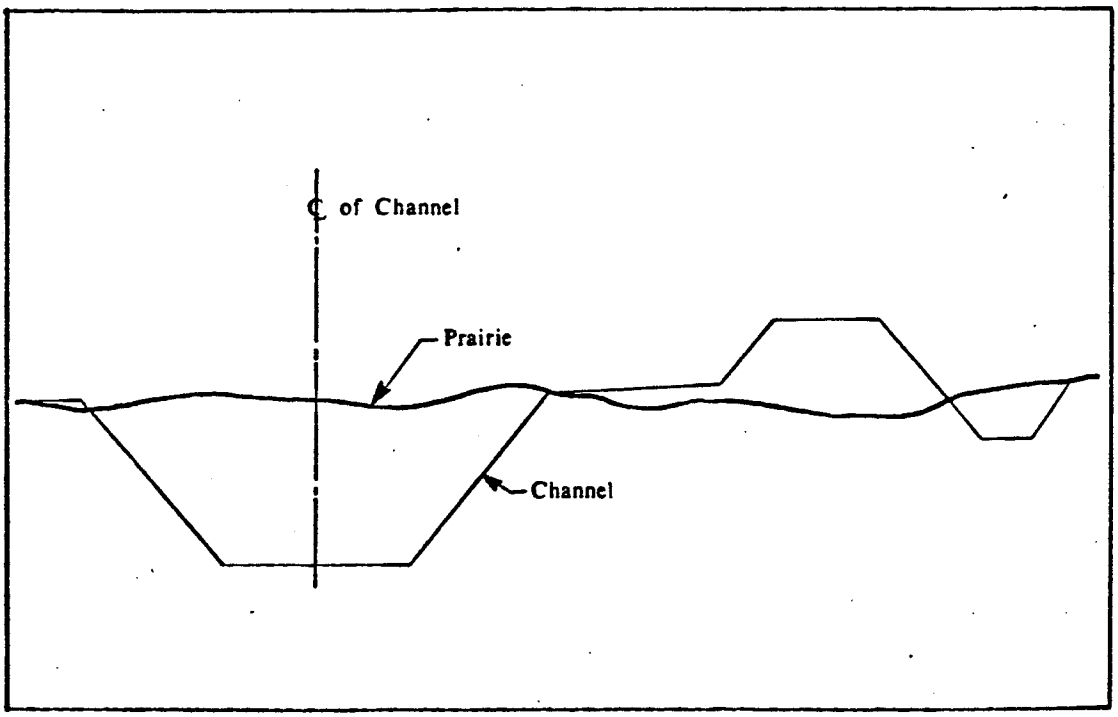

Figure 8.2 - Main Channel Template

the overland travel time to acceptable levels. For relatively flat lands drains should be more closely spaced than for lands with moderate slope. Similarly, the spacing should be closer on heavier and more impermeable soils than on light-textured soils. The relationship between the spacing of on-farm drains and the soil texture for relatively flat areas is given in Figure 8.3. Given a certain number of on-farm drains per square mile the discharge capacity of each drain is a function of the collection drain capacity for a one square mile area. This relationship requires that the total discharge from all on-farm drains over a given area equal the capacity of the collection drain servicing the area. For a particular design level each on-farm drain has equal capacity which can be estimated by division of the collection drain capacity by the number of on-farm drains. Since the general cross-sectional shape of on-farm drains are fixed, the desired capacity, given a specific land gradient, is obtained by modifying the depth of the drain. The relationship between the depth of on-farm drains and the capacity for various land slopes is plotted in the right quadrant of Figure 8.4. When the level of drainage protection is increased the collection drain capacity increases and thus the discharge capacity of each on-farm drain must also increase. The latter is accomplished by increasing the depth of the drains since the spacing of on-farm drains remains unchanged.

The cost per lineal mile of on-farm drains is estimated on the basis of the time required by a grader to complete the operation rather than on the basis of unit excavation cost. Because of the drain template, construction is better performed by a grader. The construction costs per lineal mile for on-farm drains having specified depths are

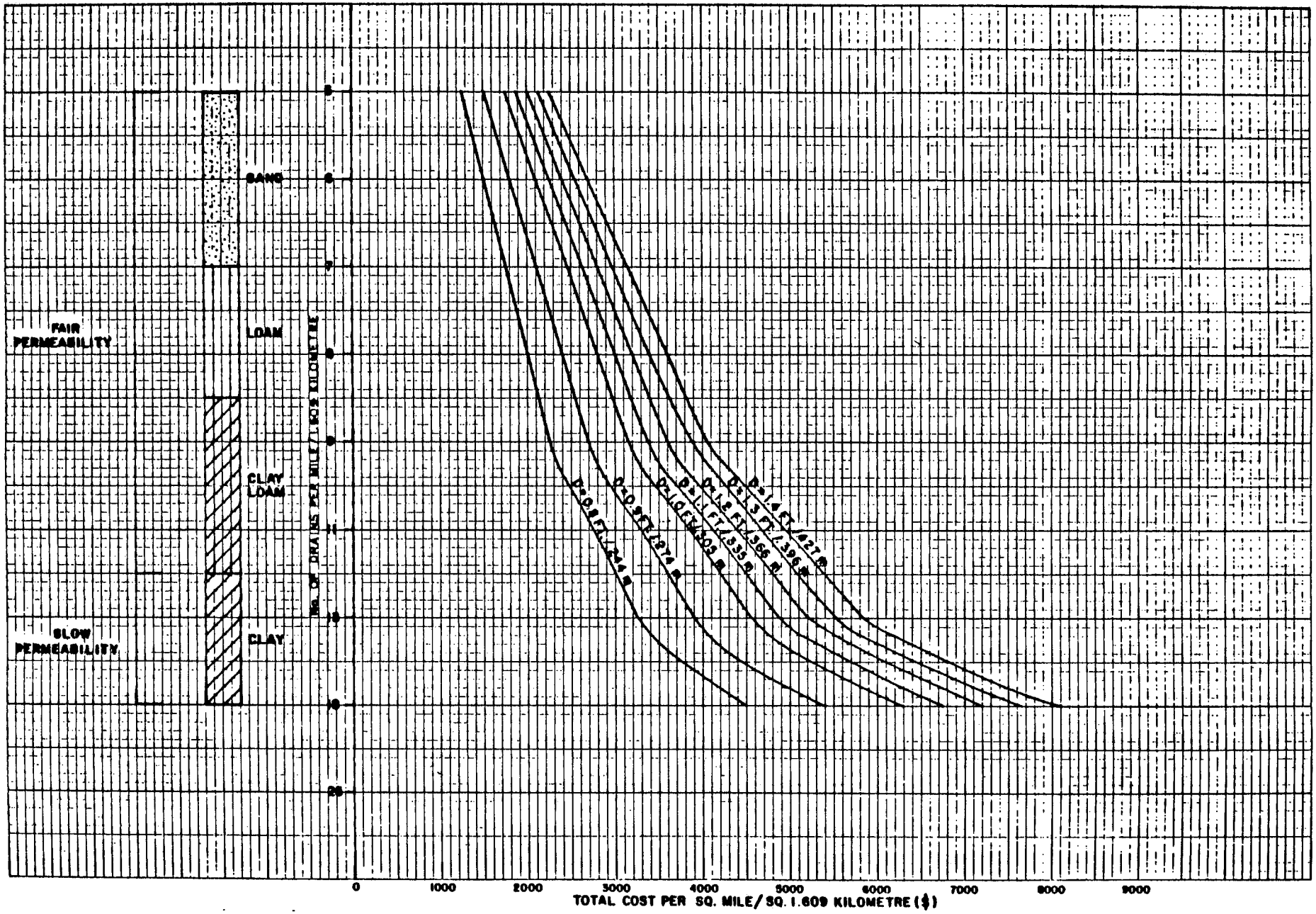

Figure 8.3 Spacing and Excavation of On-Farm Drains

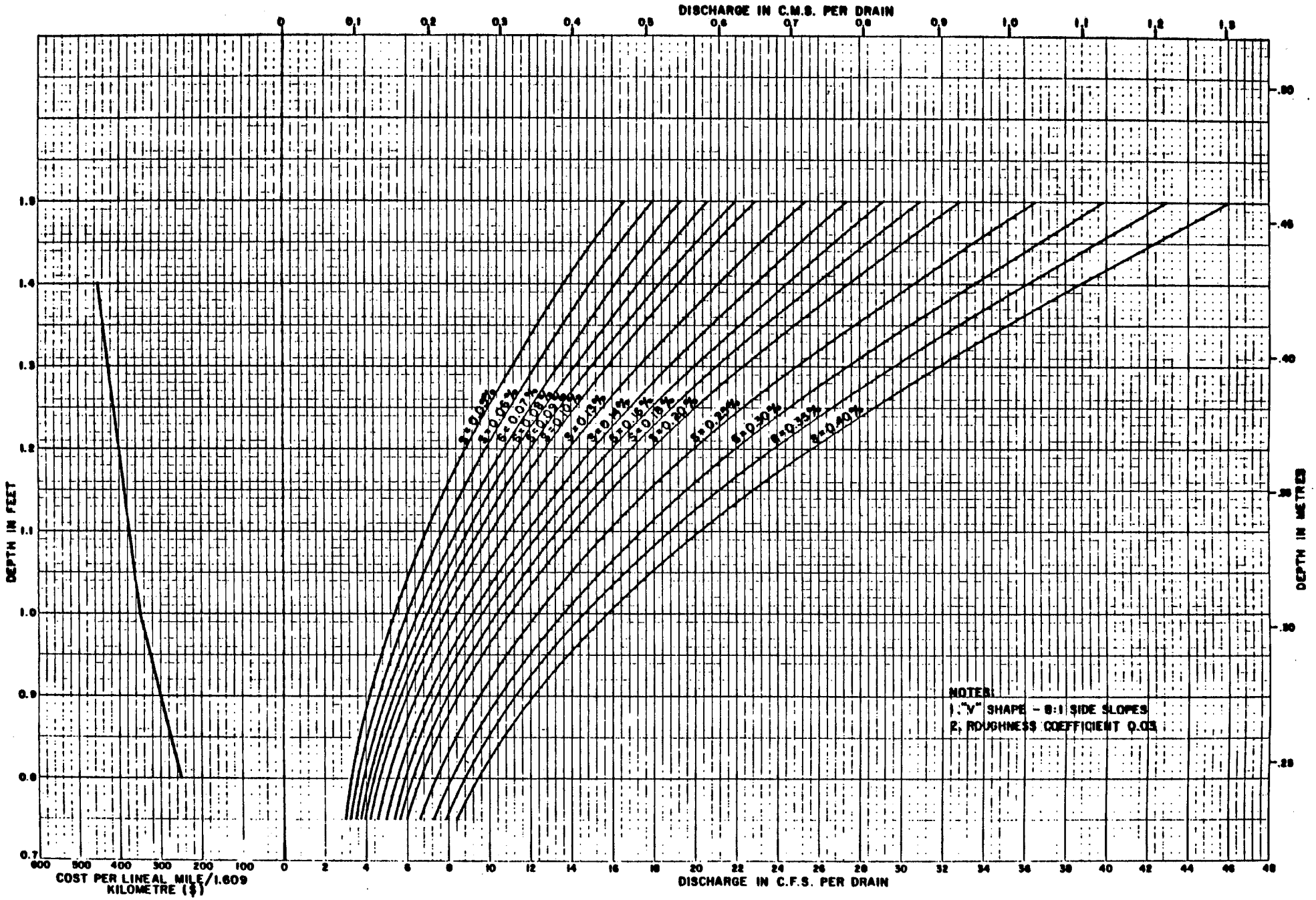

Figure 8.4 Depth-Discharge Relationship and Cost per Lineal Mile of On-Farm Drain

given in Table 8.1. This relationship is also plotted in the left quadrant of Figure 8.4.

The hydraulic design of on-farm drains, as is the case with the main and lateral drains, is based on Maning's equation (Linsley et al, 1949:272):

$$Q = \frac{1.486\ ar^{2/3}s^{\frac{1}{2}}}{n}$$

where: Q = design discharge

n = roughness coefficient

a = cross-sectional area

r = hydraulic radius

s = gradient

The depth-discharge relationship depicted in Figure 8.4 is based on the above formulation, an 8:1 side slope and a roughness coefficient of 0.03.

TABLE 8.1

UNIT CONSTRUCTION COSTS FOR ON-FARM DRAINS

Depth	Cost per Lineal Mile
9.5	$250
10.5 inches	300
1.1 feet	350
1.1 "	375
1.3 "	425
1.4 "	450

Design of Lateral and Main Drains

The lateral and main drains are designed with a trapezoidal cross-sectional area. The main drains are constructed with dykes as

shown in Figure 8.2. This is the design template employed by the Water Resources Division for the design of the main channels. Lateral or collection drains are constructed without dykes. These have a 3:1 side slope, a minimum width of eight feet and a minimum capacity of 15 cfs.

In order to minimize the maintenance requirements which arise because of erosion and sedimentation flow velocities are not allowed to exceed 2.5 feet per second. The velocity equation is:

$$V = Q/a$$

where: V = velocity in feet per second

Q = design discharge in cubic feet per second

a = cross-sectional area of the channel

If the natural channel gradient results in velocities which exceed 2.5 feet per second, gradient control structures are included to ensure that the maximum is not exceeded.

The amount of excavation involved in the construction of a drain depends on the capacity of the drain and land slope. For a given land gradient the amount of excavation increases with capacity. When drains are to be constructed in steeper areas the maximum velocity constraint makes it necessary to construct the drains so that the channel bottom has a more moderate gradient. As this divergence between the slope required for the channel bottom and the actual land slope increases the amount of excavation necessary will also increase. A large portion of the excavation for the above situation results from the over-cutting which is needed at the upper end of each reach. The unit excavation cost is $0.50 per cubic yard. The excavation cost per lineal mile of

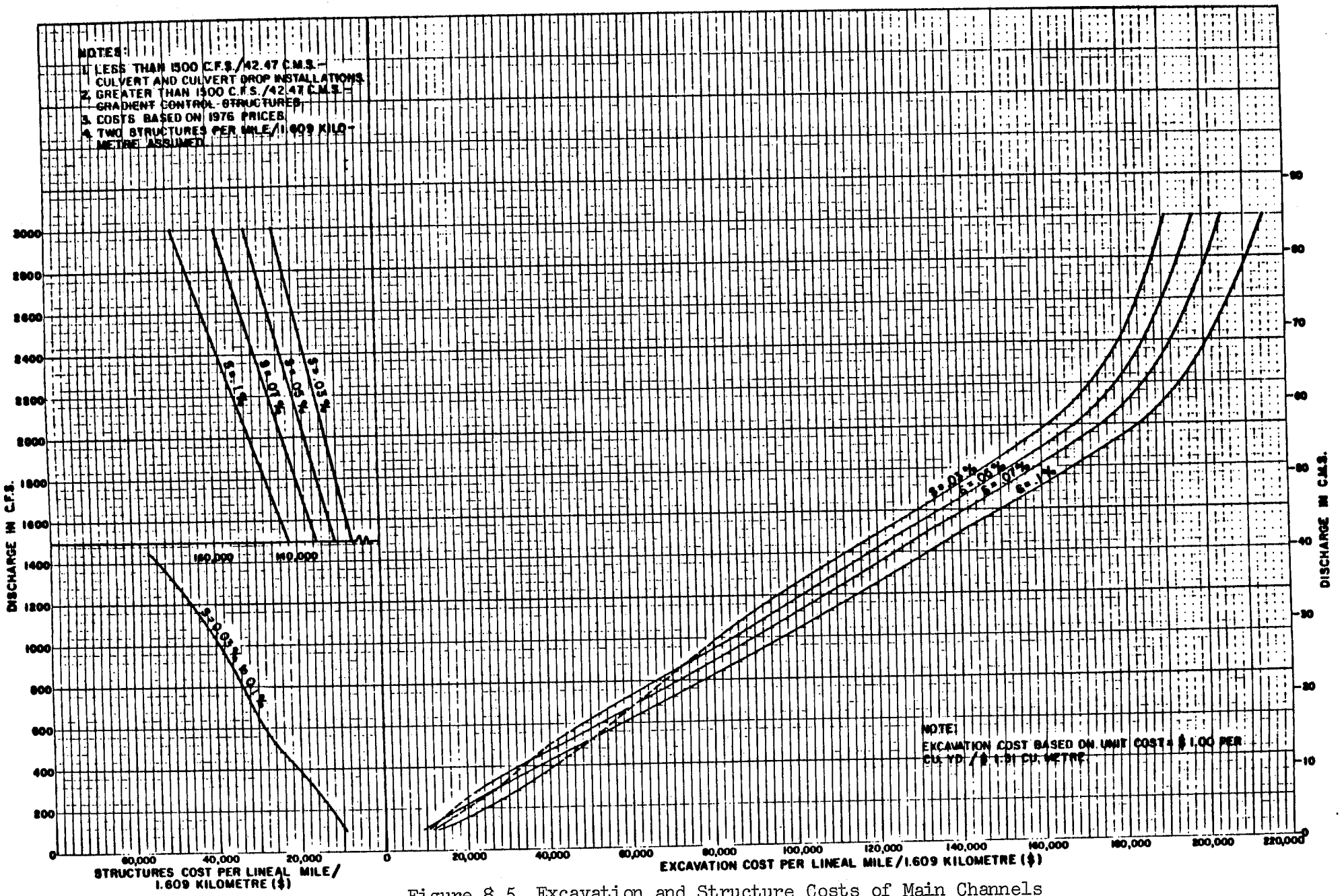

Figure 8.5 Excavation and Structure Costs of Main Channels

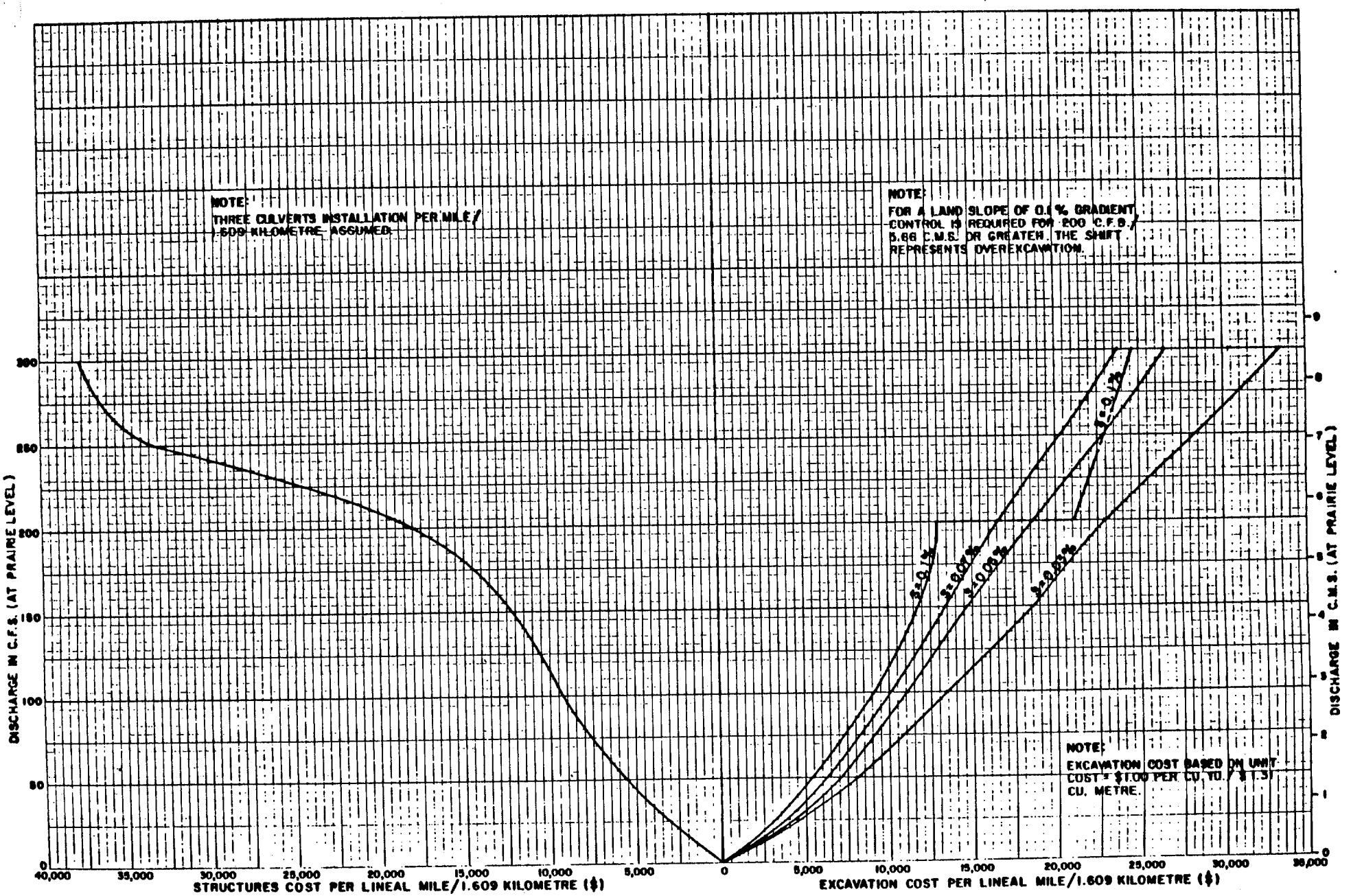

Figure 8.6 Excavation and Structure Costs of Lateral Drains

drain as a function of discharge capacity is given for various land slopes in Figures 8.5 and 8.6.

For relatively flat areas maximum velocity can be maintained without the use of gradient control structures. Wherever the latter is required, the number of structures per lineal mile of drain increases with the slope of the land. The cost of each structure is, of course, related to the channel capacity. In addition to gradient control structures, crossings are required (averaging about two per mile along main channels and along laterals three per mile) to provide access to agricultural fields. In the current study, most gradient control structures used culverts and as such also provided access to the fields. Wherever these occur they served the dual functions of gradient control and crossing. The graphs in Figures 8.5 and 8.6 also give the total cost of structures for various drain capacities and for given land gradients.

In addition to the excavation and structure cost associated with the main and lateral drains there is also the cost of right-of-way. This item is discussed next.

Right-of-Way Costs

Drainage improvement can involve more than simply modifying the existing channel. Reconstruction may be required for a large proportion of the improvement works, in which case land required for right-of-way purposes will not be available for agricultural production[1]. The cost of land used for right-of-way should equal the capitalized value of

[1]This is not strictly correct since for the larger channels some hay can be harvested from the sides of the channel.

land. For the Big Grass Watershed an average value of $200 per acre was used. Figure 8.7 gives the right-of-way cost relationships.

Design of Structures

According to the Water Resources Division's design policy all structures through provincial trunk highways and railroads are designed to a two percent frequency discharge regardless of the agricultural drainage design level. The design discharge for the two percent frequency is determined from the equation:

$$Q = 136.5\ A^{0.672}$$

All structures through provincial roadways and adjacent to provincial trunk highways are designed to a three percent discharge frequency according to the equation:

$$Q = 116\ A^{0.672}$$

Again, design for the above situation is independent of the agricultural drainage protection.

Culverts are designed to yield a 'head' build-up of 0.8 feet when the drop in invert is 1.5 feet or less[2]. It is assumed that flow through the culvert is controlled at the outlet. However, when the drop in invert exceeds 1.5 feet, it is assumed that the control is transferred to the inlet. Design is based on the condition that:

$$\frac{HW}{D} = 1$$

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[2] A 'head' build-up is defined as the difference in water surface elevation at locations immediately upstream and downstream of the culvert.

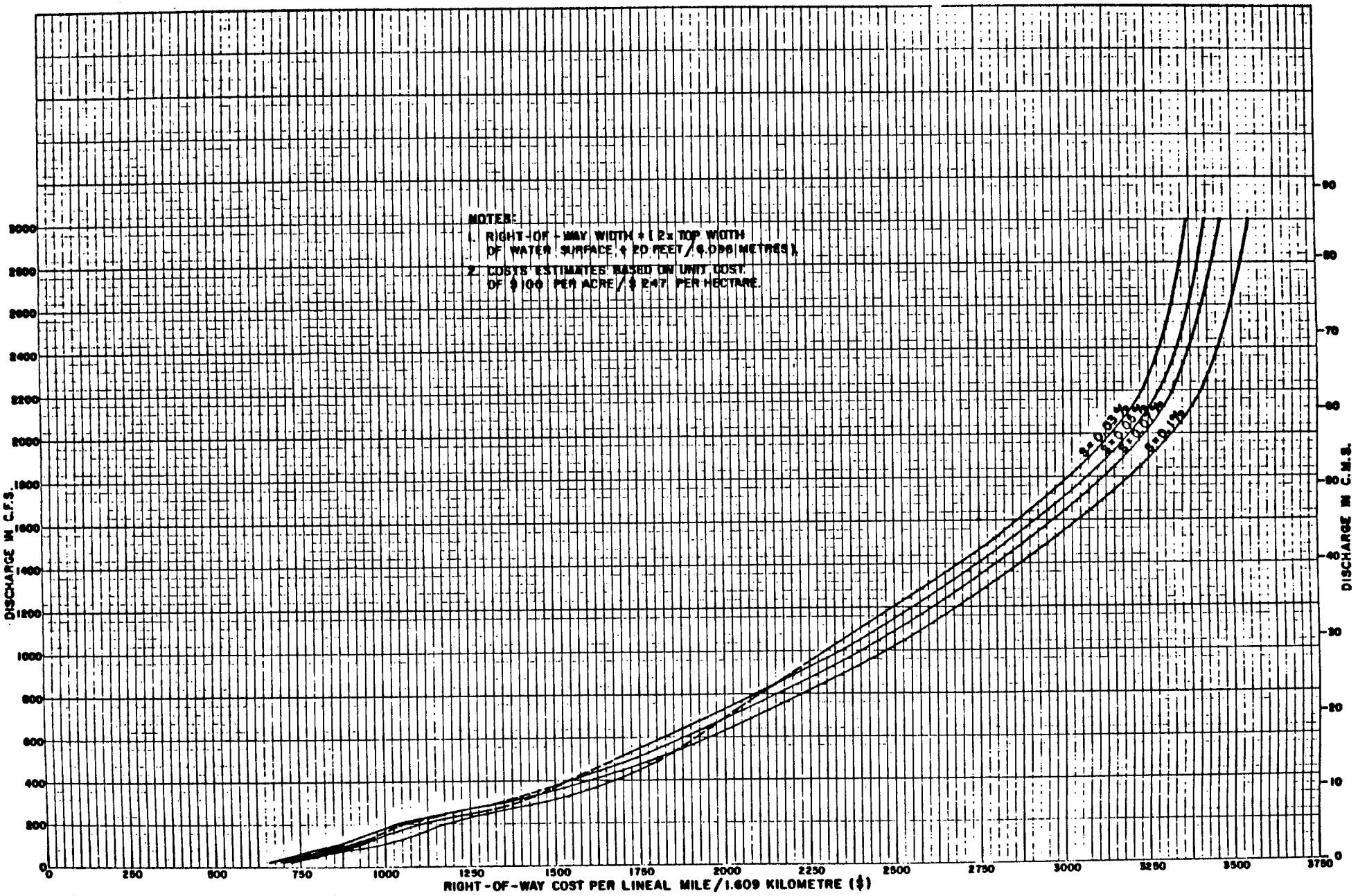


Figure 8.7 Right-of-Way Costs

where: HW = headwater

D = culvert diameter

The design discharge at the inlet is determined from nomographs using the above parameters.

Rock overflow weirs are designed according to the 'broad crested weir formula':

$$Q = cLH^{3/2}$$

where: c = constant (2.6 for the current study)

L = effective weir length

H = headwater measured above crest

Finally, bridges are designed to span 85 percent of the water surface with three feet of freeboard. The unit cost for crossings and gradient control structures are given in Tables 8.2 and 8.3, respectively.

Drainage Design Levels

Four alternate design levels are considered in this study. Level 1 is the level of protection which currently exists. Levels 2, 3 and 4 represent improvements to the system. These improvements include both the increase in capacities of the existing drains either by modification or full reconstruction and the installation of on-farm and lateral drains where they did not exist previously but are required in order to make the system effective. Level 4 is the highest level of protection chosen for the analysis.

TABLE 8.2

CONSTRUCTION COST FOR CROSSING STRUCTURES

Item	Cost
Bridges	$550 per lineal feet of span
Provincial road bridges	$650 "
Railroad bridges	$1,000 "
Provincial trunk highways bridges	$60 per sq. ft. of deck
Culverts	Culvert cost plus 15% for installation
Culvert drop	Culvert cost plus 10% of cost for riprap plus 15% for installation

TABLE 8.3

COST OF GRADIENT CONTROL STRUCTURES

	Cost* ($'000)			
	3 Ft. Drop	4 Ft. Drop	5 Ft. Drop	6 Ft. Drop
100 - 300	8	12	15	18
300 - 800	9	13	18	21
800 - 1500	10	15	21	25
1500 +	12	18	23	28

* Includes a 15 percent contingencies cost.

In order to select suitable design levels for analysis it was necessary to relate the levels to the productive potential of the land. Design capacities were therefore determined individually for each

subwatershed. The level 4 design was determined according to the relationships given in Table 8.4. As the proportion of soils belonging to capability classes 1 to 4 within a watershed decreased so did the level 4 design capacity. After determining the level 4 capacity for the outlet location of a subwatershed the capacities at other locations within the subwatershed were then determined from the 'rational' formula[3].

$$Q = CA^{0.83}$$

where: Q = design discharge

C = runoff coefficient

A = drainage area in square miles

TABLE 8.4

DESIGN DISCHARGE EQUATIONS FOR THE LEVEL 4 PROTECTION

Percent of Subwatershed in Capability Classes 1 to 4	Design Equation for Level 4
Greater than 70 percent	$Q^* = 116\ A^{0.672}$
50 - 70 percent	$Q = 94.7\ A^{0.672}$
Less than 50 percent	$Q = 68.1\ A^{0.672}$

*This equation represents the three percent frequency discharge at the Town of Glenella.

The method used is to first solve for the runoff coefficient using: (i) the drainage area corresponding to the subwatershed's outlet;

---

[3]For a discussion of the rational formula see (Linsley et al, 1949:575).

and (ii) the level 4 capacity at the outlet as the design discharge value. The runoff coefficient estimated is the value used in the rational formula to obtain level 4 design capacities at locations within the subwatershed.

The subwatershed's outlet capacities for levels 2 and 3 are selected from within the range of capacities given by the level 1 and level 4 designs. Specifically, when more than 50 percent of the subwatershed is comprised of soils in capability classes 1 to 3, then levels 2 and 3 are selected so that the incremental capacities between successive levels are approximately equal. However, when soils within a subwatershed are predominantly of a lower capability (classes 4, 5, 6) the capacities selected for the levels 2 and 3 designs are skewed towards the existing capacity. Departure from the above guidelines will occur when the capacity of the existing channels is structure controlled, that is, the capacities of structures (culverts, etc.) are significantly less than the capacities of the channels. In such cases effective channel capacity can be increased significantly by simply increasing the capacities of the structures which retard flow. In this particular situation the level 2 design is taken as the design where improvements were made only to the structures. Having determined the capacities for levels 2 and 3 at the outlet of a subwatershed, design discharge for other locations are determined in the same manner as indicated for level 4.

While the cost for on-farm drains include only the channel excavation cost, the cost items for reconstructing the main and lateral drains are for excavation, structures and rights-of-way. A contingency

cost factor equivalent to 15 percent of estimated construction cost is included in the capital cost estimates.

In drainage reconstruction the salvage of existing drains depends on the location and the amount of modification which is required. For drainage channels located alongside the roadway, generally, improvements may require total reconstruction in which case there will be no salvage value to the existing channel. If, however, improvements can be made at the site of the existing channel then some salvage value can be assigned to the existing system. For drains located 'cross-country' it is assumed that the existing channel has a salvage value. Salvage is reflected in terms of lower channel excavation cost.

Drainage Construction Costs

Cost estimates were made for improving that portion of the drainage system within each subwatershed to the selected design levels. In order to adopt the procedures outlined in this chapter to estimate costs of the public drains field surveys were carried out on the drainage system of the watershed, with the exclusion of only the excarpmental area. The field survey of the drainage system provided data on cross-section and profiles of existing drains. Additional data were collected so that drainage design and costing can be undertaken. On-farm drainage cost were estimated for the entire area within each subwatershed for drains capacities consistent with the protection provided by the public drains. A summary of drainage construction cost for the three alternate levels of improvement is given in Table C1 in the Appendix. The design capacities for the outlet of each subwatershed is also given in this table.

Maintenance Cost

The problems of channel erosion, siltation and vegetative growth can cause a reduction in the efficiency of the system. To ensure that channels function efficiently at the design level, periodic maintenance work must be undertaken. In addition to the maintenance required for the channels, structures may be damaged occasionally thus requiring maintenance. In this study average annual maintenance costs for the drainage system are used in the analysis. Estimates of these costs for the main channels are obtained from actual maintenance expenditure incurred by the Water Resources Division. The average annual maintenance cost as a percent of capital cost is given in Table 8.5. For the main channel these range from 2.6 percent to 1.2 percent, depending on the channel capacity. The larger the channel, the smaller is the amount of maintenance required.

Because lateral drains have designs which require more frequent maintenance, the annual maintenance costs are relatively higher, approximating eight percent of capital costs. For the on-farm drains it is expected that more frequent maintenance will be necessary since the surface area is cultivated. An annual maintenance cost of 12 percent is used for these drains.

TABLE 8.5

ANNUAL MAINTENANCE COSTS

Channel	Capacity (cfs)	Maintenance Cost as a Percent of Capital Cost
Main	0 - 150	2.61
	150 - 500	1.97
	500 - 1000	1.50
	1000 +	1.24
Lateral		8.00
On-farm		12.00

Chapter 9

PREPARATION OF DATA FOR THE ANALYTICAL MODEL

INTRODUCTION

The data used in the analytical model are of two types—historical and simulated. The stochastic version of the model uses both historical and simulated input data, whereas the deterministic version uses only historical data. The nature of a large portion of the input information called for by the analytical model was such as to necessitate prior synthesis and analysis of primary data. Accordingly, methods had to be developed to transform or analyze primary data to derive the required input. For example, a suitable approach had to be developed to derive watershed areal precipitation data from point rainfall; soil, land use, soil moisture and other data had to be synthesized to derive a measure of the combined effect of all these factors on runoff; and marginal crop damage coefficients were estimated by regression analysis of crop production and precipitation excess data. Also, drainage design and costs information, which were discussed in the previous chapter, were estimated from drain profile and cross-section data which were obtained from field surveys. In this chapter, the methods used to derive input data are discussed. The data used by the model are also given.

SOIL AND LAND USE DATA

The feasibility of drainage improvement is assessed at the level of small hydrologic units or subwatersheds. In the evaluation of

drainage within these units the analytical model estimates the potential benefits from drainage for all lands within the subwatershed. To accomplish this it was necessary to divide the land area into grids, whereby each block was 80 acres in area and corresponded to one-half of each quarter section. The soil properties of each block of land were used to determine the benefits from drainage and the highest use. Benefits for the subwatershed from any particular level of drainage improvement were obtained by aggregating the benefits from all lands within the subwatershed.

The land area within each 80 acre block was grouped into homogenous soil groups on the basis of soil texture property, hydrologic soil characteristics, soil capability for agriculture and soil productivity class. Each homogenous soil group was assigned a group number. It should be noted that lands from several locations or grids may belong to the same homogenous soil group. The soil characteristics are important in determining the economic response of a piece of land to drainage development. The model therefore assumes that all lands within a soil group in a given subwatershed will realize equal benefits from drainage improvement works.

Soil Texture

Soils are classified into four major textural groups depending on the content in the top horizons. The groups are clay, clay loam, loam and sand. The data on soil profiles were obtained from the Soil Survey Reports. The textural group associated with a particular area

was the one which was most pronounced. The most predominant soil texture found in the Big Grass Watershed is the clay loam.

Hydrologic Soil Groups

The hydrologic properties of each soil type together with the land use and treatment class[1] gives a hydrologic soil-cover complex. Information on the hydrologic soil-cover complexes within a subwatershed is useful in predicting the amounts of runoff from various storm events. For the present study, the runoff or water to be drained off the land directly influences the amount of precipitation excess or the duration of crop exposure to excess moisture. It is therefore useful to the analysis to identify the hydrologic characteristics of the soils in the area being studied.

The concepts of hydrologic soil groups and soil complexes were developed and used by the U.S. Department of Agriculture, Soil Conservation Service (1971). Soils were grouped into four broad hydrologic groups depending on infiltration and water transmission properties.[2]

---

[1] According to National Engineering Handbook (U.S.D.A., 1971:8.1), "Land use is the watershed cover and it includes every kind of vegetation, litter and mulch, and fallow . . . as well as nonagricultural uses . . . Land treatment applies mainly to agricultural land uses and includes mechanical practices such as contouring or terracing and management practices such as grazing control or rotation of crops. The classes consist of use and treatment combinations actually to be found on watersheds."

[2] 'Infiltration rate' is defined as the "rate at which water enters the soil at the surface and which is controlled by surface conditions, and the 'transmission rate' is the rate at which the water moves in the soil and which is controlled by horizons" (U.S.D.A., 1971:7.1).

These classifications were defined as follows (U.S.D.A., 1971:7.2):

> A. (Low runoff potential). Soil having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.
>
> B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
>
> C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
>
> D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

The U.S.D.A. classification was adopted for this study and was modified to allow for inter-group values in addition to the four groups. For example, a soil grouping with hydrologic soil characteristics between those of groups A and B was indicated as AB. Similarly, BC and CD represented soils with characteristics between those of soil groupings in this study were determined from information on soil textures and soil profiles

Table 9.1

Average Yields For Crops and Forage in the

Big Grass Watershed

Soil Productivity Groups	Productivity[1] Code	Average Yield Per Acre				
		Wheat (BU.)	Oats (BU.)	Barley (BU.)	Tame Hay[2] (Tons)	Native Hay[3] (Tons)
A	0	29.60	47.60	34.40	2.06	0.70
B	1	28.40	46.80	33.00	1.95	0.67
C	2	26.40	43.40	30.80	1.82	0.63
D	3	26.40	42.00	30.00	1.71	0.60
E	4	25.80	41.60	29.60	1.58	0.50
F	5	25.00	38.40	28.00	1.48	0.47
G	6	21.60	33.40	27.60	1.37	0.44
H	7	20.00	32.00	25.00	1.23	0.39
I	8	16.40	29.40	20.60	1.00	0.27
J	9	8.80	25.00	16.60	0.75	0.20

SOURCE: Manitoba Crop Insurance Corporation; data for Risk Area 11 in which the Big Grass Watershed is located.

1. These are the codes used in the computer program

2. The tame hay yields are those for Alfalfa mixtures.

3. Native hay yields are prorated from MCIC yields for grasses using data obtained from Manitoba Agriculture, "Agricultural Grassland Classifcation Program". The adjustment are as follows:
   (i) for groups A, B, C, D: Native hay yield = 0.44 yield of grasses
   (ii) for groups E, F, G, H: Native hay yield = 0.40 yield of grasses
   (iii) for groups I, J: Native hay yield = 0.32 yield of grasses

contained in soil survey reports.

Soil Capability

Soil capability for agriculture is determined from the general classification of soils by Canada Land Inventory. The soils with the least amount of limitation and usually the highest productivity are assigned to class one. Class seven soils on the other hand have the lowest capability and are not suited for agriculture. Detailed maps are available from Canada Land Inventory which show the capability classes and limitations. The soil capability data for the Big Grass Watershed were extracted from these maps. A good explanation of the soil capability classification is given by Jenkins (1973).

Soil Productivity Groups

While the soil capability classification gives a general indication of the suitability of soils for alternative land use and the general level of productivity, the soil productivity grouping is a more precise measure of actual productivity level. It is a classification developed by the Manitoba Crop Insurance Corporation (MCIC) from long term average yields for agricultural areas in the province. Soils are classified into ten groups—Group A to Group J, for which the highest productivity group is A. For a given risk area, MCIC

associates with each of the productivity groups specific average yield information for the various crops. Table 9.1 gives the average yields for Risk Area 11 in which the current study area is located. MCIC has mapped the soil productivity grouping for the soils in agricultural areas. The productivity grouping for lands within the Big Grass Watershed were extracted from such a map.

Land Use

Data on present land use were obtained from the Canada Census (1971). Detailed maps are available which show land use in the 1971 census period. The land use classes which are applicable to the Big Grass Watershed are as follows:

A - Croplands

P - Improved pasture and forage crops

K - Native grasslands

T, U - Trees and Bushes

M - Marsh, swamps.

For the present study, lands in the T and U categories have been

Table 9.2

Characteristics of the Soils in the Big Grass Watershed

NAME	SYMBOL	TEXTURE	HYDROLOGIC SOIL GROUP	CAPABILITY CLASS
Tobarmore loam to clay loam	To	clay loam	BC	2
Agassiz loamy sand	Ag	sand	AB	5
Agassiz loamy sand/till substitute	Ag/T	sand	AB	5
Arden loam, gravel lens phase	Arst	loam	BC	3
McCreary Assoc	My	loam	BC	3
Kelwood Assoc	Kd	loam	BC	3
Dauphin clay	Dn	clay	D	2
Lakeland clay loam	Lcl	clay loam	C	3
Lakeland clay loam/till substitute	Lcl/T	clay loam	C	3
Lakeland loam	Ll	loam	B	3
Lakeland loam/till substitute	Ll/T	loam	B	3
Almasippi fine sandy loam	Alfsl	sandy loam	B	3
Almasippi loam fine sand	Alls	sand	AB	3
Almasippi loam fine sand/till substitute	Alls/T	sand	AB	3
Westborne clay (Assoc)	Wb	clay	D	3
Erickson Assoc	Ecl	clay loam	BC	2
Querus Assoc (clay loam)	Q	clay loam	C	3
Bernie Assoc	Bi	loam	BC	4
Selina sand	Sa	sand	A	4
Granville Assoc	Gv	loam	BC	3
Wapus Assoc	Wp	loam	BC	4
Clarksville Assoc	Ck	loam	BC	4
Zaporoza	Z	gravelly sand	A	4
Isafold Assoc	Is	clay loam	C	4
Edwards silt loam to silt clay	Ed	clay loam	CD	2
Edwards semi-mature phase	Edm	clay loam	CD	2
Edwards shaly phase	Edsh	clay loam	C	3
half bog	HB		D	6
bog	B		D	7

grouped as T, whereas category O was used for grouping M together all the others not mentioned above. Only a very small portion of the total area falls into group O.

Land use changes over time are generally quite small. For the present analysis it was therefore assumed that no significant change in land use has taken place in the study area since the 1971 census information was collected.

The types of information required by the analytical model with respect to soils and land use were discussed in this section. A summary of the various soil types and their classification according to soil texture, hydrologic soil group and agricultural capability class is given in Table 9.2. The listing of all lands within the various subwatersheds according to homogenous soil groups is given in the Appendix, Table A1. The various soil classifications which were discussed in this section are given together with the land use data.

HYDROLOGIC DATA

Total runoff from various parts of a watershed together with drainage basin characteristics determine peak discharge for the inflow hydrograph. Estimates of peak discharge generated by a particular storm event can be derived for various locations along the drainage system. Estimates of peak discharge together with information on channel capacity for a given reach can be used to estimate the duration of precipitation excess in the particular sub-area. The analytical model in this study called for estimates of peak discharge at the outlet

Table 9.3

Hydrologic Data

SWS No.	H (Ft)	L (Mi)	Area (Mi^2)	LOC	CN			Distance* in ML.			
					I	II	III	D1	D2	D3	D4
3.06.20	495.0	3.28	2.50	E	67	83	93	24.8	28.0	20.0	11.5
3.06.10	650.0	7.81	2.16		58	76	89	20.8	23.5	22.5	10.8
3.06.21	395.0	2.03	1.38	E	76	89	96	24.3	27.0	20.0	10.5
3.06.11	580.0	8.28	4.72		58	76	89	20.8	22.5	22.5	10.3
3.06.05	183.5	4.68	3.21		67	83	93	17.0	21.8	26.8	15.0
3.06.06	179.5	4.21	2.09		66	82	92	17.5	22.0	26.0	14.3
3.06.07	122.0	3.28	1.35		64	81	92	17.5	21.5	25.8	14.0
3.06.18	437.0	2.80	4.13	E	63	80	91	23.3	29.0	22.5	14.0
3.06.08	707.0	10.00	5.91		58	76	89	19.0	23.0	24.5	12.8
3.04.06	4.2	1.25	0.56		62	79	91	14.0	16.5	28.5	15.0
3.04.05	21.0	2.50	2.02		63	80	91	13.5	15.3	29.3	15.8
3.03.00	8.6	1.75	1.80		44	64	81	11.8	7.0	35.0	20.5
3.06.22	1025.0	7.20	5.50	E	63	80	91	25.8	28.5	18.3	9.8
3.06.15	1074.8	8.64	0.96		70	85	94	23.5	25.5	19.5	8.8
3.06.13	75.0	2.34	0.99		47	67	83	19.0	20.3	24.0	10.5
3.06.19	1050.0	5.93	5.88	E	68	84	93	25.5	29.0	20.5	12.8
3.06.09	1300.0	11.86	4.69		58	76	89	19.8	23.0	23.8	12.0
3.06.12	1306.0	20.13	1.12		52	71	86	17.5	19.0	25.3	11.8
3.06.17	810.0	14.37	24.25	E	63	80	91	28.3	32.5	21.0	15.3
3.06.04	1060.0	21.55	3.54		62	79	91	18.0	23.0	26.8	15.5
3.06.03	1107.0	27.80	6.69		54	73	87	15.3	18.0	27.8	14.3
3.07.02	35.0	2.96	3.57		52	71	86	16.8	15.8	27.0	12.8
3.07.01	55.0	5.61	2.63		60	78	90	14.5	11.8	30.3	15.8
3.04.04	50.0	2.00	4.14		60	78	40	12.8	16.5	29.8	16.5
3.04.03	80.0	5.25	4.70		58	76	89	11.5	14.3	31.5	17.8
3.04.02	115.0	7.75	5.89		57	75	88	10.8	11.5	32.8	18.8
3.04.01	119.0	10.75	3.63		59	77	89	11.3	9.0	33.5	19.3
3.02.00	5.0	1.50	1.63		45	65	82	13.3	7.3	34.5	20.0
3.01.00	1.4	1.50	0.86		50	69	84	14.3	7.8	35.0	19.3
3.06.23	1025.0	4.64	6.63	E	75	88	95	27.3	29.0	16.8	8.8
3.06.16	1074.8	5.64	0.74		66	82	92	24.0	25.8	18.8	7.8
3.06.14	1242.8	14.05	8.31		59	77	89	20.8	21.8	22.0	8.8
3.06.02	1276.0	18.05	4.99		58	76	89	15.8	16.0	27.8	13.8
3.06.01	1305.0	22.45	4.84		58	76	89	13.0	10.8	31.8	17.3
3.05.00	1307.0	23.45	0.50		67	83	93	14.0	8.8	33.0	18.5
1.01.06	870.0	4.40	4.63	E	67	83	93	30.5	30.0	12.0	3.3
1.01.05	998.0	8.60	4.06		62	79	91	29.3	27.0	14.3	1.0
1.01.07	1021.0	9.60	0.38		46	66	82	29.3	26.0	15.3	2.8
1.01.04	1020.0	6.80	14.75	E	63	80	91	30.5	31.0	11.5	5.3
1.01.03	1246.2	12.60	6.54		67	83	93	27.3	25.5	15.8	1.5
1.01.02	1272.5	16.60	5.33		64	81	92	27.0	23.5	19.0	5.8
1.01.01	1281.6	19.60	4.93		66	82	92	25.8	20.0	22.0	9.5
4.04.03	6.0	3.00	5.90		68	84	93	24.3	12.5	37.8	24.5
4.06.00	42.2	5.20	7.04		55	74	88	20.8	10.8	34.0	20.3
4.05.00	14.0	2.00	1.38		62	79	91	19.5	8.0	37.3	23.5
4.07.02	6.0	2.00	4.77		38	58	76	21.5	13.3	30.3	16.8
4.07.01	45.0	7.18	6.66		57	75	88	18.8	8.8	34.3	20.3
4.08.00	47.2	4.30	3.49		57	75	88	17.0	7.0	35.8	21.3
4.02.00	10.4	1.69	1.89		51	70	85	17.3	4.8	40.3	26.0
4.04.06	23.0	2.00	4.50		63	80	91	24.0	15.5	30.0	16.8
4.04.05	40.0	4.00	6.00		55	74	88	23.8	14.0	32.8	19.3

Table 9.3 (continued)

Hydrologic Data

SWS No.	H (Ft)	L (Mi)	Area (Mi^2)	LOC	CN I	CN II	CN III	Distance* in ML. D1	D2	D3	D4
4.04.04	50.0	6.00	5.50		60	78	90	24.0	13.0	35.5	22.0
4.04.02	60.0	8.00	1.71		60	78	90	22.3	10.8	36.5	23.0
4.04.01	81.5	13.75	5.38		62	79	91	20.8	8.8	37.8	24.5
4.03.00	83.0	17.17	1.69		64	81	92	17.3	5.0	38.8	24.8
1.02.00	12.0	3.00	3.39		48	68	84	25.3	18.0	25.8	13.0
2.06.03	35.6	2.00	3.87		68	84	93	26.3	23.5	17.8	3.8
2.06.02	60.0	5.00	6.02		66	82	92	24.5	20.5	21.0	7.0
2.06.01	73.0	8.50	5.39		63	80	91	22.5	17.3	24.8	11.0
2.10.00	17.0	3.43	6.36		32	52	71	23.5	16.3	27.8	14.5
2.05.00	2.8	1.30	1.16		54	73	87	20.5	14.5	27.0	13.3
2.04.05	1068.0	7.18	10.38	E	75	88	95	29.0	29.5	14.0	6.3
2.04.04	1225.2	10.77	6.19		63	80	91	25.3	24.0	18.0	4.0
2.04.03	1259.4	13.58	6.86		66	82	92	23.0	21.3	20.0	6.0
2.04.02	1278.0	16.70	7.36		64	81	92	20.5	18.0	23.3	9.3
2.04.01	1294.2	19.51	5.16		63	80	91	19.5	15.0	27.0	12.5
2.03.00	10.5	1.48	1.75		63	80	91	18.0	13.0	28.8	14.3
2.08.00	14.4	2.77	2.65		46	66	82	18.3	11.5	30.0	16.0
2.02.05	831.6	4.30	3.88	E	75	88	95	26.5	27.8	16.3	6.5
2.02.04	940.0	7.60	5.00		63	80	91	24.0	24.0	18.3	5.5
2.02.03	1014.6	10.60	3.00		63	80	91	20.8	19.3	22.3	8.0
2.02.02	1028.8	13.70	3.00		60	78	90	18.5	16.0	25.5	11.5
2.02.01	1053.0	17.20	3.74		60	78	90	16.8	11.8	30.0	15.5
2.07.00	13.6	1.98	2.54		42	62	79	17.3	9.5	32.0	18.0
2.01.04	60.0	2.00	2.00		58	76	89	22.3	22.5	20.3	7.0
2.01.03	165.0	3.00	3.34		60	78	90	19.8	19.5	23.3	9.3
2.01.02	175.0	6.00	3.09		57	75	88	17.5	15.8	26.5	12.0
2.01.01	190.0	10.00	4.09		62	79	91	15.5	11.3	30.5	16.0
4.09.00	3.0	1.50	1.45		60	78	90	16.5	5.0	38.0	23.8
5.06.00	50.0	3.60	3.45		57	75	88	14.5	5.0	37.0	22.5
5.05.00	41.6	2.60	3.63		55	74	88	13.3	3.8	37.8	23.5
4.01.00	8.0	1.87	2.29		66	82	92	15.3	2.8	40.3	26.3
5.04.00	60.0	2.72	4.34		54	73	87	12.0	3.3	39.0	24.3
5.03.00	72.4	6.60	6.47		52	71	86	10.8	3.3	39.5	24.8
5.02.02	50.0	2.00	2.63		55	74	88	9.3	4.5	39.8	25.0
5.02.01	71.0	5.10	2.97		62	79	91	10.8	2.5	43.0	28.3
5.01.02	55.0	3.60	7.59		57	75	88	8.3	6.3	38.3	24.0
5.01.01	78.0	7.80	3.50		62	79	91	10.0	3.8	43.8	29.3
1.05.00	13.1	3.40	3.88		62	79	91	30.3	24.3	20.0	9.8
1.04.00	13.0	3.20	5.11		66	82	92	28.3	22.5	21.0	9.3
1.03.04	25.0	3.83	8.38		47	67	83	34.5	26.8	22.8	15.3
1.03.03	50.0	7.16	8.25		55	74	88	28.8	21.5	24.8	13.5
1.06.00	5.0	1.52	5.24		64	81	92	31.0	24.3	21.3	11.5
1.03.02	6.2	3.21	1.41		66	82	92	28.5	21.5	23.0	11.5
1.03.01	14.0	9.36	1.41		66	82	92	26.5	19.5	24.3	11.8
2.11.00	14.0	4.90	2.91		59	77	89	23.5	17.3	25.5	11.8
2.09.00	37.0	9.50	1.90		42	62	79	19.5	13.5	28.8	14.8
4.10.00	88.0	17.90	4.04		55	74	88	15.5	6.3	36.0	21.5
5.07.00	98.0	19.10	0.64		64	81	92	14.3	2.3	39.8	25.5
5.08.00	100.0	19.90	0.48		60	78	90	13.8	1.3	40.8	26.5
6.02.00	106.0	21.90	2.59		62	79	91	13.3	1.0	47.0	28.0
6.01.00	124.0	28.30	6.59		66	82	92	12.5	5.8	42.3	32.5

* Distance from the precipitation stations: Plumas (D1), Grass River (D2), Riding Mountain (D3), Kelwood (D4).

location of each subwatershed.

To estimate peak discharge from a given depth of runoff, data must be obtained on the drainage area, the difference in elevation between the subwatershed's outlet and the most distant ridge (H) and the length of the watercourse (L) from the subwatersheds outlet to the most distant ridge. When the drainage area increases in size the volume of water discharged through a given reach will increase. The area for each subwatershed is given in Table 9.3. This value was aggregated with the upstream area to obtain the gross drainage area.

Peak discharge is also influenced by the time of concentration for the subwatershed's drainage area. "Time of concentration" is defined as the time required for water to travel from the most remote portion of the basin to the subwatershed's outlet. An increase in the time of concentration causes a decrease in the peak discharge. Data on the length of the main watercourse (L) and the elevation difference (H) for each subwatershed is given in Table 9.3. These were determined from topographic and watershed maps.

The hydrologic model in this study explicitly allowed for interdependent relationships among subwatersheds. Accordingly, for daily storm events runoff from each subwatershed was traced through the system. Since the depth of runoff generated by a particular storm event varies spatially over the watershed, so too will the volume of runoff from within each subwatershed vary. In order to trace runoff through each subwatershed it is necessary to consider for each subwatershed all inflows from:

(i) feeder (inflow) tributaries which enter the outflow channel in the specific subwatershed;

(ii) runoff from subwatersheds located upstream along the outflow channel through the specific subwatershed.

From the above data, runoff and peak discharge from a particular storm can be determined for all subwatersheds within the drainage basin. The data used by the hydrologic sub-model are given in Table 9.3. In addition to the information on the drainage area, L and H for each subwatershed, Table 9.3 also provides estimates of the runoff curves numbers (CN I, CN II and CN III), the distances from the centroid of each subwatershed to the precipitation recording stations and an indicator (E) to denote the location of a subwatershed on the escarpment. The CN information represents a consolidation of the soil characteristics, soil cover (land use) and land treatment into a single variable which indicates the likely infiltration and consequently the runoff under various soil moisture conditions. This is discussed in greater detail in a subsequent section. The distances and the indicator (E) are used to derive subwatershed precipitation. These are discussed in the next section.

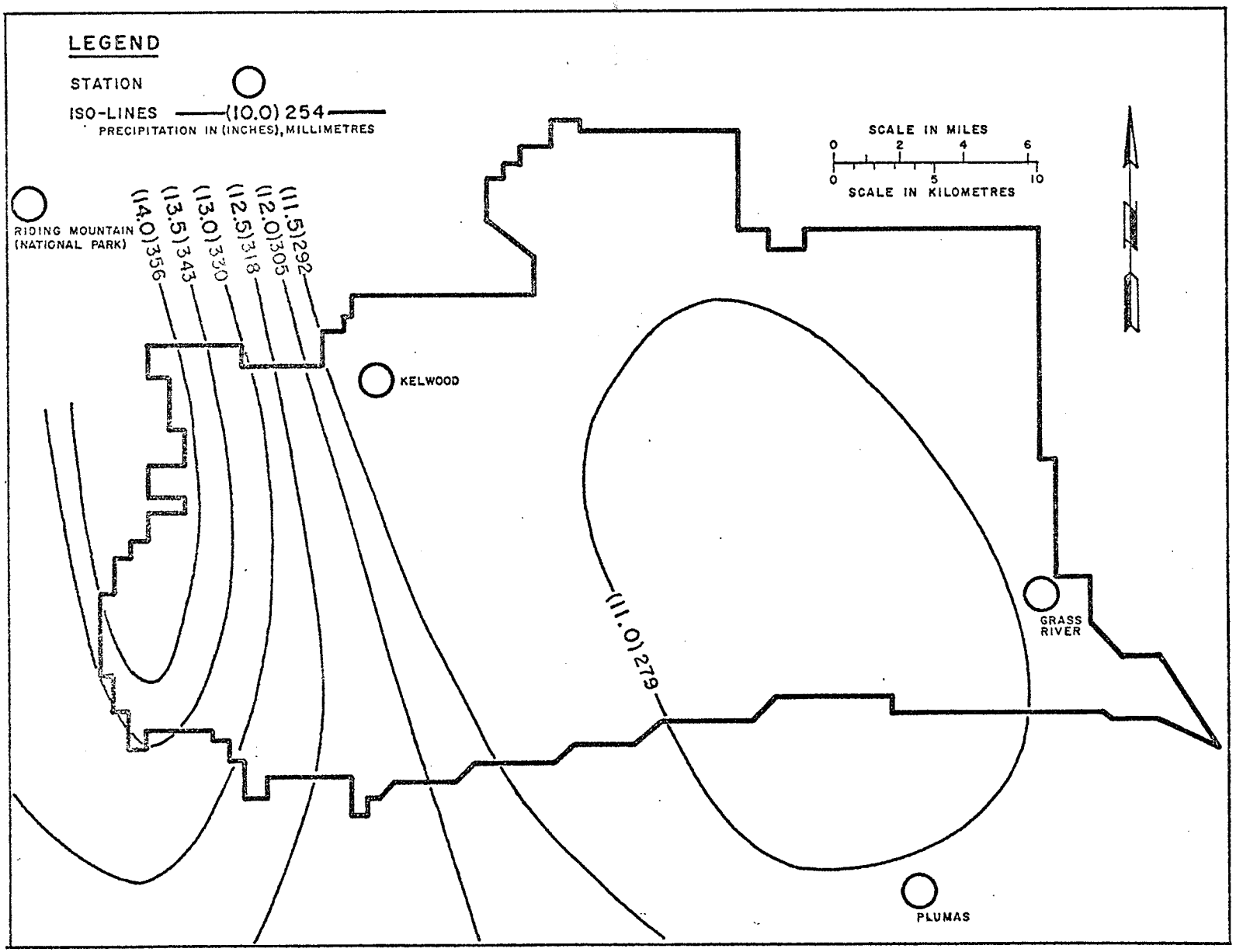
The logical sequence in which the runoff from storm events was traced through the system by the simulation model is given by the order of the subwatersheds in Table A3 in the Appendix. Table A3 contains all the information for each subwatershed which were required by the runoff and PE submodels.

PRECIPITATION DATA

Estimating Watershed Precipitation

There are three precipitation recording stations located within the Big Grass Watershed--Riding Mountain (Town), Kelwood and Grass River. From these stations the data for Riding Mountain (Town) were not used in this study sincelonly two years of records are available. Although the data for the station at Kelwood were included in the study there is a large amount of missing observations. The station located at Grass River provided daily precipitation records for the complete period, 1958 to 1975. Grass River is located in the lowland portion of the watershed and it is expected to experience precipitation which is fairly representative for locations in the lowland areas.

The topography of this watershed, characterized by a steep escarpmental western section and lowland areas of the east, exerts significant orographic effects on the weather. The isohyets in Map 9.1 show the average growing season precipitation which indicates fairly uniform precipitation for the lowland areas. The isohyets reflect different storm patterns for the escarpmental areas and precipitation which is distinctly greater than that for the lowland areas. The information contained in Map 9.1 suggests the suitability of precipitation data recorded at Grass River for representation of precipitation in the lowland areas but not for locations on the escarpment. Kelwood, located at the foot of the escarpment, has average precipitation which is less than that of escarpmental areas. A more suitable representation



Map 9.1

Isohyets Showing Average Growing Season Precipitation in the Big Grass Watershed

of precipitation in the escarpment is that recorded at the station of Riding Mountain (Park) which is located about ten miles from the northwest corner of the watershed. The recorded data which are available for this station are for the period 1958 to 1975 and for the months of May to September.

While the seasonal precipitation and the storm frequencies observed at a point such as Grass River may be representative for the surrounding area, the precipitation measured at such a point for a specific storm will often differ from the observed precipitation at other locations in the surrounding area. That is, the amount of precipitation generated by a storm varies spatially over an area. Point observation constitutes only one of a number of values which may be observed over such an area. The greater the distance of a given location from the recording site the greater is the variance between precipitation recorded at the station and that obtained at the particular location. Since only point precipitation data are available the spatial variability in storm values must be determined. The precipitation for a subwatershed from a given storm event was estimated from the precipitation recorded at the various stations. The weighting procedure used is based on an inverse relationship of the distance of each station from the centroid of the subwatershed. This follows from general observations that the magnitude of a storm decreases with increasing distance from the centre of the storm. The specification of this procedure is given in the discussion of the analytical model.

In order to improve the estimates of precipitation for

various locations on the basis of a spatial relationship, the precipitation-recording station of Plumas, located about ten miles south-southeast of Grass River, was included among the data. The recorded data for Plumas are for the period 1958 to 1975. The distances of each subwatershed from the precipitation recording stations: Riding Mountain (Park), Kelwood, Grass River and Plumas are included in Table 9.3.

Normality of Precipitation Data (1961-75) for Project Analysis

Precipitation data for this watershed are available for at least three of the stations for an 18-year period. The suitability of this data (specifically the data from 1961 to 1975) to evaluate the current project depends on whether the storm frequencies observed closely follow the expected long term frequencies. To test whether this condition was satisfied, attempts were made to locate a precipitation recording station having a long period of recorded data and with long-term storm frequencies which are expected to closely approximate the frequencies from at least one of the stations providing the watershed's precipitation data. From an examination of weather patterns and climatological data the meteorologist at the Water Resources Division indicated that long term storm frequencies observed at Brandon (located about 55 miles to the south-west of the watershed) are expected to correspond closely to those at Grass River and Plumas. Accordingly, the long-term storm frequencies for Grass River were assumed equal to frequencies recorded at Brandon over an 80-year period.

The suitability of the recorded data at Grass River from the period 1961 to 1975 for project analysis can be established if it is shown that storm frequency distribution over this period was approximately normal or average. It was therefore necessary to compare the storm frequencies obtained from the recorded precipitation at Grass River for the 1961 to 1975 period to the surrogate long-term frequencies for this station—that is, the frequencies recorded at Brandon. The chi-square test was used to compare monthly frequency distributions. The results of this test indicate that the recorded storm frequencies at Grass River in each of the months, April to September, follow similar distributions to the long term frequencies, evaluated at the five percent level of significance. The results are given in Table B1 in the Appendix. From the foregoing it was concluded that the recorded precipitation at Grass River is normal and therefore suitable for the analysis.

Given the conclusion of the normality test for recorded data at Grass River, it is reasonable to assume that the data recorded at the other stations from which the watershed's precipitation data are derived will also be normal because of their proximity to Grass River. Thus, the suitability of the recorded data at the stations selected for the period 1961 to 1975 for the evaluation agricultural drainage benefits.

Runoff Curve Numbers

The amount of excess moisture from a given storm event

which occurs as surface storage and subsequently runoff is influenced by the soil texture, the land use, land treatment, topography, the moisture content of the soil prior to the storm and the storm magnitude. Together, these factors determine, firstly, the amount of initial moisture generated by the storm event which is primarily dissipated through saturation of the soils—referred to as 'initial moisture abstraction'; and secondly, the proportion of the remainder of the storm which eventually results in surface runoff.

The U.S.D.A., Soil Conservation Service, in the National Engineering Handbook has analyzed the influence of the factors cited above on the initial moisture abstraction and the runoff from storm events over agricultural watersheds. The inter-relationships among the various characteristics for a watershed are used to determine runoff curve numbers or CN values. The runoff curve number is used as an independent variable in an empirical relationship which predicts runoff for various storm events. For a given land area, CN values vary with the amount of antecedent soil moisture. This variability reflects the fact that the proportion of storm moisture which results as runoff is influenced by antecedent soil moisture condition.

The concept of CN numbers, developed by the U.S.D.A., is discussed in chapters 7 to 10 in the National Engineering Handbook, Section IV: Hydrology. This approach is adopted for use in the current study. In the remainder of this section, the procedure for deriving CN values is presented.

CN values for a subwatershed are determined from the soil-

cover complex and the hydrologic soil grouping. The former is comprised of land use, treatment or practice and hydrologic condition. In a previous section of this chapter, the classification of soils into hydrologic soil groups on the basis of infiltration and water transmission properties was discussed. The hydrologic condition referred to above is a classification which denotes whether the soils have good, fair or poor hydrologic properties. Conditions other than those cited above may affect the amount of runoff. For example, infiltration rates will be greater for soils in pasture land which is not grazed than on grazed pastures. In this case the hydrologic condition is denoted as 'good'. When conditions tend to produce large amounts of runoff the hydrologic condition is designated as 'poor'. Such is the case for soil groups in steeper areas. The CN values for the various hydrologic soil-cover complexes and the four hydrologic soil groups are given in Table 9.4. These values are for use in predicting runoff when there is moderate soil moisture saturation, referred to as antecedent moisture condition II (AMCII). CN values for intermediate hydrologic soil groups, such as AB, are assigned the median value value of the respective groups.

The CN II values which are determined from Table 9.4 are used to determine the CN I and CN III values which correspond to the same hydrologic soil-cover complex. These relationships are given in Table 9.5. CN I values are applicable for runoff estimation when soils are dry and CN III are applicable when the soils are saturated.

Because of the diversity in soil characteristics and land

Table 9.4

Runoff Curve Numbers (AMC II)

for Hydrologic Soil – Cover Complexes

Cover			Hydrologic Soil Group			
Land Use	Treatment or Practice	Hydrologic Condition	A	B	C	D
Fallow	Straight row	—	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and Terraced	Poor	66	74	80	82
	Contoured and Terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured and Terraced	Poor	61	72	79	82
	Contoured and Terraced	Good	59	70	78	81
Close-seeded legumes[a] or rotation meadow	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
	Contoured and Terraced	Poor	63	73	80	83
	Contoured and Terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woods		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		—	59	74	82	86
Roads (dirt)[b] (hard surface)[b]		—	74	84	90	92

[a] Close-drilled or broadcast.

[b] Including right-of-way.

Source: Soil Conservation Service, (U.S.D.A.), National Engineering Handbook, Section IV, Hydrology.

Table 9.5

Runoff Curve Numbers for AMC I and AMC III

1	2	3	4	1	2	3	4
CN for Condition II	CN for Conditions I	III	S Values	CN for Condition II	CN for Conditions I	III	S Values
100	100	100	0	60	40	78	6.67
99	97	100	.101	59	39	77	6.95
98	94	99	.204	58	38	76	7.24
97	91	99	.309	57	37	75	7.54
96	89	99	.417	56	36	75	7.86
95	87	98	.526	55	35	74	8.18
94	85	98	.638	54	34	73	8.52
93	83	98	.753	53	33	72	8.87
92	81	97	.870	52	32	71	9.23
91	80	97	.989	51	31	70	9.61
90	78	96	1.11	50	31	70	10.0
89	76	96	1.24	49	30	69	10.4
88	75	95	1.36	48	29	68	10.8
87	73	95	1.49	47	28	67	11.3
86	72	94	1.63	46	27	66	11.7
85	70	94	1.76	45	26	65	12.2
84	68	93	1.90	44	25	64	12.7
83	67	93	2.05	43	25	63	13.2
82	66	92	2.20	42	24	62	13.8
81	64	92	2.34	41	23	61	14.4
80	63	91	2.50	40	22	60	15.0
79	62	91	2.66	39	21	59	15.6
78	60	90	2.82	38	21	58	16.3
77	59	89	2.99	37	20	57	17.0
76	58	89	3.16	36	19	56	17.8
75	57	88	3.33	35	18	55	18.6
74	55	88	3.51	34	18	54	19.4
73	54	87	3.70	33	17	53	20.3
72	53	86	3.89	32	16	52	21.2
71	52	86	4.08	31	16	51	22.2
70	51	85	4.28	30	15	50	23.3
69	50	84	4.49				
68	48	84	4.70	25	12	43	30.0
67	47	83	4.92	20	9	37	40.0
66	46	82	5.15	15	6	30	56.7
65	45	82	5.38	10	4	22	90.0
64	44	81	5.62	5	2	13	190.0
63	43	80	5.87	0	0	0	infinity
62	42	79	6.13				
61	41	78	6.39				

SOURCE: Soil Conservation Service, (U.S.D.A.), National Engineering Handbook, Section IV, Hydrology, p. 107

use it was necessary to compute a weighted CN value for each subwatershed. Firstly, the CN II value was estimated by weighting on the basis of hydrologic soil groupings and soil-cover complexes in the subwatershed. An example of the computational procedure is given in Appendix B. Table 9.3 lists the CN values for each subwatershed in this study. The actual CN value which is used to predict runoff from a storm event is a function of the antecedent soil moisture index (API). The actual relationship is given in the section on specification of the model.

The potential amount of moisture from a storm event which will be absorbed by the soil is dependent on soil characteristics and antecedent soil moisture which are used to determine the CN value. The potential moisture abstraction index (S) is estimated from CN as follows:

$$S = \frac{1000}{CN} - 10$$

Moisture retention increases for increasing S values.

AGRONOMY DATA

Land Use Alternatives

The Canada Land Inventory soil classification scheme groups soils into soil capability classes denoting general suitability for agriculture. The soils within each class are comprised of different subclasses which indicate the type of limitation or hazard but having the same degree of limitation. Jenkins (1973) discusses the basic assumptions on which the soil capability classification was developed and interprets the information conveyed.

Soils are grouped into seven classes. Additionally, for soils containing a high percentage of organic matter the interpretive soil capability classification is not applied. Such soils are designated as 'organic'. For the classified soils the alternative uses to which each class is generally restricted because of physical capabilities is given by Jenkins (1973:9-13). These are as follows:

a) Class 1-3: Soils are capable for sustained production of common field crops.

b) Class 4: Soils have severe limitation that restrict the range of crops.

c) Class 5: Soils have severe limitations that restrict their capability to producing perennial forage crops and improvement practices are feasible. However, some soils in this class may be used for field

crops provided good management practices are followed.

d) Class 6: Soils are capable of producing only perennial forage crops. Improvement practices are not feasible.

e) Class 7: Soils have no capability for arable culture or permanent pasture.

Based on the general suitability indicated above, the land use alternatives which were evaluated in this study were determined from the soil capability class. The alternative uses which were evaluated for each capability class are given in Table 9.6. From these the land use which generated the highest net return was chosen by the analytical model, providing other production and marketing constraints were satisfied. The restraints on land use and production are discussed next.

Table 9.6

Land Use Alternatives

Soil Capability Class	Alternative Uses*
1	A,P
2	A,P
3	A,P
4	A,P
5	A,P,K
6	K
7	-

* A = field crops: wheat, oats, barley
P = cultivated forage
K = native grassland

Land Use Restraints

Restraints had to be introduced in the model to ensure that the land use solutions are realistic. Such solutions must conform to the limitations which are imposed on production decisions as a result of physical, economic and institutional conditions.

Physical limitations include the suitability of soils for specific crops, the need to control disease and weeds and the inability of some soils to support continuous cropping. The soils and climatic conditions in this region of the Province have resulted in wheat, oats, and barley being the most important field crops. Only a very small amount of flax is grown. It is reasonable to assume that for acreages in the study area which are allocated for field crop production, that wheat, oats and barley will remain the important crops.

Land use decisions should also be consistent with the objectives of minimizing the risk of disease occurrence and maintaining land productivity. Traditional crop rotation practices, which includes the fallowing of land, have been effectively used for these purposes. Production record data from MCIC indicate that an average of about 29 percent of the surveyed cropland were left in fallow, annually. This percentage appears high relative to other areas (such as McKinnon watershed) which are located in the same region and having similar soils. For such areas an average of 25 percent of cropland was in fallow. One likely factor accounting for this higher percentage of fallow in the Big Grass Watershed is the inability to seed some acreages or the destruction of

crops because of excess moisture. If the above is a valid hypothesis then drainage improvement will tend to cause a reduction in the amount of fallow. Consistent with the practice in similar areas it was assumed that fallow will reduce to 25 percent of the cropland acreage.

Land designated for field crop production were allocated for wheat, oats, barley and fallow use according to the proportion given in Table 9.7. Seventy-five percent of cropland acreage were seeded in the above crops and the remaining 25 percent were fallowed.

Table 9.7

Allocation of Cropland Acreages

Land Use	Proportion of Cropland Acreage	Proportion of Crop Acreage On:	
		Fallow Seedbed	Stubble Seedbed
Wheat	0.27	0.61	0.39
Oats	0.30	0.17	0.83
Barley	0.17	0.20	0.80
Fallow	0.25	-	-

The relative proportions of wheat, oats and barley are the average computed from MCIC data for the period 1966-75. Table 9.7 also gives the proportions of each crop which are grown on fallow and stubble seedbeds. According to production records, about 66 percent of all fallow land are seeded to wheat in the following year.

Economic conditions (which also includes financial) which influence production result from the variability in prices and market conditions. Farm operators usually follow production plans which are expected to minimize losses and maximize long-term gains. Crop rotation also reflects the desire of farm operators to diversify among crops so as to minimize impacts from adverse market conditions. Crop rotation also assists in satisfying marketing quota restrictions imposed by the Canadian Wheat Board.

One important restriction on agricultural production in this watershed is the market limitation on forage. At the present time about nine percent of the watershed's area is used for forage production. While it is possible that forage may better compete with cereal grain for a larger proportion of the watershed's area (than the nine percent) it is necessary to restrict the land use solution to reflect the marketing limitation. Consequently, it was decided that in the event that land use solution resulted in forage production which represented more than 50 percent increase in acreage then competition between field crops and forage will be restricted to lower productivity soils since, generally, forage is relatively more profitable on lower capability soils. A 50 percent increase in acreage is the maximum allowed for in this model.

Crop Yield Data

Average yields for the various soil productivity groups were

determined using soil productivity ratings. Associated with each productivity group are the average yields for the various crops which were obtained from MCIC data. Table 9.1 gives the average yields for wheat, oats, barley, tame hay and native hay which are applicable to the soils in the Big Grass Watershed.

The average yields given in Table 9.1 were used to estimate net returns for the various soil groups for the existing drainage level. It also provides the basis for estimates of yields and net returns after drainage improvements. The productivity ratings for soil groups are given in Table A1 in the Appendix.

ECONOMIC DATA

Agricultural Prices and Production Costs

Because prices fluctuate over the short-run it is important to use average or normal prices to evaluate benefits and costs. Prices over the period 1970-76 ranged from very high to low and so the averages were appropriate for the evaluation in the deterministic model. The average farm price for each of the years 1970-76 were converted to constant 1976 dollar value and then averaged. This computation is given in Table C2 in the Appendix. The normalized prices are presented in Table 9.8.

Cost of production for wheat, oats, barley, tame hay and native hay (equivalent) are also shown in Table 9.8. These estimates exclude the cost of land, labor and management. For the production of

Table 9.8

Agricultural Prices and Production Costs

Crop	Crop Code	Unit	Price[1] (4)	Cost of Production[2] ($/Acre)
Wheat	01	BU.	3.59	38.00
Oats	02	BU.	1.44	34.00
Barley	03	BU.	2.15	37.75
Cultivated forage	50	Tons	35.96	12.12 + 8.50 Y
Native hay	70	Tons	35.96	8.50 Y

1. Prices are normalized average farm prices (1970-76)in constant 1976 dollars. Computations are given in Table C2 in the Appendix.

2. Costs of production exclude the cost of land, labor and management. For specific assumptions see Table C3 in the Appendix. Cost for forage production is a function of amount of crop harvested (yields). Since the returns to native hay are based on the value of forage produced a harvesting cost is imputed for this activity.

forage, costs are given as a function of yield. This variable component primarily reflects the harvesting cost which is directly related to yields. The assumptions used to derive these estimates and the primary source of information are given in Table C3 in the Appendix.

Land Development Costs

One of the provisions allowed for in the analysis is for change in land use. To facilitate such changes land development is usually required. The type of development and the costs involved depends on the nature of the change. For lands in the Big Grass Watershed the native vegetation is typically 'parkland' trees and bushes.

Thus, if a piece of land in native trees and bushes is to be seeded to forage or crops then clearing, piling and burning, breaking and discing operations must be performed. If only a change in native grassland (pasture usage) is desired then clearing, piling and burning of trees and bushes are required. Additionally, there is a cost for fencing areas which are used for pasture. If the change is from native grassland to seeded forage or crops then breaking and discing operations are necessary. The costs associated with the various changes are given in Table 9.9

Table 9.9

Land Development Costs

Present Use	Proposed Use	Operations	Cost/Acre ($)	Total Cost/Acre ($)
a) Trees & bushes	Seeded Forage or Crops	1. Clearing	45.00	
		2. Piling & burning	15.00	
		3. Breaking	14.50	
		4. Discing	5.50	80.00
b) Trees & bushes	Native Grassland (pasture)	1. Clearing	45.00	
		2. Discing	15.00	
		3. Fencing*	56.00	116.00
c) Native Grassland	Seeded Forage or Crops	1. Breaking	14.50	
		2. Discing	5.50	20.00
d) Cultivated Forage	Crops	1. Discing	5.00	5.00

Source: Costs are obtained from P.F.R.A. and reflect tender prices for 1977 and 1978. These years were chosen, rather than 1976, since the latter was a period of abnormally high construction prices. The prices given above are closer to normal.

*The cost of fencing with 4-strand barb-wire is $3000/mile. An average cost per acre was computed on the basis of an 80-acre block of land having 1.5 miles circumference.

INTERNALLY GENERATED STORM DATA

The deterministic model evaluates the economic impact of drainage development under the assumption that economic variables, such as prices and production costs, and storm frequencies take on their mean expected values. The stochastic version of the model is specifically designed to analyze the effects of the random behavior of these variables on the output of the system. It is constructed with the facility to generate, internally, the random variables which were hypothesized as having the most significant stochastic influence on the behavior of the system. As previously indicated, these variables are the agricultural prices, production costs and storm data. In Chapter 7 the various relationships which are involved in generating input data were discussed. To randomly generate values for a specific variable it is necessary to have information on the statistical distribution of the variable. In this section, the basic data together with the methodology used to construct statistical distribution for simulating storm data are presented. In the following section the discussion focuses on the economic variables.

Generating Storm Data

The procedure followed in simulating storm data for the watershed is to generate daily precipitation for each of the following stations - Grass River, Plumas and Riding Mountain (Park). This meant that statistical distributions for storm events at the various stations were

required. But because of the proximity of these stations to each other daily storm occurrences at the various locations cannot be viewed as independent events. Joint probability distributions for storms at various locations were required by the model. Estimates of the statistical distributions of the population were made using samples of historical storm data. Empirical distributions were derived.

In order to generate daily storm data for various locations in the watershed it was necessary to assume independence (that is, relative to other locations) for storm occurrence at one location. Such a station was designated as the "prior station" and its independent storm probability distribution as the "prior probability". From this distribution daily storm data were generated for the prior station.

The occurrence of storm events at other stations was assumed to be conditional on the particular occurrence at the prior station. Accordingly, it was necessary to have information on the conditional storm probability distribution for such stations given various storm occurrences at the prior station. These stations were referred to as "conditional" and the conditional distributions were estimated from samples of historical data giving joint daily occurrences at the prior station and each conditional station.

Grass River was selected as the 'prior' station in this study since a long period of historical storm data was available for estimating the statistical distributions. Surrogate data, corresponding to an 83-year

period for Brandon, were used to derive a sample estimate of the storm probability distribution. Daily storm data were randomly generated for Grass River from the derived empirical distribution according to a randomly selected pattern of storm occurrences.

Riding Mountain and Plumas were designated 'conditional stations'. Empirical conditional distributions were estimated from samples of historical data giving joint daily storm occurrences over the period 1958-75. These were used to randomly generate storm data at the conditional stations given certain events at the prior station.

Because there are significant differences in total precipitation and storm frequencies among the summer months it was necessary to derive separate probability distributions for each of the months of interest. While the main interest of the study was for storm occurrences in the months of June, July and August, data were generated for the period April to September. Precipitation in April and May were used to estimate antecedent moisture. September was included to obtain some indication of moisture build-up for the following spring.

In estimating empirical storm probability distributions storms were grouped into ranges and the probabilities for daily occurrences were estimated. The distributions for Grass River for the months April to September are given in Appendix D. The posterior or conditional probability distributions for Plumas and Riding Mountain are also given in Appendix D. Since there was no recorded data for Riding Mountain for the month of April, the data for Plumas were used as surrogate to derive

the distribution for this month. This is expected to have virtually no effect on the analysis since storm data for April is used only to estimate antecedent moisture.

Storm Event Patterns

While the statistical distributions discussed above measure the daily storm probabilities, it would be unrealistic to generate daily storm data under the assumption of independence among events for consecutive days. Data indicate that joint occurrences are common. However, the actual magnitudes for storms on consecutive days seem random. Storm magnitude for a given day does not appear to be dependent on the previous day's storm magnitude. On this basis if the number of consecutive days over which storm events will be generated by a particular weather disturbance is known apriori, then random generation of storm data from the probability distributions are expected to provide satisfactory data. In essence, therefore, the storm occurrence patterns should be known. Because storm patterns are influenced by numerous complex variables which make prediction rather difficult, for the current study storm patterns were determined from historical storm data. A pattern was defined in terms of the occurrence or non-occurrence (without regard to magnitude) of daily storm events on consecutive days for period April 1 to September 30.

Historical data for Brandon (80 years) provided 80 patterns. Before generating precipitation data for a given year a pattern of storm

events was randomly chosen (assuming a uniform statistical distribution) from this sample to determine the days for which a storm event should be generated and the days when precipitation was zero. The actual storm magnitude was generated randomly from the probability distributions for the respective stations and respective months.

CROP DAMAGE COEFFICIENTS

The crop damage coefficients indicate the marginal damage of crops in terms of yield reduction due to increases in precipitation excess. Alternatively, when drainage improvement works are used to reduce the amount of PE the crop damage coefficients indicate the marginal benefit or increases in crop yield because crop damage is averted. Thus these coefficients are used to compute the benefits to drainage improvement works.

Previous research (Rigaux and Singh, 1975: Vol. 2) has shown that susceptibility of crops to excess moisture varies among crops. The most important factor influencing the amount of damage from PE is the texture of the soils, with clay soils showing the greatest damage and sands and loams the least. Damage coefficients also vary between crops grown on fallow seed-bed and crops grown on stubble seed-bed. While crop damage coefficients were estimated in the above study for wheat, oats, barley and flax using data from selected watersheds in Agro-Manitoba, in this study it was appropriate to re-estimate the coefficients for

crops grown on clay loam soils since these soils predominate in the Big Grass Watershed. Clay loams comprise about 65 percent of the watershed whereas loams, sands and clays account for 14, 13 and 6 percent, respectively.

The most important field crops in the Big Grass Watershed are wheat, oats and barley. Regression analysis was used to estimate the functional relationship between the dependent variable, crop yield, and the explanatory variables - fertilizer input, soil productivity and PE levels in each of the months, May to August. The general form of the equation is:

$$Y = f(X_1, X_2, \ldots, PE5, PE6, PE7, PE8)$$

Where: Y = crop yield in bushels per acre

X_1 = explanatory variables other than PE

PE5, .., PE8 = total amounts of PE occuring in the months, May to August, respectively.

The analysis was performed using crop production data for the period, 1966 - 75, and corresponding estimates of PE over the same period for the various subwatersheds in the Big Grass Watershed. Functional relationships were estimated for the three crops indicated above for production on the clay loam soils on fallow and stubble seed-beds. Additionally, data availability permitted the estimation of relationships for wheat crop on loamy soils (fallow and stubble), oats on loamy soils (stubble) and oats on sandy soils (stubble). The results of the regression analysis are given in Appendix F.

The marginal crop damage coefficients are given by the relationship:

$\delta Y/\delta PEi$, where i = month of PE occurrence (5, 6, 7, 8)

Table 9.10 gives the crop damage coefficients which were used in this study to evaluate benefits. The table does not include coefficients for PE occurrence in May since these showed no significant damage. The coefficients shown for wheat, oats and barley are those estimated in this study supplemented by results from the Rigaux-Singh study for cases where there were insufficient data. The damage coefficients for tame hay could not be estimated by regression analysis since there is almost no data available for this type of analysis. Estimates were arrived at from discussions with researcher, L. D. Bailey, at the Brandon Research Station. His own experience in forage research together with the findings of Heindricks (1972) resulted in these estimates of probable damage. Since forage accounts for only 10 percent of the land use in the watershed it was felt that the error from such an approximation will not significantly affect the final results. Research by Heindricks had also shown that grasses were negligibly affected by excess moisture. For the levels of PE experienced in the Big Grass Watershed no significant damage is expected and so no significant benefits will be derived from a reduction in PE. Thus the damage coefficients for native hay is given as zero.

Table 9.10

Marginal Crop Damage Coefficients for Estimating the Improved Productivity from PE Reduction

Soil Texture	Crop	Unit	Stubble			Fallow		
			Reduction in Yield from PE in			Reduction in Yield from PE in		
			June	July	August	June	July	August
Clay	Wheat	bu./PE-hr.	-.103	-.201	-.035	-.023	-.071	0
	Oats	"	0	-.253	-.059	0	0	0
	Barley	"	-.100	-.275	-.143	0	-.210	-.182
	Tame Hay	tons/PE-hr	-.0042	-.0042	-.0042	0	0	0
Clay Loam	Wheat	bu./PE-hr	-.017	0	0	-.039	0	-.025
	Oats	"	-.091	0	-.020	-.152	0	0
	Barley	"	-.068	0	-.029	-.101	0	-.028
	Tame Hay	tons/PE-hr	-.0042	-.0042	-.0042	0	0	0
Loam	Wheat	bu./PE-hr.	0	0	0	0	0	0
	Oats	"	0	0	0	00	0	0
	Barley	"	0	-.056	0	0	-.471	0
	Tame Hay	tons/PE-hr	0	0	0	0	0	0
Sand	Wheat	bu./PE-hr	.048	-.072	-.004	-.022	0	.160
	Oats	"	-.093	0	0	0	0	0
	Barley	"	.034	-.084	.032	.166	-.067	0
	Tame Hay	tons/PE-hr	0	0	0	0	0	0

Note: 1. It was assumed that native hay production is not significantly influenced by the levels of PE usually experienced in this Watershed.

2. Damage to crops in areas designated as half-bogs are assumed equal to that for the clay loam soils since this is the predominant soil type in the watershed.

INTERNAL GENERATION OF ECONOMIC DATA

In order to randomly generate input data on agricultural prices and production costs for the stochastic version of the model, prior information is needed on the statistical distribution of these variables and the relationships which are important in this component of the model. Samples of historical data were used to study the characteristics of agricultural prices and of farm input prices. The relationships which were considered relevant in simulating the values of these variables were presented in the discussion of the model. In this section the derivation of statistical distribution is given. Other input data and assumptions used in this particular component of the model are also discussed.

Average annual farm prices for crops and tame hay over the period 1950-76 exhibited significant short-run fluctuations and gradual upward trends over the longer-run. On the other hand when these prices were deflated by the farm input price index[3] each price series was shown to fluctuate within a given range about same mean value. To identify the statistical distributions for the deflated prices of wheat, oats, barley and tame hay, histograms were constructed for the data from the sample period chosen. For all the price series examined the histograms revealed good approximations to the normal distribution. This finding

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3. The farm input price index excludes the cost of land and the base is 1971 = 100. Table C4 in the Appendix gives the index for the period 1946-76.

provided a good basis for randomly generating price data since the parameters of the normal distribution - the mean and standard deviation, can be readily estimated. Sample estimates of the mean and standard deviation of the deflated price series for wheat, oats, barley and tame hay are given in Table 9.11. Since the production for native grassland was converted to tame hay equivalent on the basis of nutritional value only the tame hay price was required for the evaluation of benefits.

Table 9.11
Mean and Standard Deviations for Deflated
Agricultural Prices (1950-76)

Crop	Mean Value	Standard Deviation
Wheat	2.13	0.50
Oats	0.86	0.22
Barley	1.30	0.36
Tame Hay	19.55	2.93

Note: Deflated prices computed from average farm prices in Manitoba and the farm input price index.

The chi-square test was used to verify the goodness of fit of each of the deflated price series for the period 1950 to 1976. The results, given in Tables C5 to C8 in the Appendix, support the null hypothesis that the deflated prices follow a normal distribution at the five percent level of significance.

The statistical distributions identified above can be used to randomly generate deflated prices. In order to be able to use these

to evaluate benefits they must be inflated to the money equivalent for the respective years. This requires data on the farm input price index for the various years of the project.

Examination of farm input price index data over the period 1946 to 1976 indicates a gradual upward movement. The average annual change in the index was 2.84 for the period 1946 to 1976, excluding the 1973-75 data. The short-run year to year changes seem to be normally distributed and was verified to be so using the chi-square test. The result is given in Table C9 in the Appendix.

While the mean annual change of 2.84 in the farm input price index is estimated from a relatively large sample it is not really representative of the current level of relatively higher rates of price increases. Price structure showed a significant change in 1973. The changing structure of the world economy and changing structure and conduct of agricultural supply industries seem to indicate that a higher rate of farm input price increases than was revealed for the 1947-72 period should be expected for the future. While the increases in farm input price index in the 1973-75 period were abnormally high, 20.4 and 19.4, respectively, it is unlikely that for the immediate future the rate of inflation for these inputs would return to the values of the 1950's and 1960's. Consequently, it was felt that a more realistic estimate of the mean annual change and standard derivation for the farm input price index would be obtained from more recent data - 1965 to 1976, excluding 1973-75.

These estimates are:

(i) mean annual change in the farm input price index = 4.75

(ii) standard deviation of annual change in the farm input index = 3.85

The annual change in the farm input price index was randomly generated consecutively for each year of the project, starting from the initial year. By addition of these changes to the price index of the previous year, price index data were derived. These were used to inflate the randomly generated deflated prices for the various years.

While the historical data on annual change in the index provided an estimate of a distribution from which sampling can be done, the data showed that reductions (or negative changes) in input prices are quite rare. General reductions in farm input prices were observed for only three years over the period 1947-76 and these were small. The foregoing suggests that the left tail of the normal curve is skewed towards the mean. To reflect this peculiarity of the distribution, annual changes in the farm input price index which were less than (-0.5) were rejected.

The farm input price index was also used to generate cost of production data. The deflated costs for the initial year of the project were inflated by the price index for various years to derive production costs.

Chapter 10

THE FEASIBILITY OF DRAINAGE IMPROVEMENTS

INTRODUCTION

The analysis of drainage development impact in this study progressed sequentially from the estimation of runoff and PE to the derivation of an optimum development plan for the watershed. Given the estimates from the runoff and PE submodels, the analysis of benefits and drainage feasibility was conducted in three main steps. In the first, preliminary analysis of benefits and costs was conducted for individual subwatersheds. This first step was considered preliminary since the benefits and costs which entered the analysis were estimates only of those which accrue within the subwatershed. No downstream effects were considered in this step. Because the associated costs for downstream channel modifications and any benefits which may be generated from such improvements were neglected in step one, the analysis thus far could have only been viewed as preliminary. This omission of certain costs and benefits meant that the drainage optimum could not be derived from the data in step one. Thus optimization of drainage works was the focus of the analysis in the second step. Here subwatersheds were grouped in units which were convenient sizes and entities for construction works. It was more suitable to optimize drainage for groups of subwatersheds. This essentially provided an indirect approach for the reallocation of main channel costs from within the group to the

subwatersheds which comprise the group.

After optimization of drainage within groups the downstream impacts in terms of additional protection which may be required further along the main channel as a result of upstream improvements were evaluated. Required designs for the main drainage channel, the associated costs and benefits generated were estimated. From the foregoing the optimum watershed development plan was derived. Here levels of drainage development, channel diversions, agricultural land use changes, wildlife uses and the aggregate output data for the economic variables were derived. Further analysis was conducted using the deterministic version of the model. The price sensitivity of the benefit/cost ratios for selected subwatersheds was studied to discern the influence of prices (of agricultural output) on drainage improvement feasibility. The discussion of the results from the deterministic analysis follows the logical order outlined above.

PRELIMINARY BENEFIT/COST ANALYSIS

The Big Grass Watershed was divided into 102 hydrologic units or subwatersheds. For some of these, the natural land gradient is sufficiently great to permit overland runoff in a reasonable time period. More important is the fact that for such areas the PE which results from water detention on the land due to channel storage are likely to affect

only a small area relative to the widespread effects in flatter areas. After studying times of concentration and the possibility of storage for various land slopes it was concluded that no significant PE levels will be experienced in areas where land slope exceeds 25 feet per mile. Only very small portions of such areas will be affected by PE of the type considered in this study. The more serious problem in these steeper areas is likely to be the problem of flooding, resulting primarily from upstream runoff. Subwatersheds with average gradient exceeding 25 feet per mile were therefore assumed to have no significant drainage problem. Benefits from further drainage improvement works are expected to be negligible thus resulting in a benefit/cost ratio of approximately zero.

Table 10.1 indicates that about one-third of the Big Grass Watershed is comprised of areas requiring no further agricultural drainage improvement because of land gradient. This area occupies the western portion of the watershed (Map 10.1), and includes the escarpment and a large part of the sub-escarpment. There are 28 subwatersheds in this group which covers an area of 146 square miles or 34 percent of the watershed.

The remainder of the watershed is characterized by flat to gentle relief. Excess moisture is a significant limitation to agricultural productivity in this part of the watershed. This area is comprised of 74 subwatersheds which occupies an area of about 280 square miles.

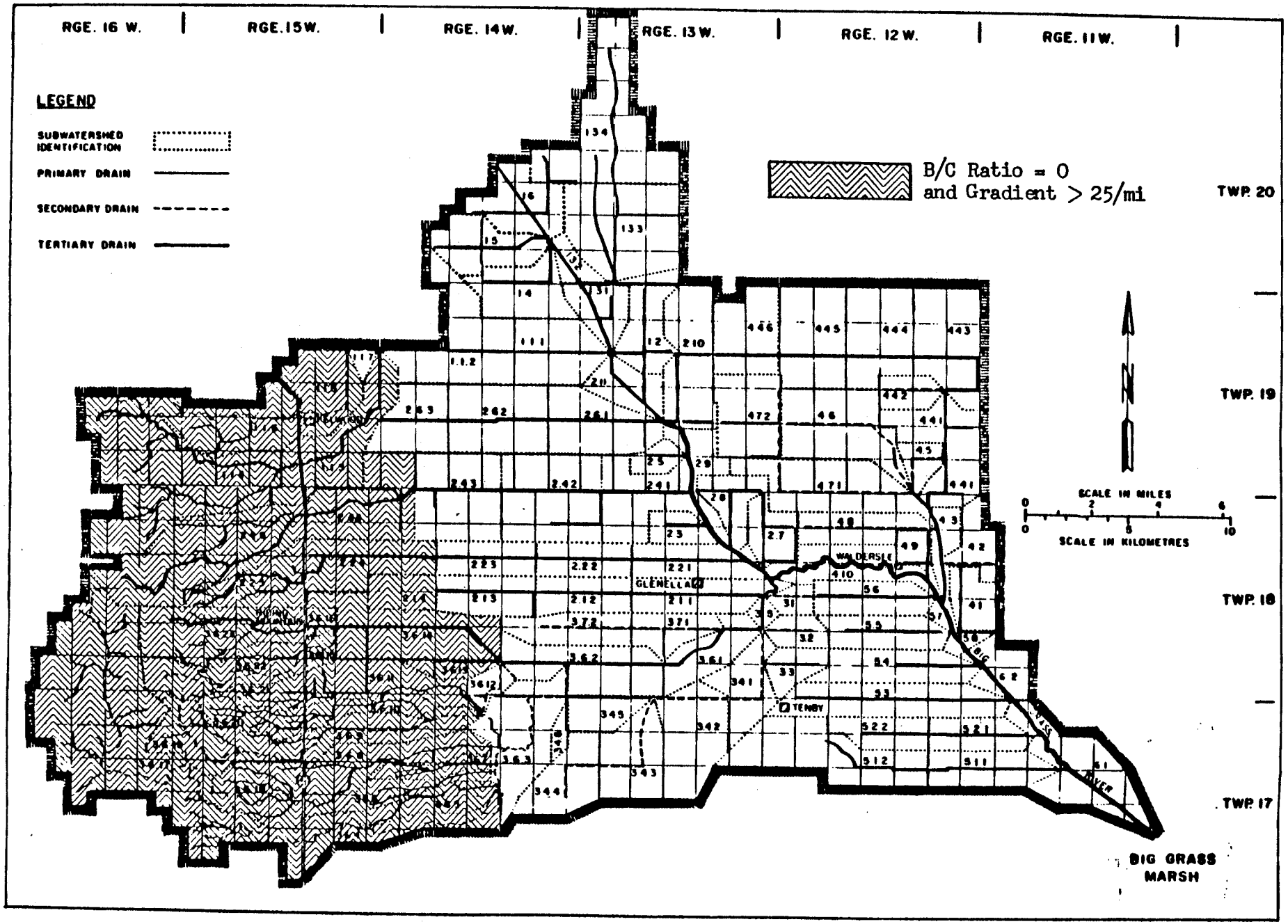
The analysis of benefits and costs was conducted for all sub-

Table 10.1

Preliminary Benefit-Cost Analysis Results for the

Big Grass Watershed: Summary of Findings

		Range of Highest B/C Ratio	No. of Subwatersheds	Area (Mi^2)	Percent of Watershed
A. Non-Feasible Subwatersheds					
(i) gradient 25 ft/mi		0	28	146	34.3
(ii) gradient 25 ft/mi	(a)	0.01 - 0.80	51	184	43.2
	(b)	0.80 - 0.99	3	15	3.4
Subtotal: B/C > 1.00		less than 1.0	82	345	80.9
B. Feasible Subwatersheds					
	(a)	1.00 - 1.99	17	71	16.6
	(b)	>2.00	3	10	2.4
Subtotal: B/C > 1.00			20	81	19.0
TOTAL			102	426	100

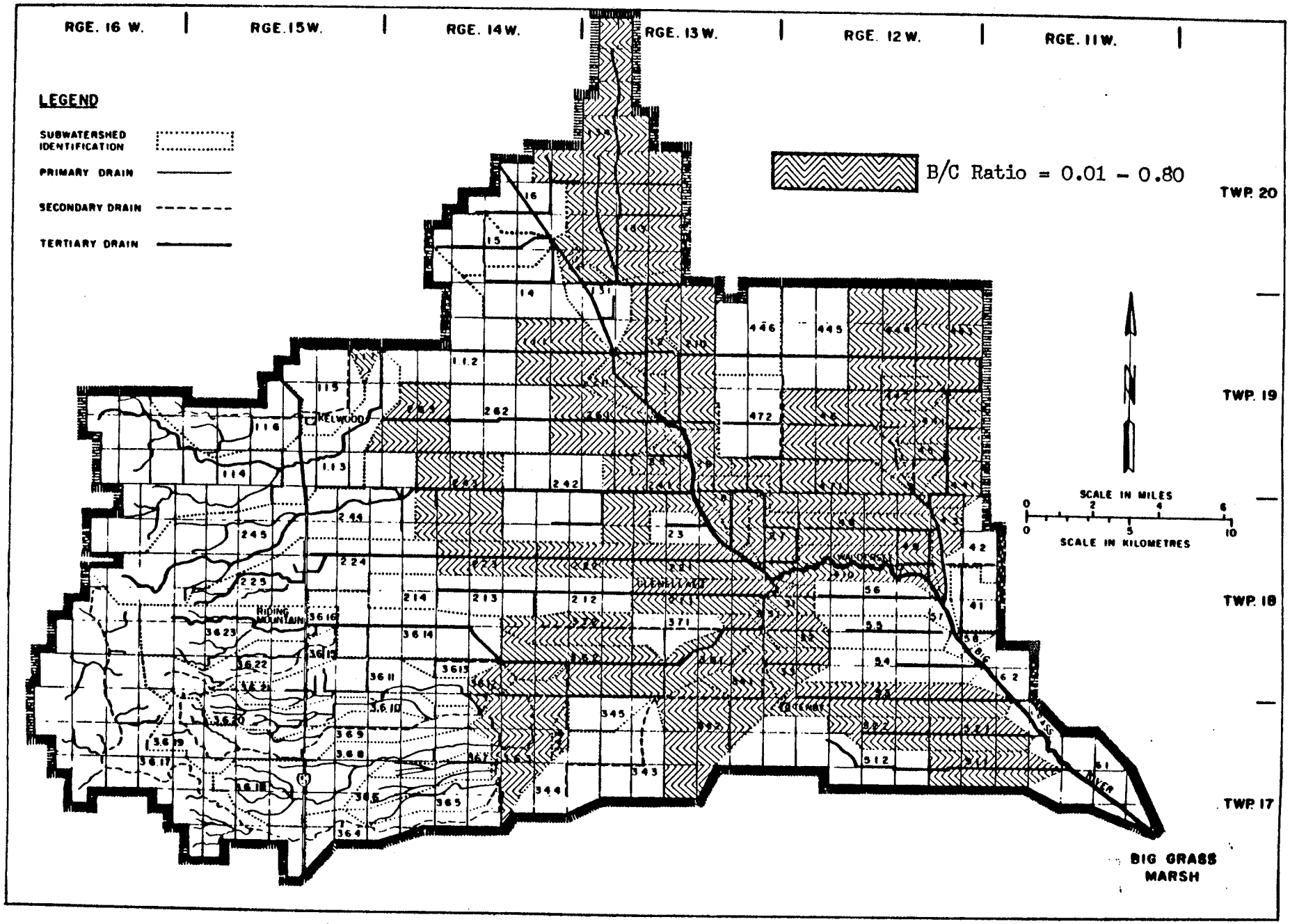


Map 10.1 – Subwatersheds Requiring No Drainage Improvements Because of Adequate Natural Drainage

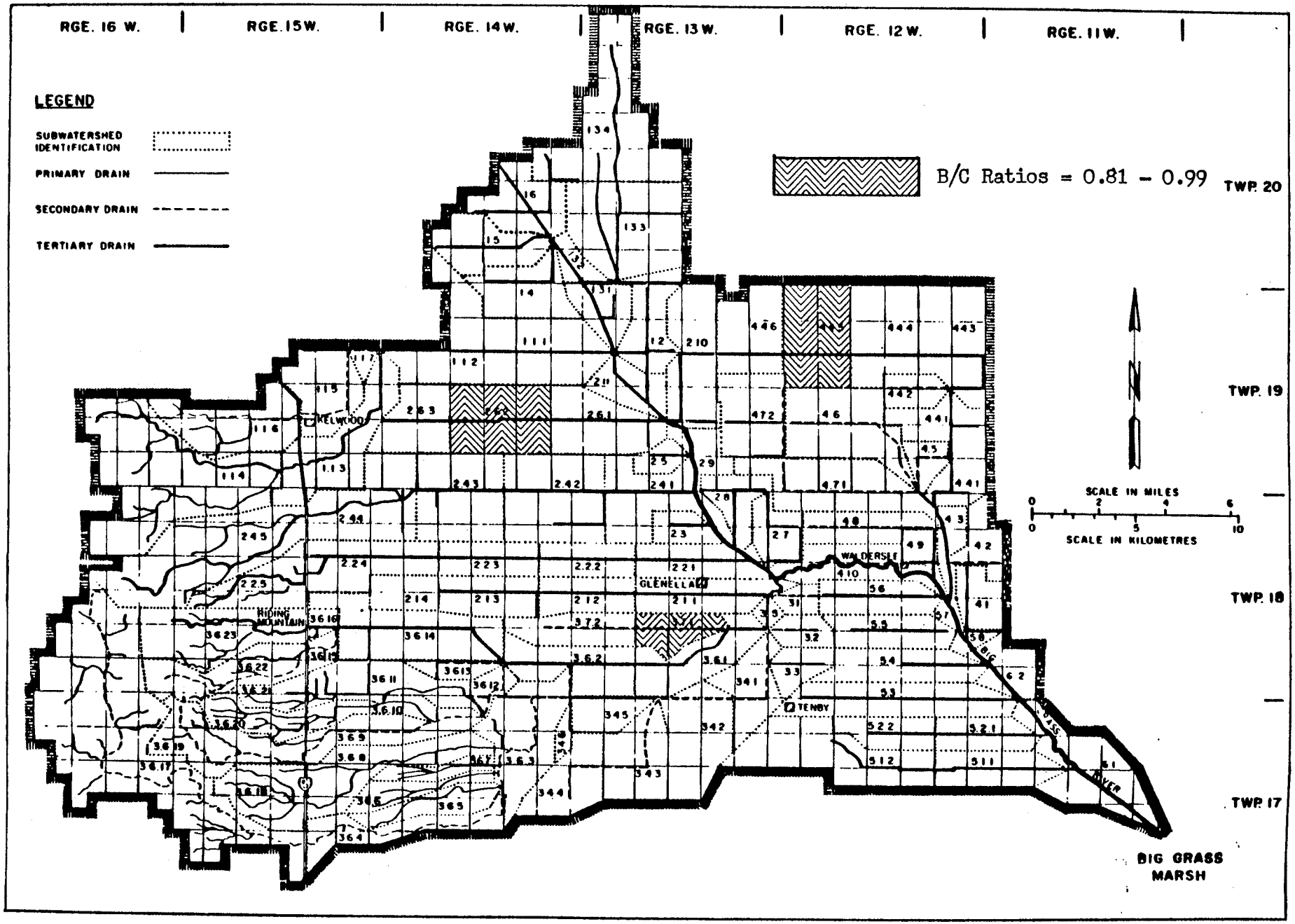
watersheds with average land slope of less than 25 feet per mile. The results for the 74 subwatersheds which belong to this classification is summarized in Table G1 in the Appendix. These preliminary findings were examined to determine feasibility of drainage improvement works on the basis of only the benefits and costs internal to the subwatersheds. Based on the highest benefit/cost ratio for any level of the design levels considered these results were tabulated as shown in Table 10.1. There were 51 subwatersheds with benefit/cost ratios in the range from 0.01 to 0.80. These accounted for 184 square miles or 43 percent of the watershed as shown on Map10.2. While generally, internal costs for upstream subwatersheds may underestimate the true drainage development costs for the subwatershed there were downstream subwatersheds on the other hand for which internal costs are likely to exceed the true development costs for additional protection within its boundaries. Because of this fact some downstream subwatersheds which are shown to be non-feasible for drainage works in the preliminary analysis may prove to be feasible if proper reallocation of costs is made.

Table 10.1 and Map 10.3 show that 3 subwatersheds or 3.4 percent of the watershed had ratios which were in the range of 0.80 to 0.99. Thus on the basis of these results there are 82 subwatersheds which showed benefit/cost ratios below the feasible ratio of one. These accounted for 345 square miles or 81 percent of the watershed.

Most of the subwatersheds which were shown to be feasible for drainage improvement works on the basis of the preliminary analysis had



Map 10.2 - Subwatersheds Which Showed B/C Ratios From 0.01 to 0.80



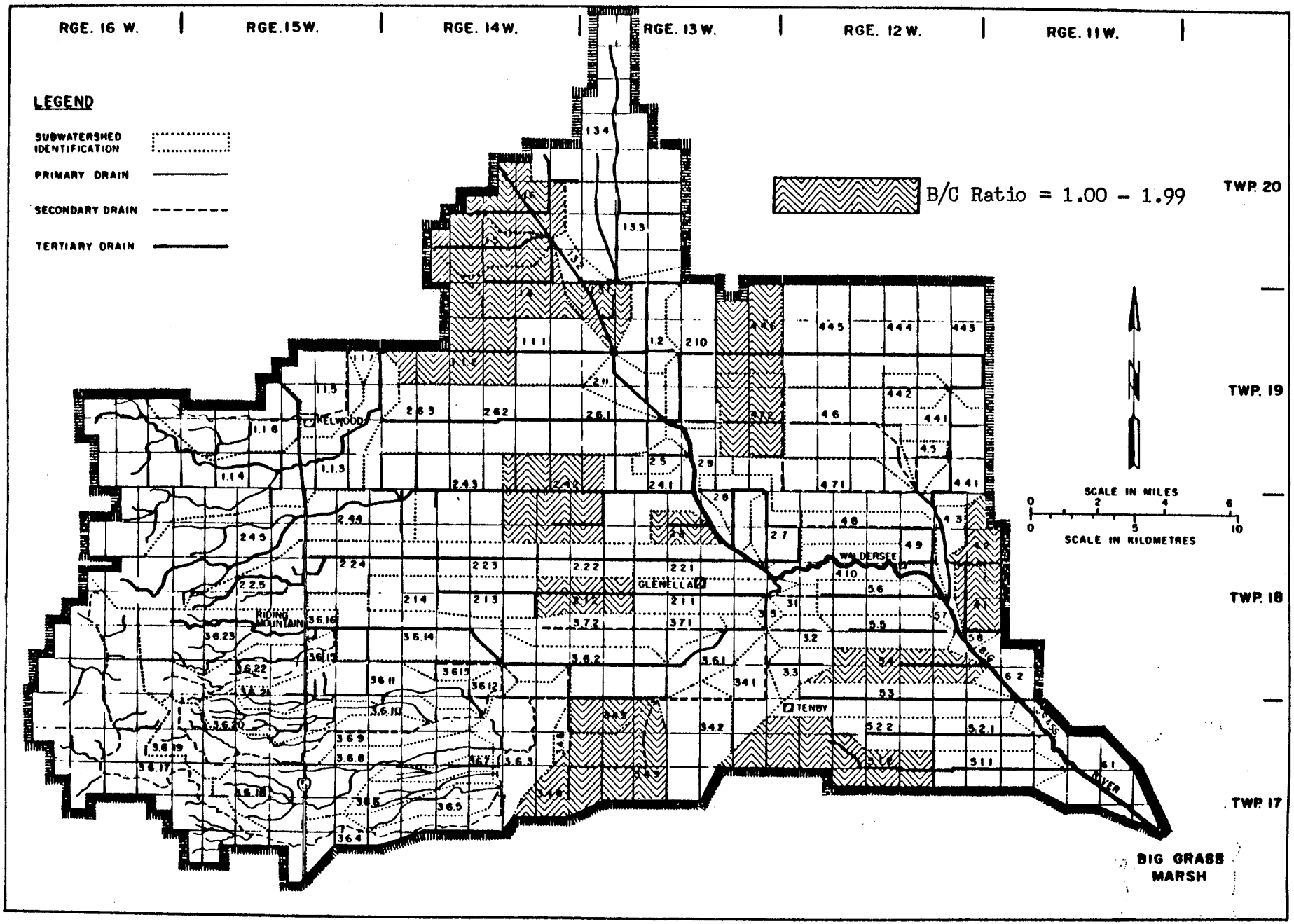
Map 10.3 - Subwatersheds With B/C Ratios from 0.81 to 0.99

ratios which were less than 2.0. There were 20 subwatersheds which were feasible and of these 17 had ratios in the range of 1.00 to 1.99. These accounted for 71 square miles or about 17 percent of the watershed (map10.4). The remaining three subwatersheds had ratios which ranged from 2.00 to 2.75 (Map10.5).

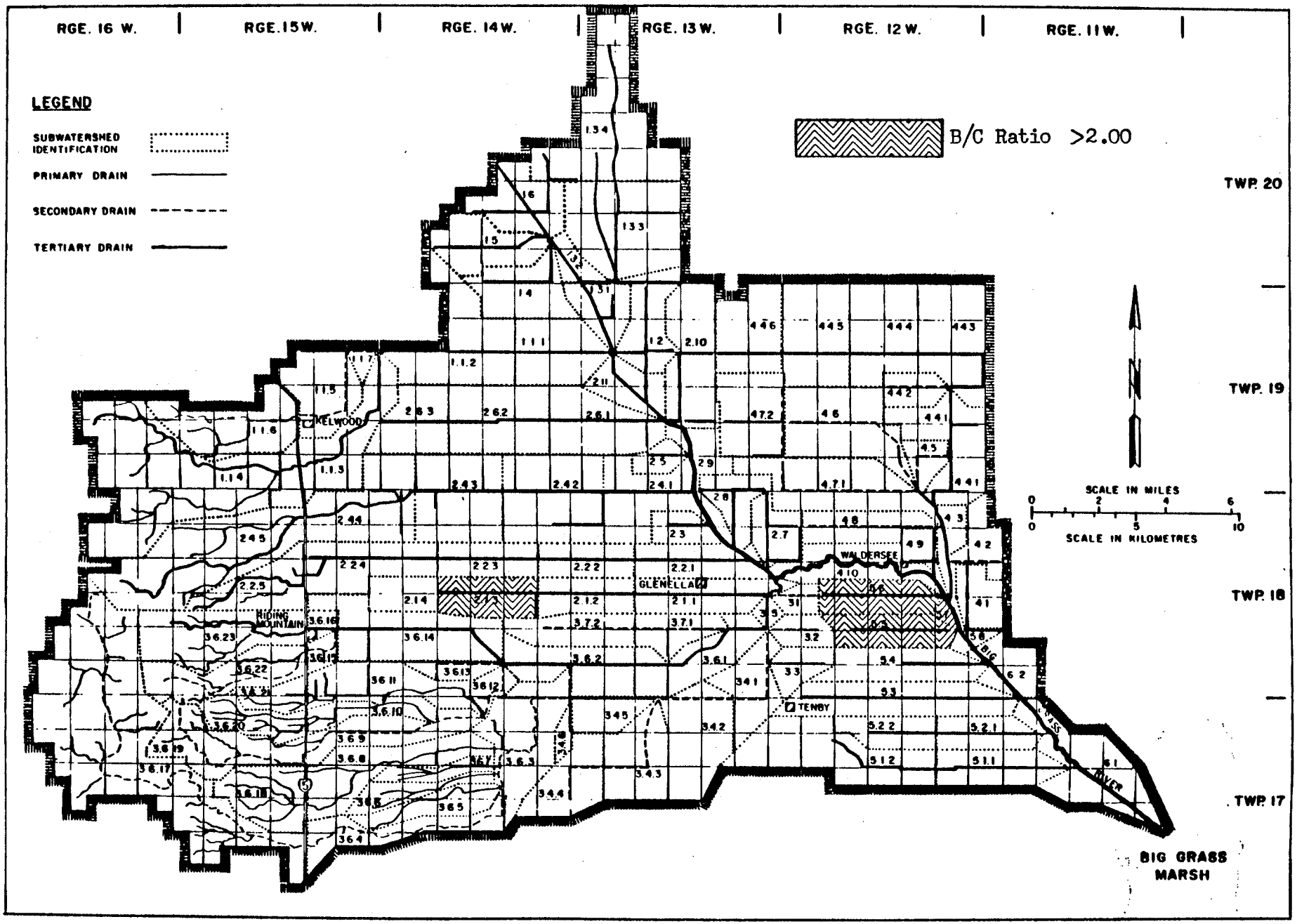
While these preliminary findings indicate that about 19 percent of the watershed (81 square miles) is feasible for drainage improvements this percentage is liable to change in either direction in the subsequent step of the analysis where subwatersheds are grouped before proceeding to optimize the level of drainage service.

OPTIMIZING THE LEVEL OF DRAINAGE DEVELOPMENT

The division of the watershed into small hydrologic units or subwatersheds was necessary in order to apply to the hydrologic model which estimates PE. After application of the PE submodel and the estimation of benefits and costs for these subwatershed units it was necessary to conduct the optimization of the level of drainage improvement by considering logical groups of subwatersheds. The optimization of drainage for a group of subwatersheds in a given location resulted in a uniform drainage design for a larger area than the individual subwatershed. From a practical viewpoint this essentially is to facilitate the actual reconstruction works. While the analysis at this stage optimized drain-



Map 10.4 - Subwatersheds With B/C Ratios from 1.00 to 1.99



Map 10.5- Subwatersheds With B/C Ratios from 2.00 to 2.75

age to uniform design level within a group, the level of optimum drainage design varied among groups depending on the characteristics of each group. Subwatershed groups are given in (Table 10.2) .

The preliminary benefit/cost analysis results were used to delineate areas where drainage works may be economically feasible. Thus the subwatersheds which were shown to be feasible provided the starting point for the formation of groups. Adjacent subwatersheds which were feasible were grouped together. These groups were expanded wherever necessary to include subwatersheds immediately downstream which were initially shown to be non-feasible because of large main channel costs and for which main channel reconstruction was necessary to accomodate the greater peak discharge from the improved upstream drainage areas. Map10.6 identifies the 13 groups of subwatersheds which were considered for further analysis. For the areas outside of these groups drainage improvement works were not feasible in the preliminary analysis and there exists no possibility for these to become feasible by grouping and reallocating of main channel costs. Of course, possible exceptions being the subwatersheds which are located downstream from the various groups for which channel improvements are required to facilitate improved upstream drainage. For these subwatersheds, given that the main channel is improved because of necessity, if the incremental costs for collection and on-farm drains are less than the associated benefits then the drainage in these areas should be improved to a level consistent with the main

Table 10.2

Subwatershed Grouping for Drainage Optimization

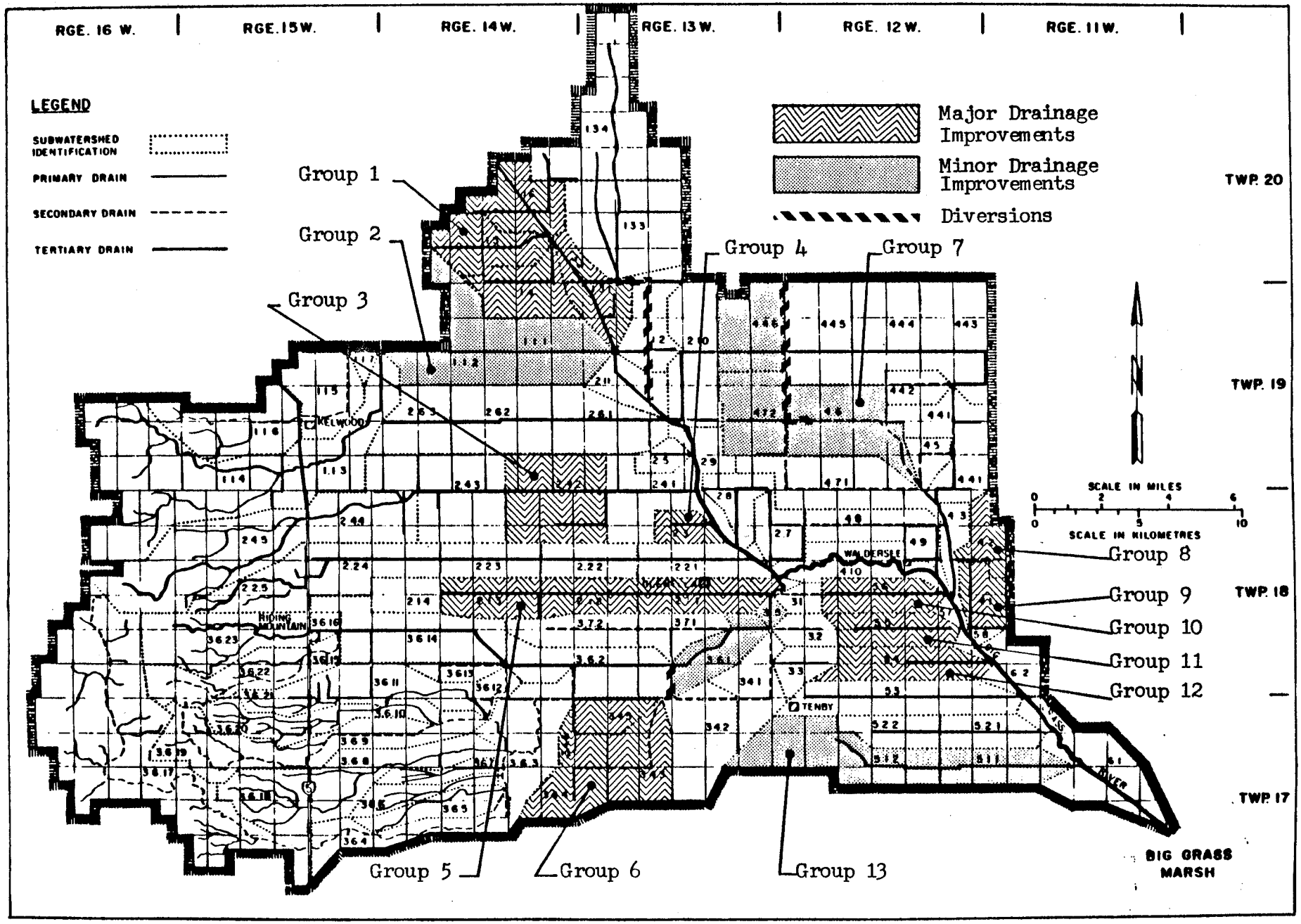
Group No.	Subwatersheds	Area of Group (mi^2)
1	1.04.00 1.05.00 1.06.00 1.03.02 1.03.01	18.36
2	1.01.02 1.01.01	10.26
3	2.04.02 2.04.01	7.36
4	2.03.00	1.75
5	2.01.03 2.01.02 2.01.01	10.52
6	3.04.04 3.04.03 3.04.05	10.86
7	4.04.06 4.07.02 4.06.00	16.31
8	4.02.00	1.89
9	4.01.00	2.29
10	5.06.00	3.40
11	5.05.00	3.60
12	5.04.00	4.30
13	5.01.02 5.01.01	11.09
Total		102

channel. It will be observed from Map10.6 that some groups consist of only one subwatershed. This resulted whenever it was not feasible to include other subwatersheds into the group.

Procedure for Optimizing Drainage

The optimum level of drainage service for an individual subwatershed can be determined from graphical analysis in which benefits and costs or marginal benefits and marginal costs are plotted against the corresponding channel outlet capacities. This procedure for determining optimum drainage with respect to discharge capacity, measured in cubic feet per second (cfs), cannot be used to determine optimum drainage for several subwatersheds since for a uniform level of drainage protection, drain capacity (cfs) varies with drainage area. Expressed differently, a given discharge capacity will provide different levels of protection in subwatersheds having different drainage areas.

Optimization of drainage for a group of subwatersheds can be accomplished by graphical analysis in which aggregate benefits and costs (or marginal benefits and costs) for the group are plotted against the runoff coefficient. The runoff coefficient is the drain design criterion which indicates a given level of protection. Accordingly, when drains in various subwatersheds are constructed to the standard of a given runoff coefficient or C - value the drains are compatible in terms of design and thus the corresponding benefits for each subwatershed can



Map 10.6 – Subwatershed Groups For Which Drainage Improvements Are Proposed

be aggregated to give the benefits for the entire group. Similar aggregation of costs gives group drainage costs. The optimum identifies the level of drainage protection or C – value at which net benefits are maximized. From the optimum drain design level the optimum capacities in cfs for each subwatershed can be estimated.

The drain design equation used for the Big Grass Watershed is:

$$Q = C A^{0.72}$$

where: Q = design discharge in cfs

C = runoff coefficient

A = drainage area in square miles.

The exponent 0.72 reflects the influence of basin characteristics on runoff.

In the discussion which follows the results of the optimization analysis for each subwatershed group are discussed.

Group 1 Subwatersheds

This group is comprised of five subwatersheds and has an area of 18.36 square miles. The drainage areas, outlet capacities and benefits and costs for each of these subwatersheds is given in Table10.3. It is not surprising that this group of subwatersheds is feasible for drainage improvement works since the soils are predominantly clay loams and clays and there is no large upstream drainage area. This group is comprised of about 64 percent clay loam soils, 29 percent clays and six

Table 10.3

Benefit-Cost Results for Group 1 Subwatersheds at the Optimum

Subwatersheds: 1.04.00, 1.05.00, 1.06.00, 1.03.02, 1.03.01

Optimum: C = 34

Benefits = $992,000

Cost = $666,000

Drainage	=	$646,000
Diversion	=	20,000
		$666,000

B/C ratio = 1.49

Net Benefit = $326,000

SWS	D.A. ($Mi.^2$)	A ($Mi.^2$)	Outlet Exist C	Outlet Optimum Q (cfs)	B	C	Net. Ben
1.04.00	5.11	5.11	7.72	110	$277,000	$135,000	$142,000
1.05.00	3.88	3.88	9.42	90	178,000	123,000	55,000
1.06.00	14.23	5.24	4.43	230	422,000	230,000	192,000
1.03.02	15.56*	1.41	8.28	246	52,000	102,000	- 50,000
1.03.01	18.36*	2.69	15.99	276	63,000	56,000	7,000
Diversion						20,000	
Total		18.36			$992,000	$666,000	$346,000

* Excludes the area for SWS 1.03.04 and 1.03.03 which are diverted through 1.02.00

percent loams. Largest benefits per unit-hour reduction in PE are associated with the clays while the clay loam soils are associated with the next highest benefits. In areas having these soils the tendency is for benefits to be large relative to areas where a higher proportion of loams are found or where there are no clay soils. Drainage feasibility in these subwatersheds is also influenced by the fact that main channel reconstruction is less than for subwatersheds in which the main channels serve a large drainage area.

It will be observed that the current level of drainage design is not uniform for the various subwatersheds. The C - value ranges from 4.42 to 15.99 reflecting poor to fair drainage protection. Geographical analysis of benefits and costs which is given in Figure 10.1 indicates an optimum drain design level of C equal to 34.

Under the current drainage pattern subwatersheds 1.03.04 and 1.03.03 discharge through the outlet area of subwatershed 1.03.02 and then through 1.03.01. Given this drainage area the cost of main channel improvement in 1.03.02 and 1.03.01 is relatively high. Diversion of the runoff from subwatersheds 1.03.04 and 1.03.03 through subwatersheds 1.02.00 and then to the Angle Drain reduces main channel improvement costs in 1.03.02 and 1.03.01. The cost of this diversion is estimated at $20,000. This modification of the drainage pattern results in an improvement in overall net benefit for Group one.

The benefit and costs for Group one subwatersheds at the op-

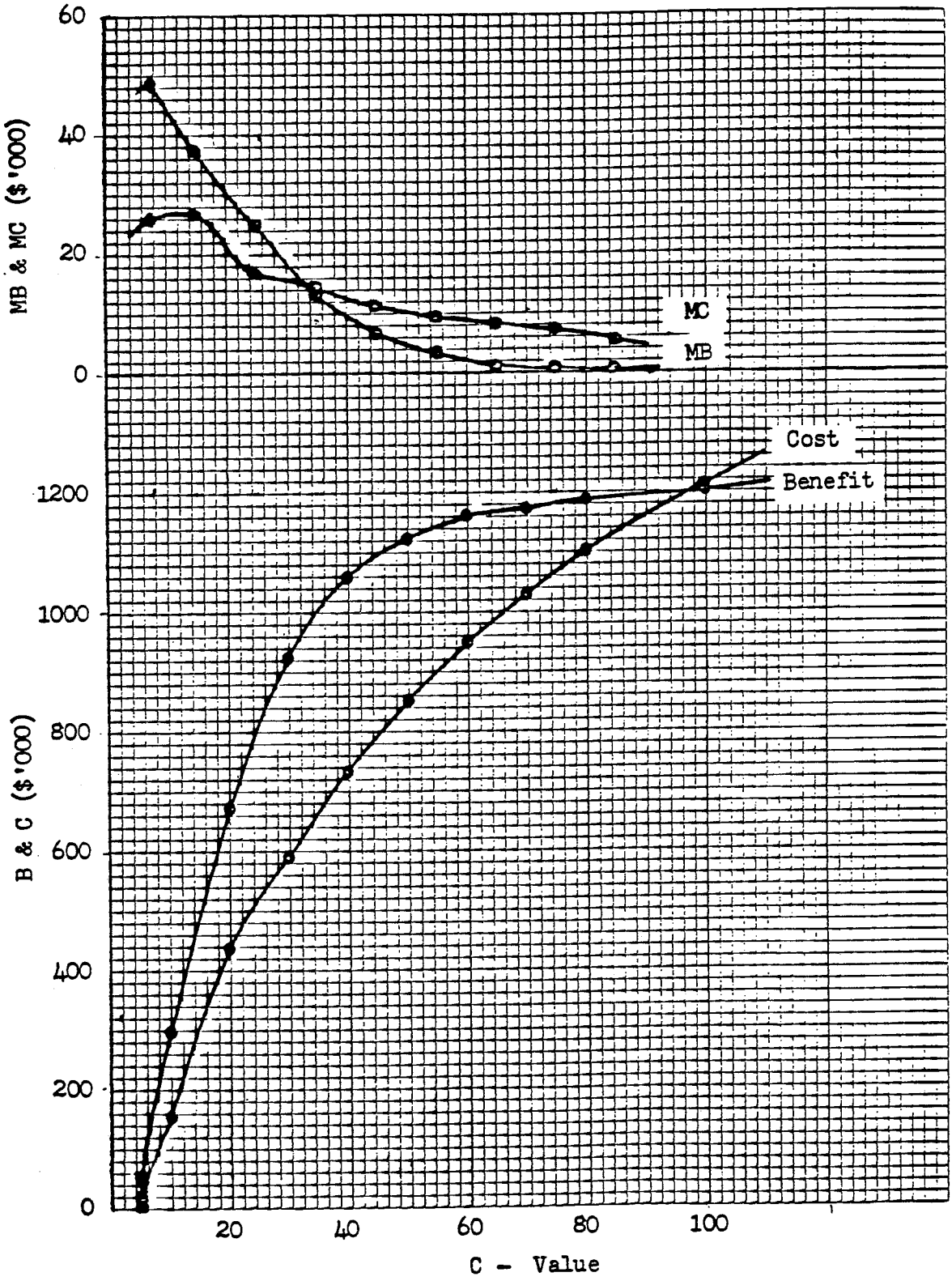


Figure 10.1

Benefit-Cost Relationships for Group 1 Subwatersheds

timum drainage design are approximately $1.0 million and $0.7 million, respectively (Table10.3). It should be noted that benefits and costs referred to in the discussion of the results are present values of discounted benefits and costs unless otherwise indicated. The net benefit is $326,000 and the benefit/cost ratio is 1.49.

Group 2 Subwatersheds

Unlike the Group one area, the main drainage channel flowing through the Group two subwatersheds serves a drainage area of about 40 square miles. Thus the cost of main channel improvements for this group is relatively high for the various designs considered. The greatest costs are incurred for structures which includes the replacement of a railway bridge in subwatershed 1.01.01 which costs approximately $90,000. Structure costs in these subwatersheds account for over 50 percent of the total costs.

All the soils in 1.01.01 are clay loams whereas in 1.01.02 about 67 percent is clay loans and 28 percent loam.

The optimum drainage design for Group two subwatersheds is at a runoff coefficient (C) value of 9.50, as shown in Figure 10.2. This is a relatively low level of drain protection indicating very nominal improvements. The results of the preliminary analysis had shown subwatershed 1.01.01 to be non-feasible. From Table10.4 it will be observed that the current level of protection is much lower in 1.01.02 than 1.01.01. The improvements to an optimum design of 9.50 for the

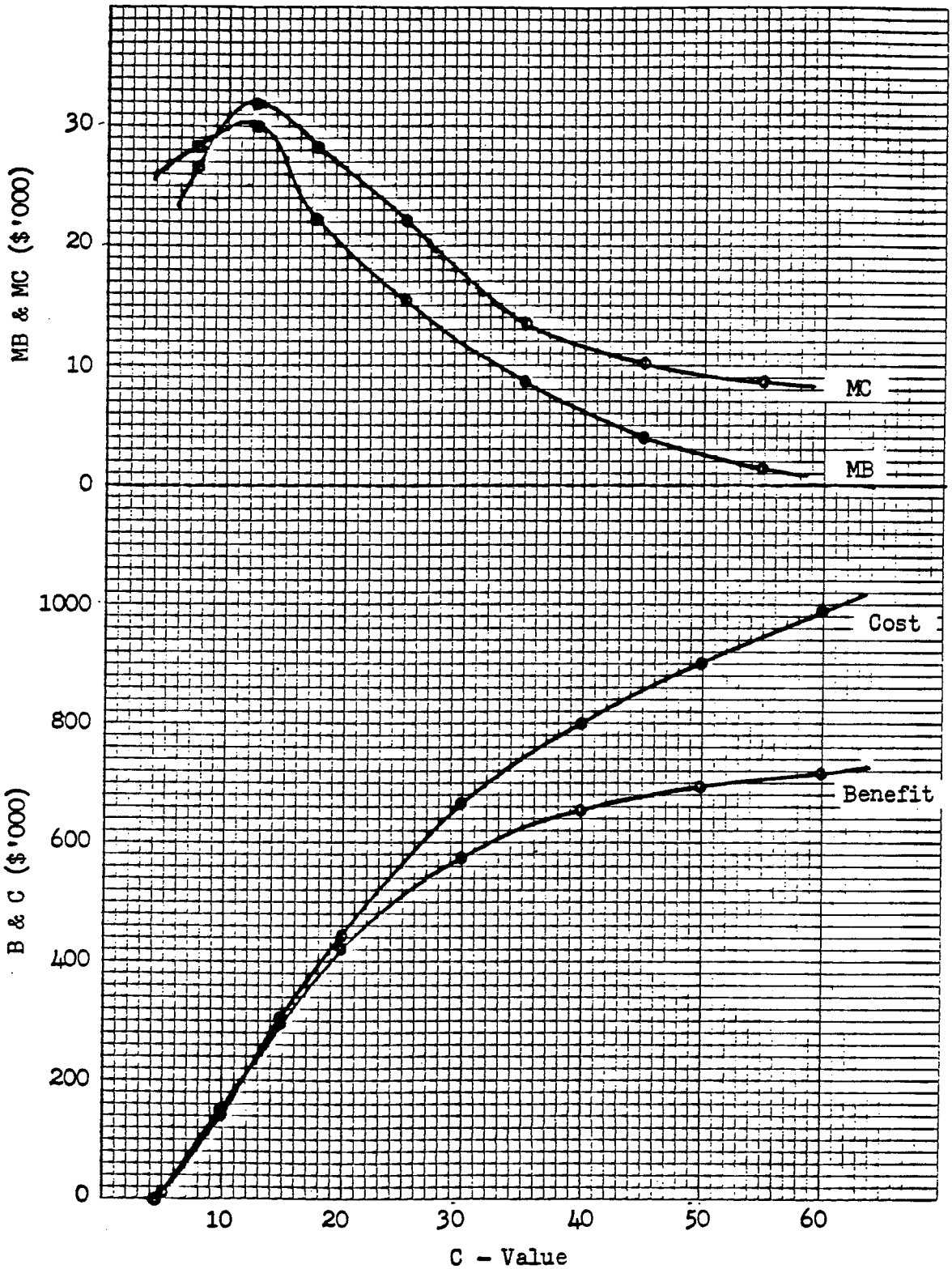


Figure 10.2

Benefit-Cost Relationships for Group 2 Subwatersheds

Table 10.4

Benefit-Cost Results for Group 2 Subwatersheds at the Optimum

Subwatersheds: 1.01.02, 1.01.01

Optimum: C = 9.50
Benefits = $130,000
Costs = 124,000
Net Benefit = 6,000
B/C ratio = 1.05

SWS	D.A. ($Mi.^2$)	A ($Mi.^2$)	Outlet		B	C	Net. Ben
			Exist C	Optimum Q (cfs)			
1.01.02	35.7	5.33	4.42	125	$ 80,000	$ 62,000	$ 18,000
1.01.01	40.6	4.93	7.09	136	50,000	62,000	-12,000
TOTAL		10.26			$130,000	$124,000	$ 6,000

runoff coeffient primarily results in the improvement of 1.01.02 to utilize the relatively higher level of protection in subwatershed 1.01.01.

At the optimum the benefit/cost ratio for drainage development in Group two is 1.05 with a net benefit of $6,000. The net benefit for improvements in 1.01.02 is $18,000 whereas there is a disbenefit of $12,000 in 1.01.01. This can properly be allocated to 1.01.02 as the cost of downstream channel improvements. The benefit for group 2 at the optimum is $130,000 and the costs are $124,000.

Group 3 Subwatersheds

Group 3 is comprised of subwatersheds 2.04.02 and 2.04.01. The latter was not feasible for further drainage works in the preliminary analysis but was included here to examine feasibility after downstream main channel drainage costs were reallocated. The soil in these subwatersheds are predominantly clay loams (over 90 percent).

The existing level of drainage protection is much higher in 2.04.01 (C = 19.05) then in 2.04.02 which is at a C - Value of 7.56.

Substantial improvements of drainage can be made in subwatershed 2.04.02 (to a C - Value of 19.05) without any corresponding improvements being required for the main channel in 2.04.01.

Optimization of drainage in group 3 resulted in an optimum level of protection corresponding to a C - Value of 19.05 (Table 10.5 and Figure 10.3). Thus no changes are proposed for 2.04.01 whereas 2.04.02 is improved from C - Value of 7.56 to C - Value of 19.05. The benefit/

Table 10.5

Benefit–Cost Results for Group 3 Subwatersheds at the Optimum

Subwatersheds: 2.04.01, 2.04.02

Optimum: C = 19.05
Benefits = $273,000
Costs = 200,000
Net Benefits = 73,000
B/C ratio = 1.37

SWS	D.A. ($Mi.^2$)	A ($Mi.^2$)	Outlet		B	C	Net. Ben
			Exist C	Optimum Q (cfs)			
2.04.02	30.74	7.36	7.56	230	$273,000	$200,000	$ 73,000
2.04.01	35.9	5.16	19.05	251	0	0	0
TOTAL					$273,000	$200,000	$ 73,000

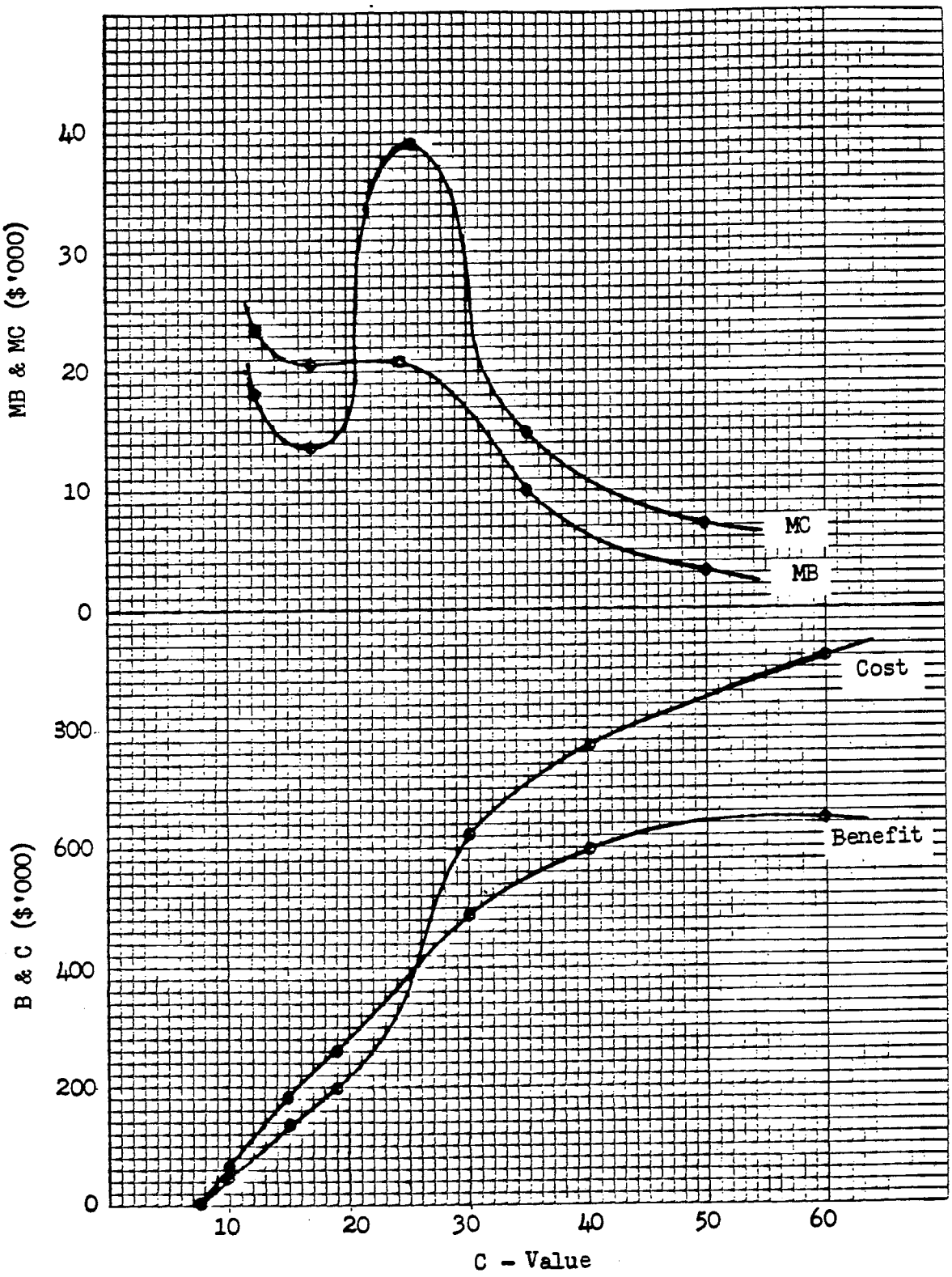


Figure 10.3

Benefit-Cost Relationships for Group 3 Subwatersheds

cost ratio at the optimum is 1.37 with a net benefit of $73,000. Total benefits amount to $273,000 whereas costs are $200,000.

Group 4 Subwatershed

This group consists of only one subwatershed, 2.03.00, having a drainage area of only 1.75 square miles. Because there is no upstream runoff flowing through 2.03.00 main channel costs are relatively lower than for areas where channels must be constructed to accommodate upstream discharge. Currently, the drainage design level is at C - Value of 16.71. Relatively low costs together with the fact that all the soils in 2.03.00 are clay loams resulted in a high level of drainage protection at the optimum. The graphical analysis of benefits and costs shown in Fig.10.4 gives an optimum design capacity of 75 cfs which corresponds a C - coefficient value of 50. The benefit/cost ratio (Table 10.6) at the optimum is 1.23 with benefits of $43,000 and costs of $35,000.

Group 5 Subwatersheds

This group of subwatersheds form a linear drainage area which starts at the foot of the escarpment. The drainage area is comprised of subwatersheds 2.01.04, 2.01.03, 2.01.02 and 2.01.01. Because of adequacy of natural drainage the most upstream of these subwatersheds, 2.01.04, was not included in group 5 for proposed drainage improvements.

The current level of drainage protection in subwatersheds 2.01.03 and 2.01.01 is rather low (Table 10.7). The drainage survey

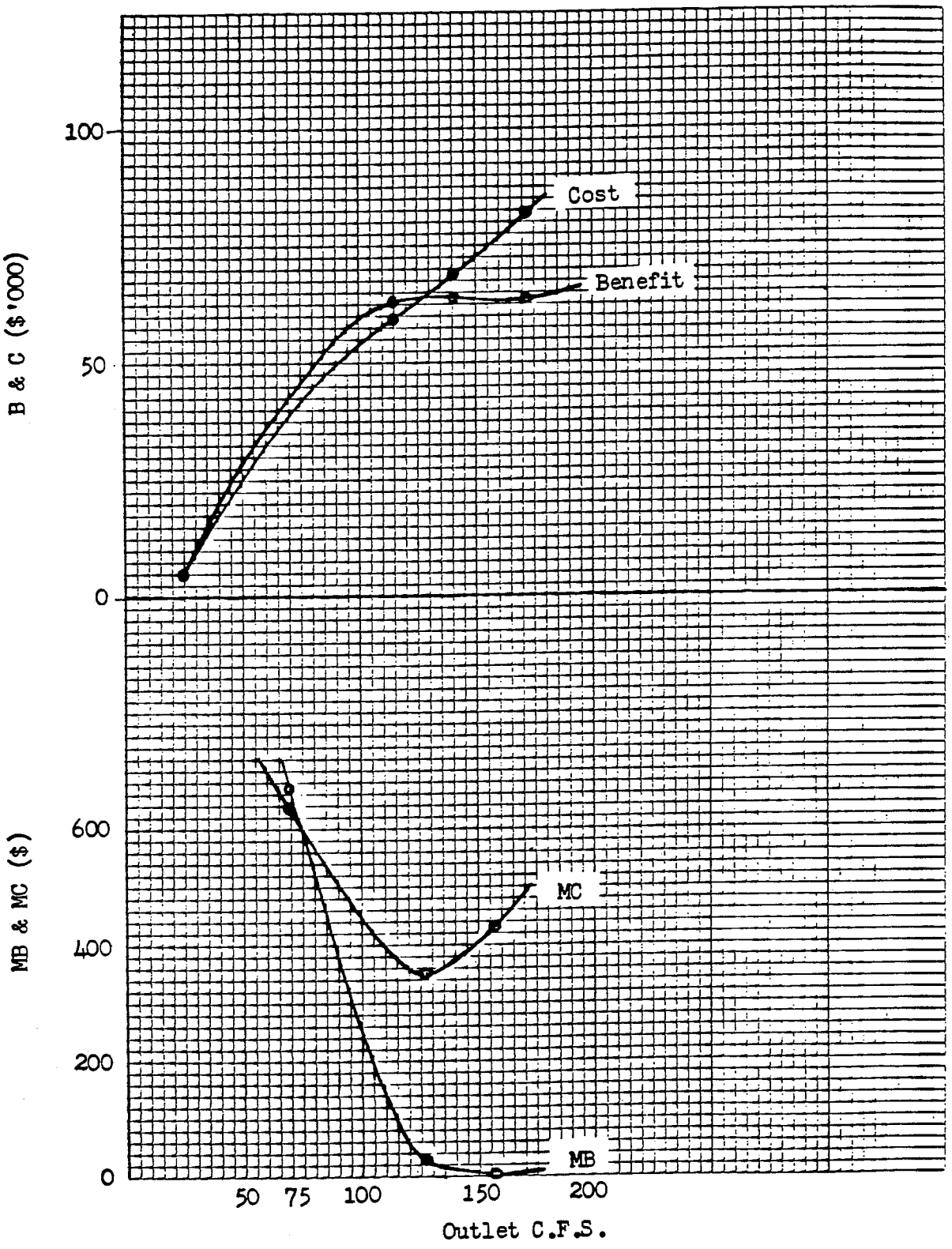


Figure 10.4

Benefit-Cost Relationships for Group 4 Subwatershed

Table 10.6

Benefit-Cost Results for Group 4 Subwatershed at the Optimum

Subwatershed: 2.03.00

Optimum: C = 50
Benefits = $43,000
Costs = 35,000
Net Benefit = 8,000
B/C ratio = 1.23

A = 1.75 mi^2
Outlet: Exist. C = 16.71
Optimum Q = 75 cfs

Table 10.7

Benefit–Cost Results for Group 5 Subwatersheds at the Optimum

Subwatersheds: 2.01.03, 2.01.02, 2.01.01

Optimum: C = 19.0
Benefits = $369,000
Costs = 257,000
Net Benefit = 112,000
B/C ratio = 1.44

SWS	D.A. (Mi.^{2})	A (Mi.^{2})	Outlet		B	C	Net. Ben
			Exist C	Optimum Q (cfs)			
2.01.03	5.34	3.34	2.10	63	$178,000	$ 30,000	$148,000
2.01.02	8.43	3.09	11.42	88	41,000	15,000	26,000
2.01 .01	12.52	4.09	1.13	117	150,000	212,000	-62,000
TOTAL		10.52			$369,000	$257,000	$112,000

data indicated that discharge capacities in these subwatersheds are constrained by the existing channel structures (culverts). Replacements of these structures with ones which provide capacities comparable with the existing channel will result in a significant improvement in drainage protection at a relatively small cost. As a result, although about 24 percent of the soils are sands (and one percent clay, 75 clay loam) drainage improvement was found feasible for this group of subwatersheds.

The graphs in Figure10.5 show an optimum design at a runoff coefficient value of 19.0. Table 10.7 indicates that the largest net benefit ($148,000) accrues in subwatershed 2.01.03. The disbenefit of $62,000 for subwatershed 2.01.01 results from the high costs $212,000). A large proportion of this is for the main channel, which includes an $80,000 structure cost for replacement of a railway bridge. These costs must be reallocated to the upstream subwatershed in a manner which will result in a uniform design level at the optimum. The benefit/cost ratio at the optimum is 1.44 with a net benefit of $112,000. Total cost is $257,000 and total benefit is $369,000.

Group 6 Subwatershed

The subwatersheds included here are 3.04.04, 3.04.03 and 3.04.05. These subwatersheds have predominantly clay loam soils which comprise about 80 percent of the area. Loams account for 15 percent and sands five percent of group 6.

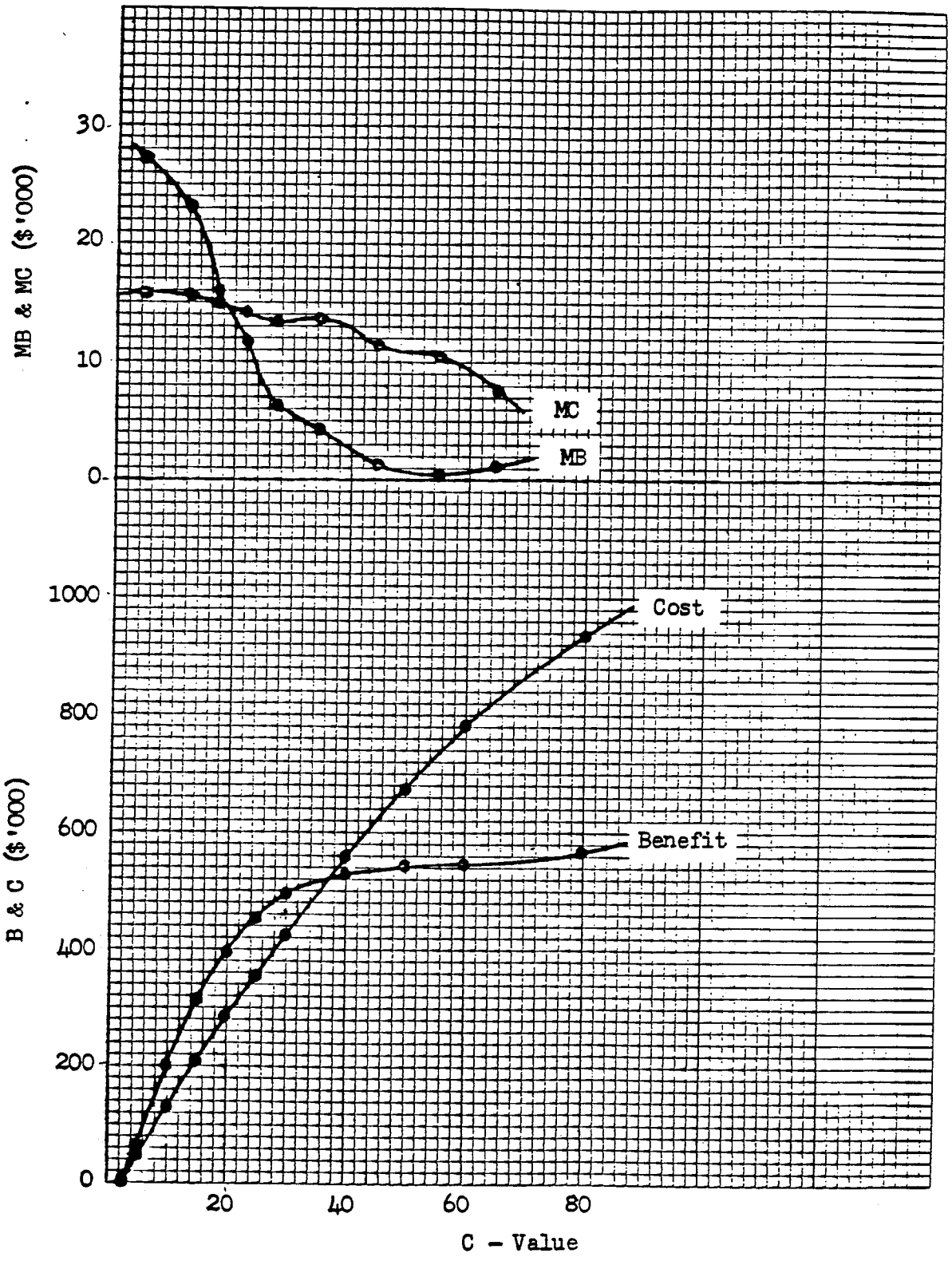


Figure 10.5

Benefit-Cost Relationships for Group 5 Subwatersheds

The optimum drainage design for this group is at a runoff coefficient value of 23.5 (Figure 10.6). The benefit/cost ratio at the optimum is 1.34 with total benefits of $247,000, total costs equalling $185,000 and therefore net benefits of $62,000 as given in the Table 10.8.

Group 7 Subwatersheds

The preliminary analysis of benefits and costs for individual subwatersheds showed that net benefits can be expected from drainage improvements in 4.04.06 and 4.07.02. Further analysis of drainage development in these subwatersheds after the inclusion of downstream costs for routing discharge from these areas which can be improved showed that the additional costs which will be incurred exceeds the net benefits.

The existing drainage pattern from subwatershed 4.04.06 is eastward through 4.04.05, 4.04.04, 4.04.03 and then south. The main channel modifications following this route which were made necessary by improvements in 4.04.06 were in excess of the net benefits. Subwatershed 4.07.02 follows a different drainage route. The drains flow south and east through 4.07.01. The necessary modifications in the latter greatly exceeded the benefits to be derived from improvements in 4.07.02.

Further study of the problem revealed the possibility of reducing the required downstream costs by changing the existing drainage pattern. Diversion of discharge from 4.04.06 south through 4.07.02 and then east through 4.06.00 resulted in a much lower aggregate downstream

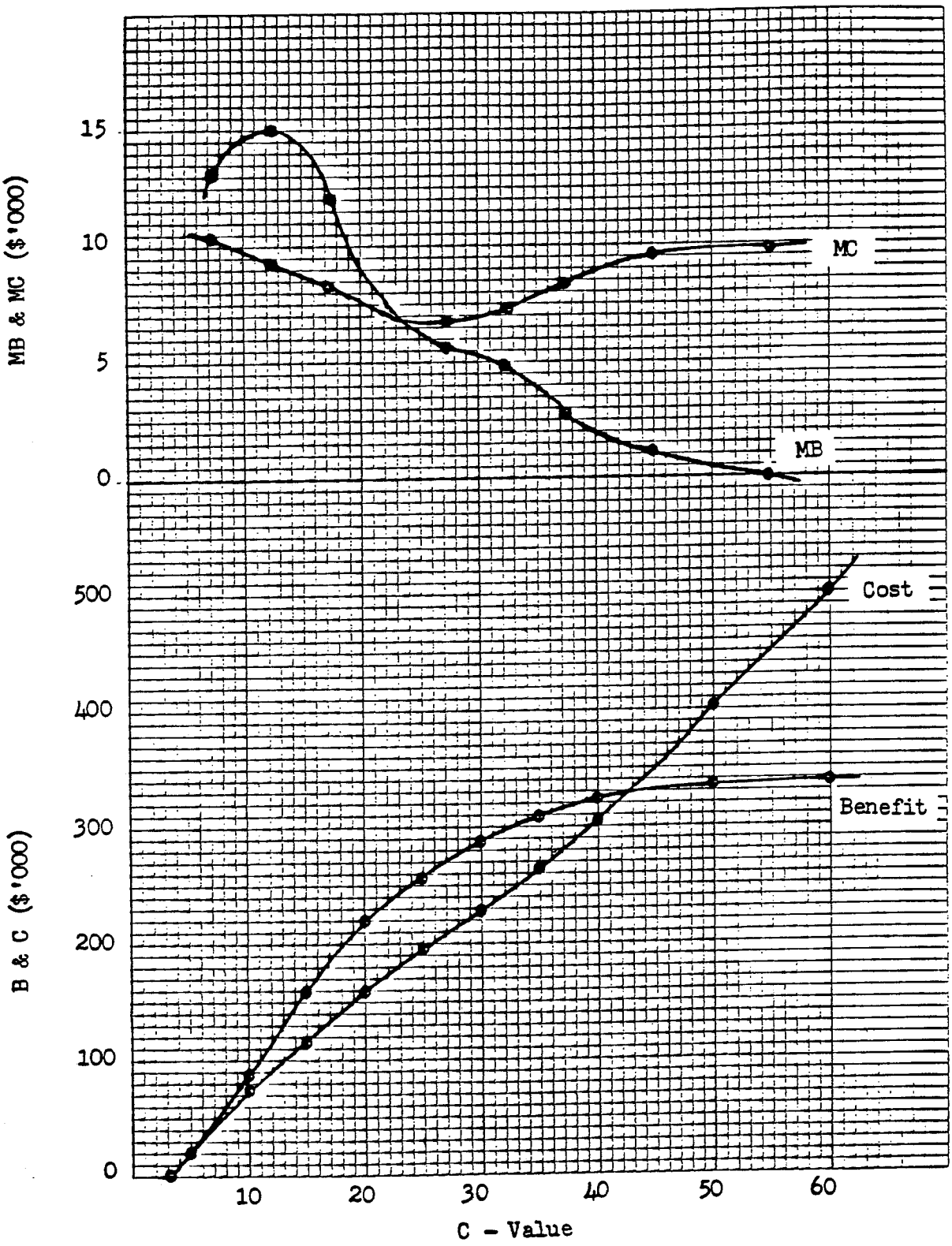


Figure 10.6

Benefit-Cost Relationships for Group 6 Subwatersheds

Table 10.8

Benefit-Cost Results for Group 6 Subwatersheds at the Optimum

Subwatersheds: 3.04.04, 3.04.03, 3.04.05

Optimum: C = 23.5
Benefits = $247,000
Costs = 185,000
Net Benefit = 62,000
B/C ratio = 1.34

SWS	A (Mi.2)	DA (Mi.2)	Outlet Exist C	Outlet Optimum Q (cfs)	B	C	Net. Ben
3.04.04	4.14	4.14	7.19	65	$ 50,000	$ 26,000	$ 24,000
3.04.03	4.70	8.84	3.54	113	162,000	142,000	20,000
3.04.05	2.02	2.02	12.05	39	35,000	17,000	18,000
TOTAL					$247,000	$185,000	$ 62,000

channel improvement cost for subwatersheds 4.04.06 and 4.07.02. Because main channel improvements were necessary in 4.06.00, net benefits were increased by including 4.06.00 in this group of subwatersheds for optimization. For this group of subwatersheds about 71 percent of the soils are clay loams, 25 percent are loams and four percent are sands.

The optimum level of drainage development identified in Figure 10.7 is at a C - Value of 10.0. This corresponds to minor improvements in the drainage. The benefit/cost ratio is 1.04 and net benefits are only $10,000. Total cost of drainage development is $245,000 and total benefits are $255,000 (Table10.9). The largest net benefits are expected from subwatershed 4.04.06. Largest costs are for 4.06.00, equalling $140,000.

Group 8 Subwatershed

Subwatershed 4.02.00 could not be conveniently grouped with other subwatersheds for drainage optimization and reconstruction and thus was the only subwatershed in this group. It discharges directly into a main channel and seems to form a relatively separate drainage entity. Its drainage area is only 1,089 square miles and the soils are clay loams.

At the optimum drainage design, which is determined from Figure 10.8 the cost of drainage improvement is $27,000 and this is expected to induce a benefit to agriculture of $42,000. The net benefit is $15,000 and the benefit/cost ratio is 1.56. The optimum drain design level for this group is at a value of 29.29 for the runoff coefficient. This corresponds to a discharge capacity of 40 c.f.s. at the outlet of 4.02.00.

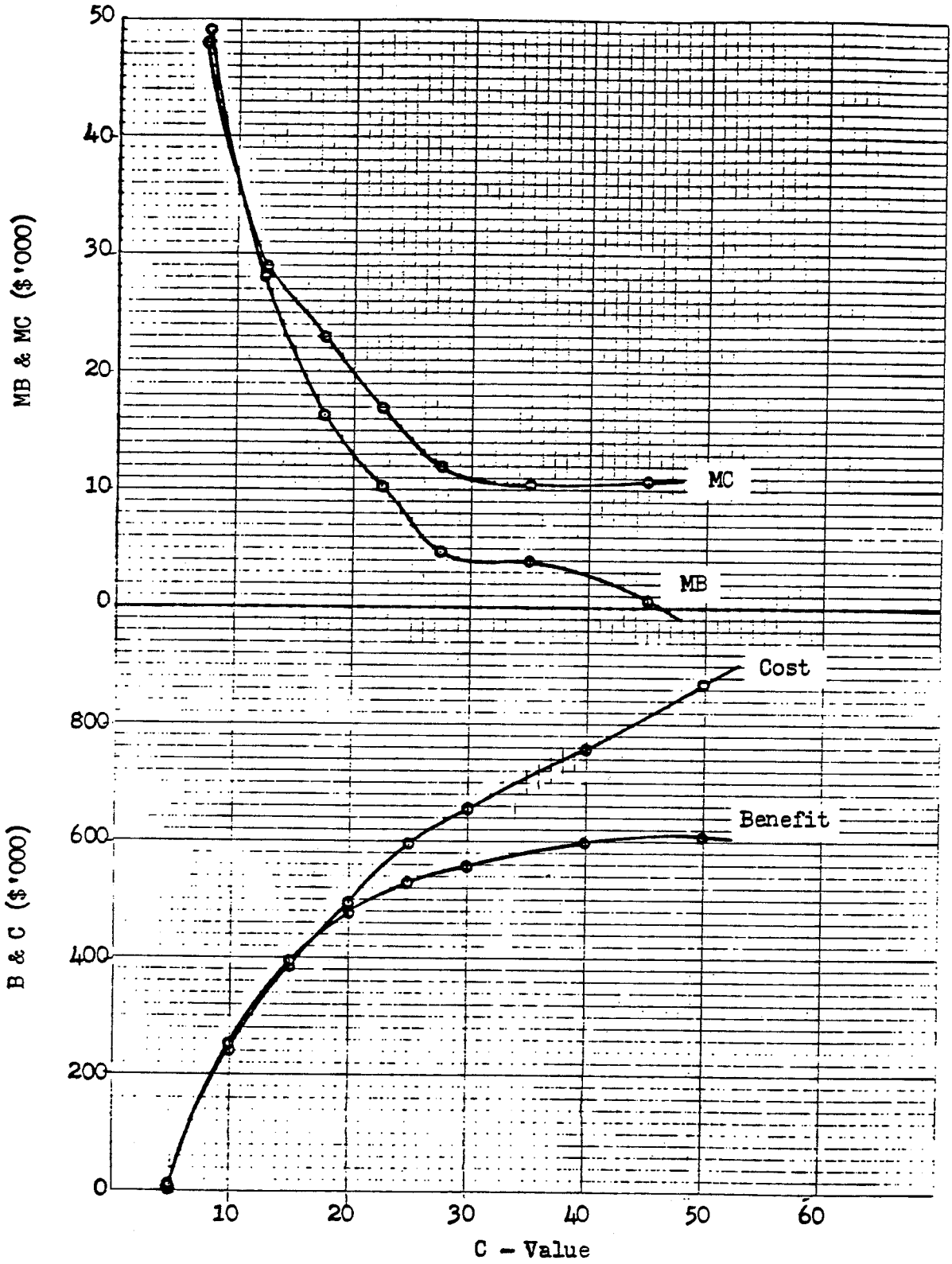


Figure 10.7

Benefit–Cost Relationship for Group 7 Subwatersheds

Table 10.9

Benefit-Cost Results for Group 7 Subwatersheds at the Optimum

Subwatersheds: 4.04.06, 4.07.02, 4.06.00

Optimum:

C	= 10.0
Benefits	= $255,000
Costs	= 245,000
Net Benefits	= 10,000
B/C ratio	= 1.04

SWS	D.A. ($Mi.^2$)	A ($Mi.^2$)	Outlet Exist C	Outlet Optimum Q (cfs)	B	C	Net. Ben
4.04.06	4.50	4.50	4.74	30	$ 95,000	$ 43,000	$ 52,000
4.07.02	9.27	4.77	6.84	50	58,000	62,000	- 4,000
4.06.00	16.31	7.04	5.36	75	102,000	140,000	-38,000
TOTAL					$ 255,000	$ 245,000	$ 10,000

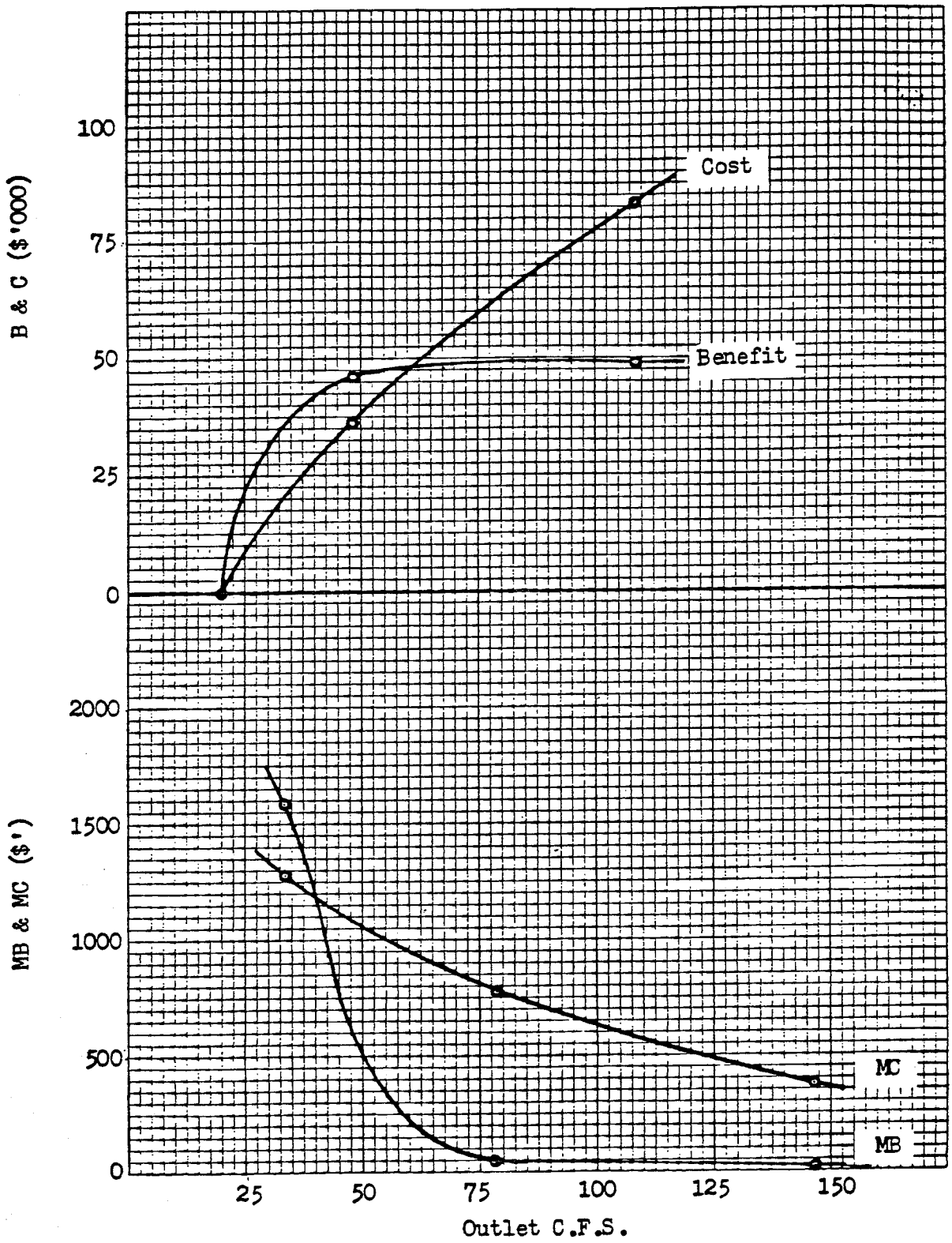


Figure 10.8

Benefit/Cost Relationships for Group 8 Subwatershed

Table 10.10

Benefit-Cost Results for Group 8 Subwatershed at the Optimum

Subwatershed: 4.02.00

Optimum: C = 25.29
Benefits = $42,000
Costs = $27,000
Net Benefit = 15,000
B/C ratio = 1.56

Area = 1.89 mi^2
Outlet: Exist. C = 12.65
Optimum Q = 40 cfs

Group 9 Subwatershed

For reasons similar to those discussed for Group 8, subwatershed 4.01.00 is the only subwatershed which is included in Group 9. This subwatershed discharges directly into the Big Grass River. It has a drainage area of 2.29 square miles and the soils are all clay loams. The optimum design discharge is identified in Figure10.9 as 57 c.f.s. at the outlet. This corresponds to a C-value of 31.39. Table 10.11 gives the benefits and costs at the optimum as $52,000 and $34,000, respectively. The benefit/cost ratio is 1.53.

Group 10 Subwatershed

Groups 10, 11 and 12 each contains only one subwatershed for the same reasons cited in the discussion of the previous two groups. These subwatersheds form linear drainage areas discharging into the Grass River. The soil composition is similar for Groups 11 and 12, comprising of clay loams which account for about two-thirds of the area and loams which comprise the remainder of the soils. However, for Group 10 clay loams comprise a higher proportion of the soils - approximately 86 percent. It is interesting to note that existing level of drainage protection is fairly uniform for these three subwatershed groups. The existing runoff coefficient values are 7.87, 7.55 and 6.65 for Groups 10, 11 and 12, respectively.

The optimum drainage improvement level for Group 10 (which consists of subwatershed 5.06.00) is at a design discharge of 68 c.f.s. or a C-value of 28.17, as shown in Figure10.10. The benefits expected at this optimum is $80,000 (Table10.12) and the cost incurred in providing optimum drainage is $36,000. Thus net benefits are $44,000 and the benefit/cost ratio is 2.22.

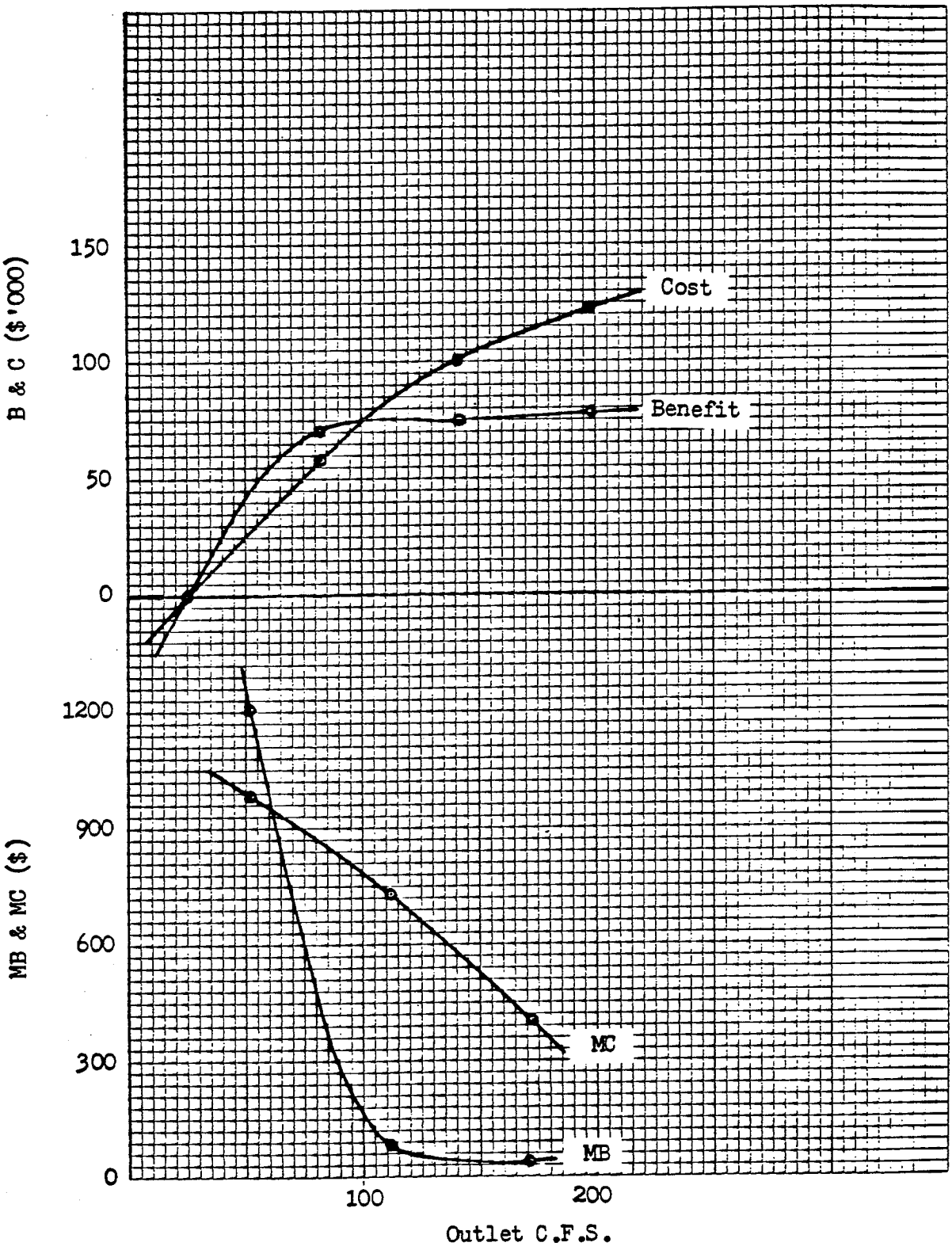


Figure 10.9

Benefit-Cost Relationships for Group 9 Subwatershed

Table 10.11

Benefit-Cost Results for Group 9 Subwatershed at the Optimum

Subwatershed: 4.01.00

Optimum: C = 31.39
Benefits = $52,000
Costs = 34,000
Net Benefit = 18,000
B/C ratio = 1.53

Area: 2.29 mi^2
Outlet: Exist. C = 13.76 (25 cfs)
Optimum Q = 57 cfs

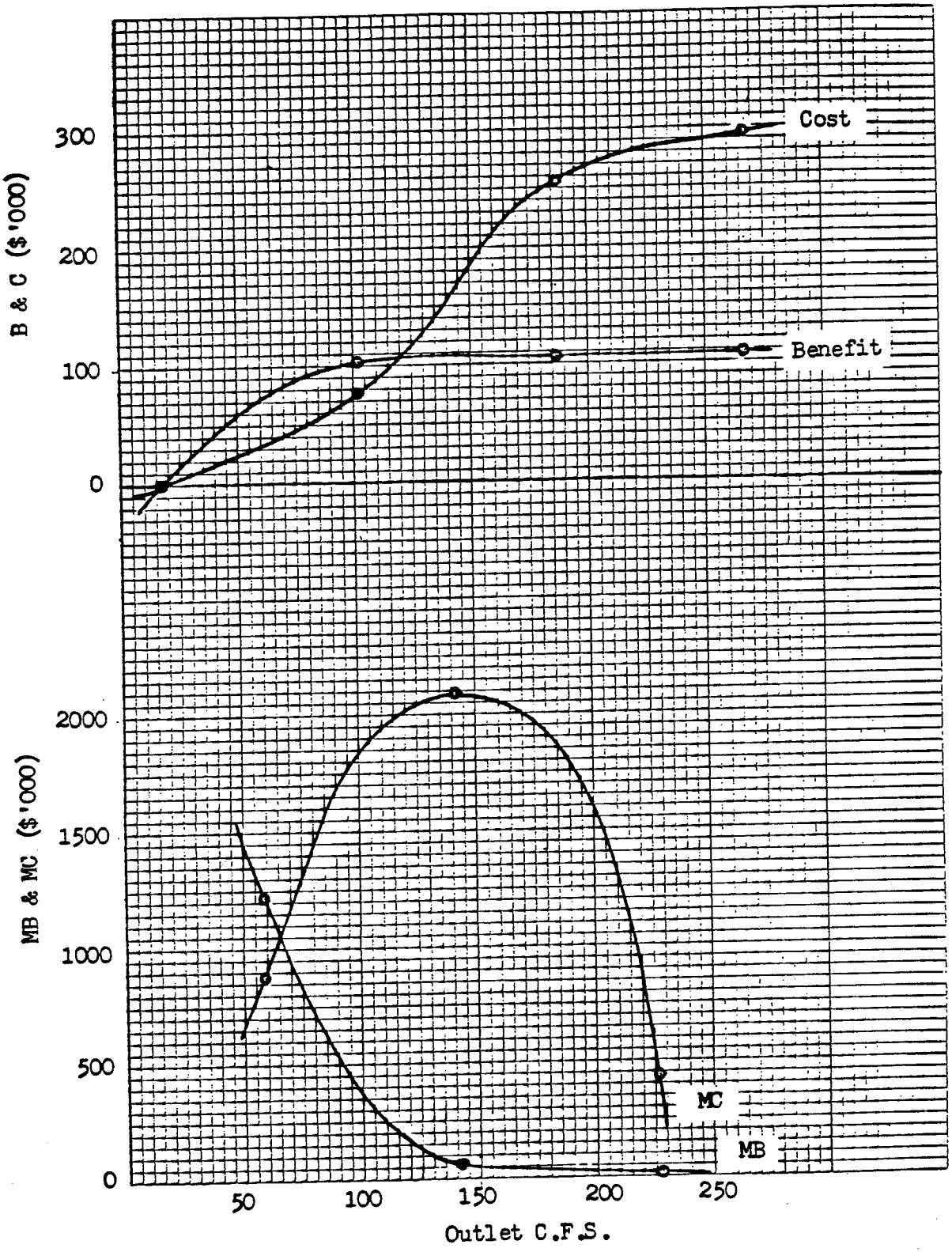


Figure 10.10

Benefit-Cost Relationships for Group 10 Subwatershed

Table 10.12

Benefit-Cost Results for Group 10 Subwatershed at the Optimum

Subwatershed 5.06.00

Optimum:	C	= 28.17
	Benefits	= $80,000
	Costs	= 36,000
	Net Benefit	= 44,000
	B/C ratio	= 2.22

Area: = 3.4 mi^2

Outlet: Exist. C = 7.87 (19 cfs)

Optimum Q = 68 cfs

The optimum drain design for Group 10 subwatershed is much higher than those identified for Groups 11 and 12. This primarily reflects the higher proportion of clay loam soils in Group 10 which responds better, in terms of improved agricultural productivity, to better drainage than loams.

Group 11 Subwatershed

Figure10.11 identifies the optimum level of drainage development for this group (subwatershed 5.05.00) as 52 c.f.s. at the outlet or a runoff coefficient value of 20.67. The drainage development costs for such an improvement is $31,000 (Table10.13) and the expected benefits are $81,000. Thus net benefits are $50,000 and the benefit/cost ratio at the optimum drainage design is 2.61.

Group 12 Subwatershed

Group 12 is comprised of subwatershed 5.04.00. At its optimum design of 63 c.f.s. at the outlet which is determined from Figure10.12 the expected benefits from drainage improvement to this level is $77,000. Drains are estimated to cost about $47,000. Thus at the optimum design of C-value 22.0 net benefits are $30,000 and the benefit/cost ratio is 1.64 for this group (Table10.14).

Group 13 Subwatersheds

The preliminary analysis showed that drainage improvement works was only feasible for one of the two subwatersheds in this group - subwatershed 5.01.02. Further examination of the basic information pertaining to both these subwatersheds, 5.01.01 and 5.01.02, reveal similarities in soils and existing level of drainage protection. The existing designs have c-values of 6.97 and 8.14 for 5.01.02 and 5.01.01, respectively. Both subwatersheds

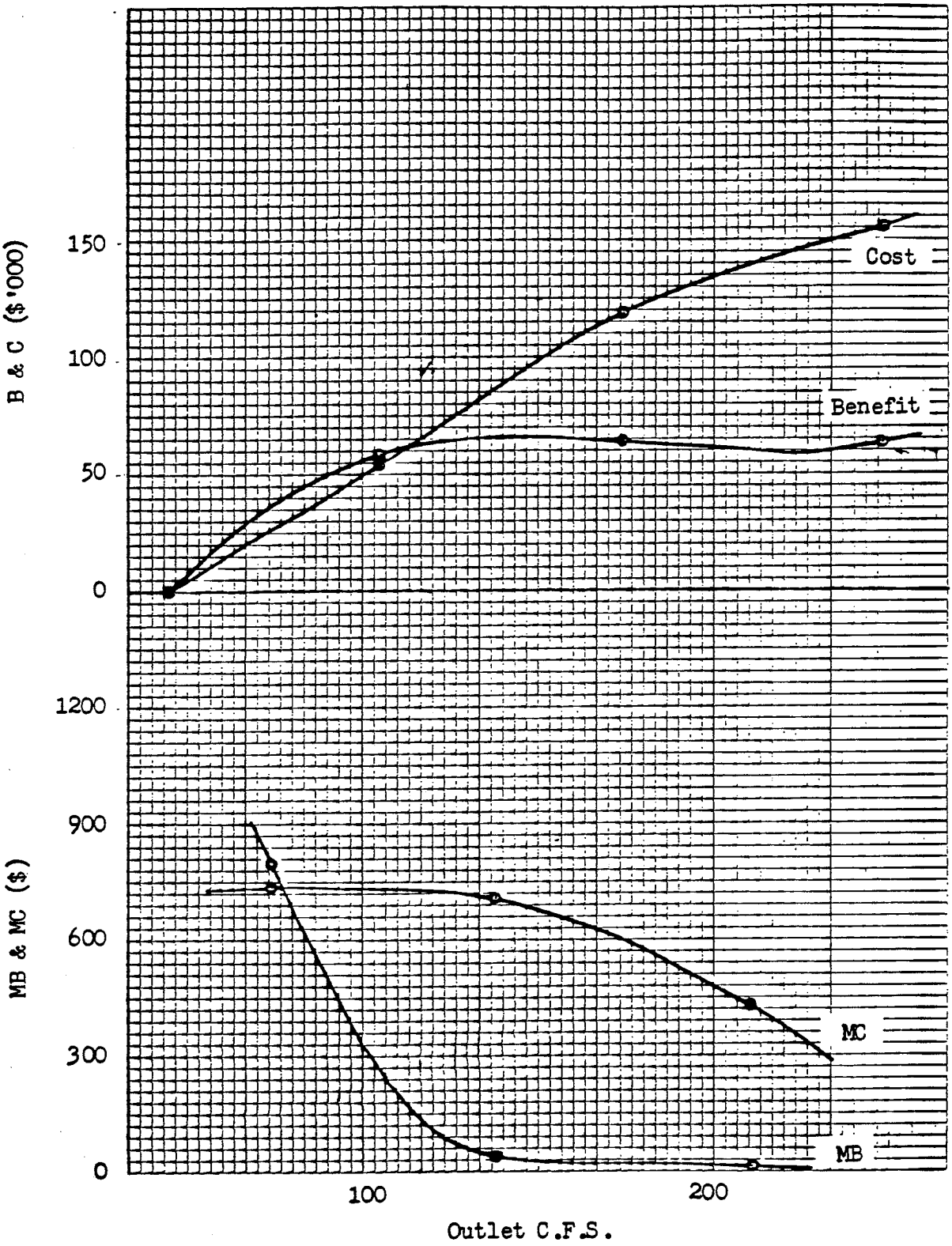


Figure 10.11

Benefit-Cost Relationships for Group 11 Subwatershed

Table 10.13

Benefit-Cost Relationships for Group 11 Subwatershed at the Optimum

Subwatershed: 5.05.00

Optimum:	C	=	20.67
	Benefits	=	$81,000
	Costs	=	31,000
	Net Benefit	=	50,000
	B/C ratio	=	2.61

Area: 3.6 mi^2

Outlet: Exist. C = 7.55 (19 cfs)

Optimum Q = 52 cfs

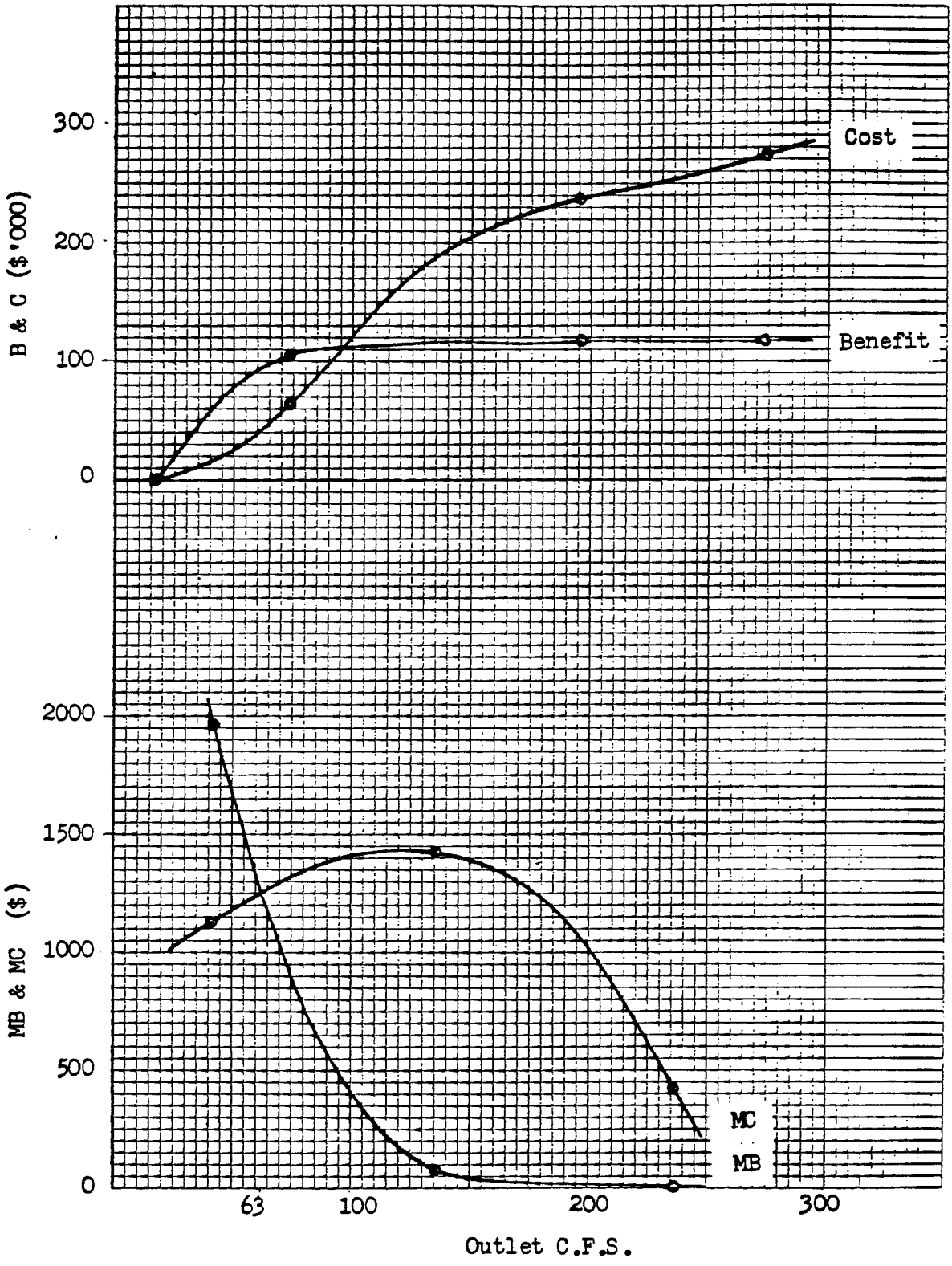


Figure 10.12

Benefit-Cost Relationships for Group 12 Subwatershed

Table 10.14

Benefit-Cost Relationships for Group 12 Subwatershed at the Optimum

Subwatershed: 5.04.00

Optimum:	C	= 22.0
	Benefits	= $77,000
	Costs	= 47,000
	Net Benefit	= 30,000
	B/C ratio	= 1.64

Area:	4.3 mi^2		
Outlet:	Exist.	C	= 6.65 (19 cfs)
	Optimum	Q	= 63 cfs

have about two-thirds of its area in clay loam soils and most of the remainder in loams. The higher benefits for 5.01.02 relative to 5.01.01 seem to arise primarily from reclamation works. The existing land use data indicate that 26.2 percent of 5.01.02 is unimproved whereas only 0.7 percent of 5.01.01 is unimproved.

Figure 10.13 locates the optimum drainage design for Group 13 subwatersheds. This is shown as 10.0 for the runoff coefficient, indicating only nominal improvements. Table 10.15 shows that the benefit/cost ratio of this Group at the optimum design level is 1.13. Benefits are $80,000 and costs are $71,000. For subwatershed 5.01.02, benefits are $73,000, costs are $57,000 and the net benefit is $16,000. Subwatershed 5.01.01 has costs of $14,000 which exceeds the benefit of $7,000 thus resulting in a disbenefit of $7,000.

This completes the discussion of the optimization results for the various subwatershed groups. Having obtained these estimates of the various levels of improvements which are desired and given that a large proportion of the watershed is not economically feasible for drainage improvements the main channels in the watershed must be examined to determine adequacy and wherever necessary, to estimate the amount of improvements which must be made to provide the level of protection consistent with the drainage levels in various parts of the watershed. The discussion which follows deals with this step in the analysis.

EVALUATION OF DOWNSTREAM CHANNEL MODIFICATIONS

In this step of the analysis an attempt is made to evaluate the

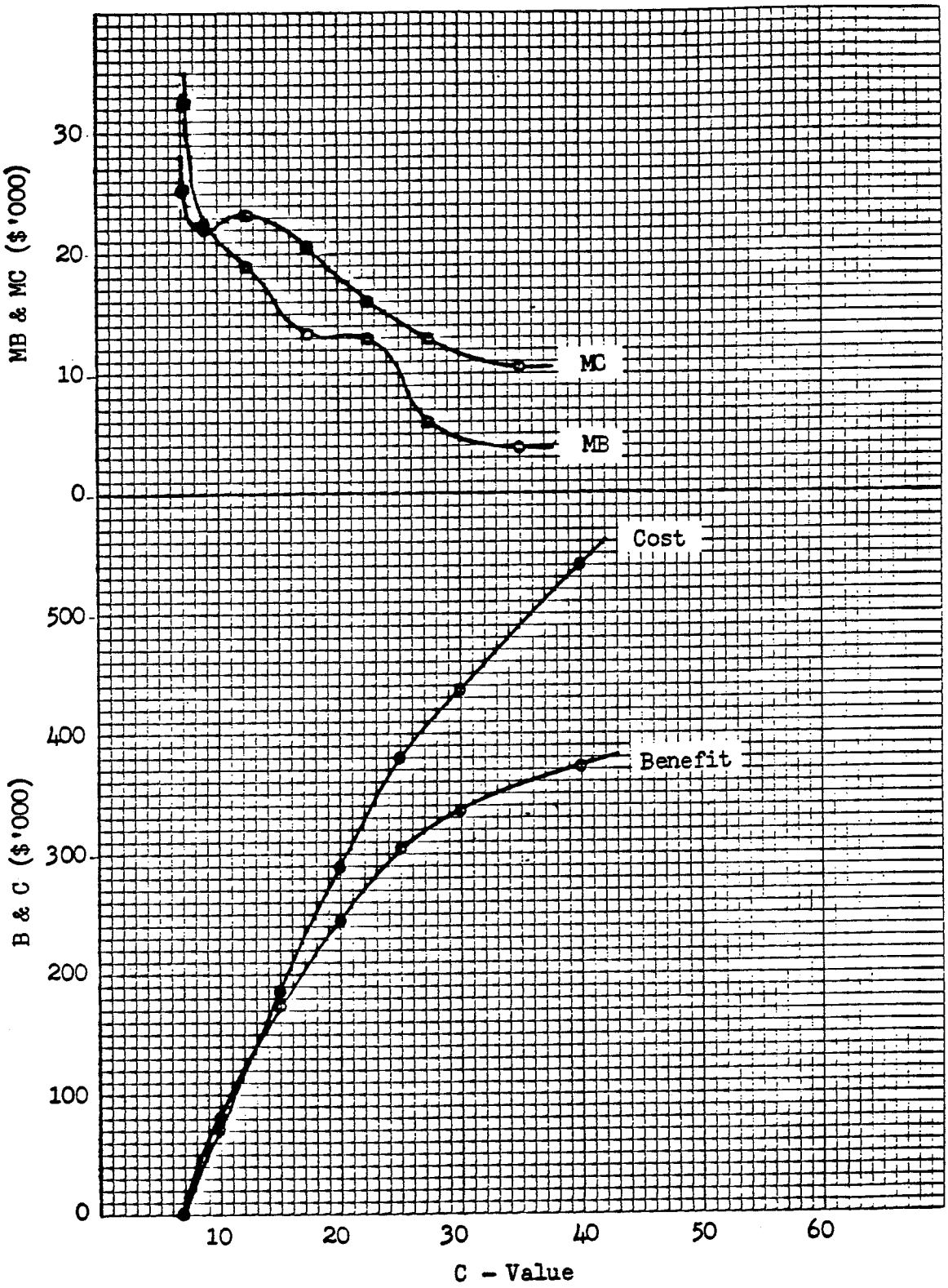


Figure 10.13

Benefit-Cost Relationships for Group 13 Subwatersheds

Table 10.15

Benefit-Cost Results for Group 13 Subwatersheds at the Optimum

Subwatersheds: 5.01.02, 5.01.01

Optimum: C = 10.0
Benefits = $80,000
Costs = 71,000
Net Benefit = 9,000
B/C ratio = 1.13

SWS	D.A. ($Mi.^2$)	A ($Mi.^2$)	Outlet Exist C	Outlet Optimum Q (cfs)	B	C	Net. Ben
5.01.02	7.59	7.59	6.97	43	$ 73,000	$ 57,000	$ 16,000
5.01.01	11.09	3.50	8.14	57	7,000	14,000	- 7,000
TOTAL					$ 80,000	$ 71,000	$ 9,000

main channels to accomodate the discharges associated with the design levels which will exist after re-construction. Some areas will remain at their current design levels but for the drainage areas within the various groups identified,the design standard will be improved and so the adequacy of the main channel must be ascertained given such variable drainage design levels.

Wherever improvements are required the costs shall be re-allocated to the group(s) which have experienced improved drainage and which are contributing drainage areas.

The improvement of the main channel in various reaches may induce benefits if investments are made in on-farm and collection drains. To the extent that the associated costs are less than the benefits derived it will be desirable to develop the drainage in such areas adjacent to the main channel to take full advantage of the larger capacities which must be provided because of upstream drainage development.

The analysis in this third step first focussed on the largest channels which are the Angle Drain and the Big Grass River. After these were evaluated for adequacy then the main channels carrying discharge to the Angle Drain and Grass River from the various groups in which drainage improvement works are proposed were studied.

Adequacy of the Angle Drain and Grass River

The drainage survey data were used to estimate the current level of drainage protection in the various reaches of the above channels. Specifically, these channels were examined at five locations. These correspond to the reaches which are located in subwatersheds 2.11.00, 2.09.00, 4.10.00, 5.07.00 and 6.02.00. Having estimated the current level of drainage design

the adequacy of these were evaluated by estimating the design level which is compatible with the levels of service in both the areas marked for drainage improvement and in areas where no improvements are proposed. The required design level for the main channel was estimated by weighting the runoff coefficients for the various contributing drainage areas having different C-values on the basis of their respective areas. The C-values used are those which exist after drainage development is made in some areas. The equation used for weighting the runoff coefficients is:

$$C = \frac{1}{DA} \sum_{i=1}^{n} a_i \, c_i$$

where: C = required C-value for the main channel at a specific location

DA = drainage area at the selected location of the main channel

a_i = area of contributing drainage area segment, i

c_i = runoff coefficient (after improvement, if improved) for contributing drainage area, i

Table 10.16 presents the estimates of the existing channel design level and the required designs based on the protection levels in the contributing drainage areas. At all locations examined the existing design level was found to be adequate. In subwatershed 2.11.00 the existing C-value of the main channel is 9.87 and the required is 9.88. Further downstream in 2.09.00 the existing channel design is at a runnoff coefficient value of 14.53 and the required level is 13.20. As one progresses downstream towards the outlet it will be observed from Table 10.16 that the existing designs are greater than the required by increasingly greater amounts. Thus from this analysis it is concluded that no drainage improvements works are required along the Angle Drain and Grass River, starting from subwatershed 2.11.00 and progressing to the outlet of the watershed.

TABLE 10.16

Existing and Required Drain Designs for the Angle Drain and Grass River

Subwatershed Location of Main Channel	Drainage Area (mi^2)	C-Coeff. Existing Design	C-Coeff. Required Design
1) Angle Drain 2.11.00	99	9.87 (270 c.f.s.)	9.88 (270 c.f.s.)
2.09.00	161	14.53 (564 c.f.s.)	13.20 (512 c.f.s.)
2) Grass River 4.10.00	320	17.36 (1105 c.f.s.)	11.98 (762 c.f.s.)
5.07.00	384	18.03 (1308 c.f.s.)	12.92 (938 c.f.s.)
6.02.00	400	19.97 (1470 c.f.s.)	12.97 (970 c.f.s.)

It should be emphasized that the recommended proposal of no channel modification in the reaches indicated is made with respect to agricultural drainage protection. It is based on the current level of agricultural drainage design which currently exists for areas undergoing no improvements and the proposed improved agricultural drainage protection for areas requiring drainage development. Adequacy of main channels is not established with respect to flood protection since this particular problem is outside the scope of the present study. Accordingly, when storms occur which make demands on the drainage system exceeding the agricultural protection provided then extended periods of PE and possibly flooding will not be avoided.

Adequacy of Main Channels Flowing into Angle Drain or Grass River

The channels which convey discharge from the various groups for

which improvements in drainage were proposed in the previous step were examined in this step to determine adequacy to handle the larger peak discharges resulting because of improvements. All subwatershed groups which extend up to the Angle Drain or the Grass River do not have to be evaluated here since drainage up to such points was already considered in the optimization analysis. Only the main drainage channels leading from subwatershed Groups 6, 7 and 8 need be evaluated.

The level of optimum drainage improvement in Group 6 subwatershed calls for corresponding modifications in subwatersheds 3.04.02 and 3.04.01, which define the current drainage route. Following this route the channel improvement costs are relatively high and exceeds net benefits expected from Group 6. Thus drainage improvements are not feasible for Group 6 if the existing channel route is retained.

An alternative course was chosen in an effort to reduce costs for downstream improvements of the main channel. This comprised of a channel diversion, as shown in Map10.6 into the Riding Mountain Drain and along the Riding Mountain Drain to the Grass River. The improvement of Group 6 subwatersheds to a C-value of 23.5 calls for modifications to the Riding Mountain Drain in reaches within subwatersheds 3.06.01 and 3.05.00.

Table10.17 gives the respective improvements for these subwatersheds. The channel diversion extends for one mile north and has a discharge capacity of 130 c.f.s. The improvements are from C = 6.94 to C = 8.28 for subwatershed 3.06.01 and from a C-value of 8.27 to a C-value of 9.60 for 3.05.00.

Because it is necessary to improve the main channels downstream of Group 6 (in subwatersheds 3.06.01 and 3.05.00) the feasibility of improving the on-farm and collection drains to the design level in the main channel was

Table 10.17

Downstream Effects From Optimum Development of Group 6 Subwatersheds

Subwatersheds: 3.04.04, 3.04.03, 3.04.05
Also: 3.06.01 and 3.05.00

Minimum Cost Route: 1 mi. Diversion North and along Grass River in Subwatersheds 3.06.01 and 3.05.00

	Exist Q	Improved Q	Amount
Costs:			
1) 1 mile diversion		130 cfs	$25,000
2) Main Channel in Subwatershed 3.06.01	240 (c=6.94)	300 cfs (c=8.28)	35,000
3) Main Channel in Subwatershed 3.05.00	288 (c=8.27)	334 (c=9.60)	11,700
4) Collection and on-farm drain in 3.06.01 and 3.05.00 to new design levels	828 and 9.60		6,000
TOTAL			$77,700
Benefits:			
5) Benefits in 3.06.01 and 3.05.00			$22,500

Table 10.17 (continued)

Downstream Effects From Optimum Development of Group 6 Subwatersheds

1. Benefits: = $269,500
   Costs = 262,700
   Net Benefit = 6,800
   B/C ratio = 1.03

2. Designs

(i)	Group 6 Subwatersheds	C	= 23.5
(ii)	1 mi. diversion to Grass River:	Q	= 130 cfs
(iii)	Main channel in 3.06.01	Q	= 300 cfs
		C	= 8.28
(iv)	Main channel in 3.05.00:	Q	= 330 cfs
		C	= 9.60

investigated. From Table10.17 it will be observed that improvements of the drainage in the periphery areas to the main channels were feasible. The cost of on-farm and collection drains in subwatersheds 3.06.01 and 3.05.00 to the level indicated for the main channel is $6,000. The associated benefits are $22,500 thus indicating a net benefit of $16,500 for drainage modifications in 3.06.01 and 3.05.00. Given the relatively small area involved in the above changes and the rather small change in C-value it is expected that no further significant improvement will be needed in the main channels.

Table 10.17 also gives the estimates of the diversion (1 mile) as $25,000 and the main channel improvements in 3.06.01 and 3.05.00 as $35,000 and $11,700, respectively.

Aggregating these costs and associated drainage benefits with those indicated for Group 6 at the optimum the benefit/cost ratio reduces to 1.03 from 1.34 which was obtained in step two analysis. Benefits are now $269,500 and costs $262,700. The net benefit after inclusion of downstream impact is reduced from $62,000 to $6,800.

The discharge from Group 7 subwatersheds flows south through subwatershed 4.03.00 before entering Grass River. The reaches of the main channel from the outlet of Group 7 to Grass River were examined to determine their adequacy to accomodate larger peak discharges which may be generated from Group 7 subwatersheds because of development.

Upon evaluation of the design level of the main channel at the outlet of 4.03.00 it was found that the existing capacity of 222 c.f.s. corresponded to a runoff coefficient value of 12.24. Since only nominal improvements are proposed for Group 7 subwatersheds, to a C-value of 10.0,

there is no need for improvements to the main channel in 4.03.00 because its current level of protection exceeds the development level in Group 7. The net benefits and benefit/cost ratio for drainage development in Group 7 remain unchanged after inclusion of downstream costs (Table10.18).

Finally, Group 8 subwatershed is the only remaining Group for which downstream impact of development must be evaluated. The development in this subwatershed will tend to affect the level of protection in the lower reach (about one mile in length) of the main channel in 4.03.00.

The level of drainage protection in Group 8 increased from a C-value of 12.6 to a C-value of 25.3 at the optimum design. However, because of its relatively small drainage area, 1.89 square miles, the effect of this change on the downstream main channel is rather small. It was estimated that the design level required in the main channel in 4.03.3 after improvement in the Group 8 subwatershed is at the runoff coefficient value of 12.67 which represents an increase of 0.43 in the current C-value of 12.24. The cost of this improvement in the lower reach of the main channel in 4.03.00 is estimated at $1700, as given in Table10.19. After inclusion of this downstream cost the adjusted cost of drainage development in Group 8 is $28,700. Benefits remain at the previous level, $42,000, net benefits are $13,300 and the benefit/cost ratio is 1.46.

OPTIMUM WATERSHED DEVELOPMENT PLAN

The evaluation conducted in this study indicate that drainage improvement works are feasible in the 13 groups of subwatersheds which were identified in Map10.6. Some of these constitute major improvement works

Table 10.18

Downstream Effects from Optimum Development of Group 7 Subwatersheds

Downstream channel improvement costs due to development in Subwatersheds: 4.04.06, 4.07.02 and 4.06.00:

Existing Q in 4.03.00 = 222 cfs
Existing C in 4.03.00 = 12.24
C value to the optimum
in group 7 = 10.0

Thus no further improvements are required in 4.03.00 to accomodate discharge from Group 7 Subwatersheds.

Optimum: C = 10.00
Benefits = $255,000
Costs = 245,000
Net Benefits = 10,000
B/C ratio = 1.04

Table 10.19

Downstream Effects from Optimum Development of Group 8 Subwatershed

Downstream channel improvement cost for an optimum development of subwatershed 4.02.00 to a C Value of 25.3:

1. Change in C value required for subwatershed 4.03.00

$$= \frac{1}{DA} \sum (a * \triangle c) = \frac{1}{DA} [1.89 * (25.3 - 12.6)]$$

$$= \frac{23.90}{56} = 0.43$$

2. Required C - value for the main channel in 4.03.00 given that Subwatershed 4.02.00 is improved to the optimum:

Existing C - in 4.03.02 = 12.24
Improved C - value in 4.03.00 = 12.67
Improved Q - value in 4.03.00 = 230 cfs

3. Improvement cost for main channel in 4.03.00 $1700

4. Benefits and costs after inclusion of downstream effects:

Benefits = $42,000
Costs = 28,700
Net Benefits = 13,300
B/C ratio = 1.46

whereas for other groups the proposed works constitute minor works requiring primarily the cleaning of the main channels and collection drains and the construction of on-farm drains where necessary. Drainage development in this watershed also required the diversion of drainage channels for three groups of subwatersheds so as to minimize the downstream channel improvement costs. Associated with the above development are the land use changes which represent the highest use of the land base at the desired level of drainage improvement. The plan which evolved as optimum for the Big Grass watershed also considered Wildlife uses as alternatives to agricultural uses so as to ensure that the concept of highest use is employed in a broad sense. These various aspects of the optimum watershed plan are now discussed.

Levels of Development

The levels of improvement in the drainage system varied among the various groups depending on characteristics of the groups with respect to factors which influence drainage feasibility. Table 10.20 which summarizes the optimum benefit/cost analysis results for the Big Grass Watershed gives the optimum drain designs for the various groups. Development range from a C-value of 8.28, representing a low level of drainage protection, to a C-value of 50.0, which can be considered a moderately high level of drainage protection. The latter is proposed for Group 4 subwatershed which has a relatively small area 1.75 square miles. Groups 8, 9 and 10 have optimum levels of development corresponding to C-values in the range of 25.0 to 35.0. These can be considered to be a moderate level of protection. Lower levels of protection, corresponding to C-values from 15.0 to 25.0 is proposed for

Table 10.20

Summary of Optimum Benefit-Cost Results for Groups of Subwatersheds Which are Feasible for Drainage Improvement Works

Group	Area (Mi^2)	Optimum C - Coef.	Benefits ($)	Costs ($)	Net Benefits	B/C Ratio
1	18.36	34.0	992,000	666,000	326,000	1.49
2	10.26	9.50	130,000	124,000	6,000	1.05
3	7.36	19.05	273,000	200,000	73,000	1.37
4	1.75	50.0	43,000	35,000	8,000	1.23
5	10.52	19.0	369,000	257,000	112,000	1.44
6	10.86	23.5	269,500	262,700	6,800	1.03
(also 3.06.01	3.63	8.28				
and 3.05.00)	0.50	9.60				
7	16.31	20.5	255,000	245,000	10,000	1.04
8	1.89	25.29	42,000	28,700	13,300	1.46
9	2.29	31.39	52,000	34,000	18,000	1.53
10	3.4	28.17	80,000	36,000	44,000	2.22
11	3.6	20.67	81,000	31,000	50,000	2.61
12	4.3	22.0	77,000	47,000	30,000	1.64
13	11.09	10.0	80,000	71,000	9,000	1.13
Total for the Watershed	107.81		2,743,500	2,037,400	706,100	1.35

Groups 3, 5, 6, 7, 11 and 12. The lowest levels of improvement are proposed for Group 2 (C-value of 9.50), Group 13 (C-value of 10.0) and the downstream subwatersheds from Group 6 (3.06.01 and 3.05.00). It will be recalled that improvements were proposed in subwatersheds 3.06.01 and 3.05.00 primarily to take full advantage of the improved main channel design level which were modified to provide a level of protection consistent with the upstream development in Group 6.

The optimum development plan therefore called for main channel, collection drains and on-farm drainage development in the various groups to the design levels shown in Table10.20. Additionally, these developments made it necessary to make improvements to the main channels in certain locations. Specifically, the main channel flowing through subwatershed 3.06.01 should be improved to a C-value of 8.28 and the main channel in 3.05.00 to a C-value of 9.60. Similarly, improvements which constitute primarily a clean-out are required for the lower reach of the main channel flowing through subwatershed 4.03.00.

The analysis indicated that on the basis of improvement works proposed the levels of protection which are presently provided by the Angle Drain and Grass River are adequate. It should be emphasized that the levels of development proposed are expected to provide protection to agriculture against storm-events of certain magnitudes. In terms of the analysis of this study this means that excess moisture on agricultural fields will be removed in a length of time sufficiently short to avoid significant crop damage. Whenever storm-events exceed the magnitudes against which protection is provided crop damage can be expected due to prolonged surface

storage of excess moisture. However the actual extent of damage will generally be lower than before the drainage works.

The objective of this study is not to evaluate flood protection works. Since flooding is generally experienced from larger storms it is very unlikely that optimum levels of agricultural drainage protection which are proposed for the Big Grass Watershed will provide any significant additional flood protection. It should also be emphasized that drainage protection is considered only with respect to summer storms and not spring runoff. Also the protection considered is only with respect to the reduction of the duration of excess moisture on agricultural fields and not with respect to reducing erosion of soils.

Channel Diversions

The optimum development plan also called for the diversion of drainage channels. Three diversions are proposed. The first is a diversion of runoff from subwatersheds 1.03.04 and 1.03.03 through 1.02.00 and then into the Angle Drain. The previous route was through subwatershed 1.03.01. This modification reduced the cost of main channel improvements in 1.03.01 and also the total drainage cost associated with developments in Group 1 subwatersheds.

The diversion from Group 6 subwatersheds to the Riding Mountain Drain resulted in costs and benefits associated with this group which made drainage improvements feasible. The current drainage route required improvements to the main channel with costs exceeding the net benefits from Group 6.

Similarly, the diversion of the drainage channel in Group 7 made improvement works feasible which under the current drainage pattern would not have had costs exceeding benefits. All three subwatersheds in this group have current drainage routes which are different. By combining these

subwatersheds into one group by diversion of the drainage channels, costs of downstream improvements were reduced and drainage improvement became feasible.

Land Use Change

In evaluating the feasibility of drainage improvement works in the Big Grass Watershed it was assumed that the land resource will be utilized at its fullest potential subject to a realistic set of production and marketing constraints. Given that excess moisture is a major limitation to agricultural production in this watershed and that for many locations production alternatives are restricted because of this limitation then the improvement of drainage will reduce the degree of excess moisture restriction and provide the opportunity for producers to consider other alternatives. From a broader group of alternatives it is assumed that producers act rationally in choosing agricultural production activities which are expected to maximize profits subject to various constraints. Constraints used in this study are production constraints such as those which arise from crop rotation for disease control purposes or for diversification. No consideration is given in this study to individual producer resource restrictions. Another constraint is the limited market for commodities.

The benefits and costs estimated in the model are those associated with the highest land use at each level of drainage improvement. The highest use is identified from the set comprising of cereal crops (wheat, oats and barley), tame hay, native hay and unimproved or no economic use. Table 10.21 gives the present land use and the highest use for each of the subwatershed groups at their respective optimum design levels. Since areas outside of these groups, except subwatersheds 3.06.01 and 3.05.00, were shown to be non-feasible for improvements in drainage, the land use

Table10.21

Land Use Modifications Associated with Optimum Drainage Development in the Big Grass Watershed*

Subwatershed Group No.	Land Use	Acreage		Change in Use	
		Present	After Development	Acres	Percent
1	A	3432	8776	+5344	+156
	P	1948	2792	+ 844	+ 43
	K	3816	120	-3696	- 97
	T	2532	40	-2492	- 98
2	A	2336	2336	0	0
	P	828	828	0	0
	K	2244	2244	0	0
	T	964	964	0	0
3	A	3004	4992	+1988	+ 66
	P	452	772	+ 320	+ 71
	K	2412	1272	-1140	- 47
	T	1664	496	-1168	- 70
4	A	492	1100	+ 608	+124
	P	48	0	- 48	-100
	K	244	0	- 244	-100
	T	316	0	- 316	-100
5	A	4044	5024	+ 980	+ 24
	P	928	1448	+ 520	+ 56
	K	548	84	- 464	- 85
	T	1104	68	-1036	- 94
6	A	2768	6024	+3256	+118
	P	612	892	+ 280	+ 46
	K	2332	4	-2328	-100
	T	1208	0	-1208	-100
7	A	3456	3456	0	0
	P	528	528	0	0
	K	2540	2540	0	0
	T	4836	4836	0	0
8	A	616	1120	+ 504	+ 82
	P	60	80	+ 20	+ 33
	K	28	0	- 28	-100
	T	496	0	- 496	-100
9	A	1112	1464	+ 352	+ 32
	P	28	0	- 28	-100
	K	208	0	- 208	-100
	T	116	0	- 116	-100
10	A	1360	2092	+ 732	+ 54
	P	84	116	+ 32	+ 38
	K	48	0	- 48	-100
	T	716	0	- 716	-100
11	A	1124	1964	+ 840	+ 75
	P	228	356	+ 128	+ 56
	K	40	0	- 40	-100
	T	928	0	- 928	-100
12	A	1692	2156	+ 464	+ 27
	P	352	588	+ 236	+ 67
	K	196	0	- 196	-100
	T	540	36	- 504	- 93
13	A	4494	4494	0	0
	P	598	598	0	0
	K	696	696	0	0
	T	1288	1288	0	0
Total	A	29930	44998	+15068	+ 50
	P	6694	8998	+ 2384	+ 34
	K	15352	6960	- 8392	- 55
	T	16708	7728	- 8980	- 54

*Land Use shown in this table are only for those groups for which drainage improvements are proposed. A= Field Crops; P= Tame Hay; K= Native Grassland; T= Unimproved Land.

remains unchanged from the present. Subwatersheds 3.06.01 and 3.05.00 are located downstream from Group 6. Only minor drainage improvement works were proposed for these subwatersheds and so the land use is expected to remain unchanged from the present. Present land use information for the subwatersheds in the Big Grass Watershed is given in Table A2 in the Appendix.

For the areas or subwatershed groups in which drainage improvement comprises minor works the land use is expected to remain unchanged. Thus for groups 2, 7 and 13, Table 10.21 shows no change in land use.

Presently, a large portion of the land area in Group 1 is in native grassland (33 percent) and unimproved land (22 percent). Field crops occupy about 29 percent of the area. Drainage development is expected to induce a shift in use from native grassland to field crops. Also, it is expected that all of the unimproved area, except 40 acres, will be developed and used for field crops or forage. From the table it will be observed that the land use change involves increases in field crop acreage by 5344 acres and tame forage by 844 acres. These correspond to increases of 156 percent and 43 percent, respectively for field crops and tame hay, and to reductions in the acreages of native grassland and unimproved land by 97 percent and 98 percent, respectively.

Similar changes in land use are expected for Group 3 but these are confined to subwatershed 2.04.02 since no drainage changes are proposed for 2.04.01. The increase in field crops and tame hay are 1988 and 320 acres, respectively. The reductions in native hay and unimproved land are 1140 and 1168 acres, respectively.

Group 4 which is comprised of only subwatershed 2.03.00 is expected to experience a change in land use which results in only cereal production after drainage development. The acreage increase is 608 which is 124 percent greater than present cereal crop acreage.

More moderate changes in land use are proposed for Group 5. Increases in cereal crop and tame hay acreages are 24 percent and 56 percent, respectively. Corresponding reductions in native hay and unimproved land are 85 percent and 94 percent, respectively. At the optimum level of drainage service the land use in this group is expected to be comprised of 5024 acres of cereal crops, 1448 acres of tame hay, 84 acres of native grassland and 68 acres of unimproved land.

Drainage improvement in Group 6 is expected to cause development of 1208 acres of unimproved land. The location of drainage optimum in terms of design level is premised on the improvement of all unimproved land (1208 acres) and the transformation of almost all the native grassland acreage (2332) to cereal crops and tame hay. After improvement in drainage it is expected that cereal crop acreage will increase by about 118 percent and tame hay by 46 percent.

The pattern of land use change which has been identified for the subwatershed groups discussed above is typical of the other groups for which drainage improvement work is proposed. For subwatershed groups 8 to 12 all of the native grassland and almost all unimproved land are to be converted to tame hay and cereal crop production. The acreage of cereal crops increased by 82 percent in Group 8 to 1120 acres; 32 percent in Group 9 to 1464 acres; 54 percent in Group 10 to 2092 acres; 75 percent in Group 11 to 1964 acres; and by 27 percent in Group 12. The

increases in tame hay production are similar to the preceding groups discussed.

The total change in land use in the Big Grass Watershed which is associated with drainage development is given in Table10.21. The highest use identified at optimum drainage development suggests that the amount of unimproved land should be reduced by 54 percent and the native grassland acreage reduced by 54 percent. These correspond to reductions of 8392 acres and 8980 acres for native grassland and unimproved land, respectively. The simultaneous increases in cereal crops and tame hay are by 50 and 34 percents. Cereals increase from 29,930 acres to 44,998 acres. Tame hay increases from 6694 acres to 8998 acres.

The benefits and the costs from which the drainage optimum is identified assume significant changes in land use. A large part of the benefits expected in this watershed are reclamation benefits since current land use information indicate that 22 and 24 percents of the areas designated for drainage improvement are in native grassland and unimproved land, respectively. After drainage development the model assumes that these acreages will respectively reduce to 10 and 11 percents of the areas for drainage improvement. To the extent that these changes are not induced by reconstruction of the drains, true benefits will be less and in fact the project may become non-feasible at this lower level of benefit. In total, about 44 percent of the area shown feasible for drainage improvement is currently used for cereal crops. These, it is assumed, will increase to 66 percent (44,998 acres) of the area after development. Tame hay production increases from 10 percent of the area to 13 percent.

Thus, in the Big Grass Watershed drainage improvement feasibility assumes that land use change will be attained. The results of the analysis indicate large increases in cereal crops and smaller amounts in tame hay. To the extent that these land use changes are not adopted by farm operators then benefits and drainage feasibility will be adversely affected.

Wildlife Uses

It was indicated in the analytical framework that the impact of drainage development will be evaluated in terms of losses of high capability wildlife habitat to agricultural uses. The alternative of preserving such areas for wildlife uses has its benefits which are difficult to quantify. The cost of allocating land for wildlife uses can more readily be quantified by adopting the approach of opportunity cost or the benefits foregone from the use of the land for agriculture after drainage development. The actual land use choice would have been left for decision-makers who must compare the benefits from wildlife use, which were not quantified, with the opportunity cost of preserving land for this use.

Only one of the subwatershed group among those which were found feasible for drainage development contained land which was indicated by the wildlife specialist as a priority wildlife area. For other areas to be improved the wildlife capability of the land was sufficiently low not to warrant concern about its use for agriculture. The priority wildlife area is located in subwatershed Group 7 and comprises the eastern half of subwatershed 4.04.06. The area involved is about 2.25 square miles.

Present land use within this priority area is primarily native

grassland and unimproved land. After drainage development in Group 7 it is expected that land use will remain unchanged from the present. It will be recalled that only minor drainage improvements are proposed for Group 7 and for such a low level of development the land use will not be modified. Thus the decision to undertake drainage development in Group 7 does not affect plans to preserve the priority wildlife area for wildlife uses. Land allocation remains unchanged. It can be concluded, therefore, that drainage development to the optimum designs does not adversely affect wildlife uses of the land resource in the Big Grass Watershed.

Summary of the Optimum Watershed Development Plan

Drainage development in the Big Grass Watershed is expected to generate $2.7 million of benefits (Table10.22) over the project life of 15 years and assuming a discount rate of eight percent. The cost of drainage development which includes both capital costs and the present value of annual maintenance costs is estimated at $2.0 million. This includes both the costs which are internal to the various groups which were designated as being feasible for development and the cost for improvement of reaches of the main channel downstream from the subwatershed groups. The net benefits at the optimum drainage designs are $0.7 million and the overall benefit/cost ratio 1.35. The total area to be improved is 108 square miles of which 87 square miles were designated as major works and the remainder as minor.

Table 10.22

Benefit-Cost Analysis Results for Optimum Drainage Development of the Big Grass Watershed

Benefits	=	$ 2.7 million
Costs	=	$ 2.0 million
Net Benefits	=	$ 0.7 million
Overall B/C ratio	=	1.35

Area affected by drainage improvement works = 106 mi^2 (24.9% of watershed)

(i) major works = 87 mi^2 (20.4% of watershed)

(ii) minor works (such as cleanout) = 19 mi^2 (4.5% of watershed)

SENSITIVITY OF DRAINAGE IMPROVEMENT FEASIBILITY TO CROP PRICES

This analysis was performed in an attempt to derive information on the sensitivity of the benefit/cost results to increases in crop prices. A sample of subwatersheds was chosen for the analysis since the computer costs for analyzing all subwatersheds in a sensitivity analysis would have been excessive. Subwatersheds were chosen so as to provide a good cross-sectional representation of cases where the various factors influencing feasibility were dominant. Two of the subwatersheds that were evaluated were shown to be feasible using the average prices of the deterministic analysis. These were included so as to examine the change in the ratio as prices increased. The remaining subwatersheds were not feasible for drainage improvements according to the previous analysis. Highest ratios were less than or equal to 0.80.

The background data seem to indicate that the high cost of drainage development in subwatersheds 1.01.02 and 2.02.01 was the likely factor for non-feasibility. In subwatershed 1.01.01 it seems that both high cost and low soil capability (about 70 percent in class 5) were responsible for non-feasibility. In subwatershed 4.04.04 the soils were predominantly of capability class 4 and 5 which was the likely factor for the results obtained. Subwatershed 2.04.01 and 2.08.00 seem to have fairly adequate drainage. For the other subwatersheds a combination of factors were present.

The results of the sensitivity analysis is presented in Table 10.23. Drainage improvement feasibility was evaluated for each subwatershed at price increases shown. The ratios given are the highest which were obtained

TABLE 10.23

Sensitivity of Drainage Improvement Feasibility For Selected Subwatersheds to Crop Prices

Percent Increase Over Average Price*	Highest B/C Ratio for Subwatersheds;**									Number of Feasible Subwatersheds
	1.01.01	1.01.02	1.03.04	2.01.02	2.02.01	2.04.01	2.08.00	5.03.00	4.04.04	
Average or Base Price	0.67	1.05	0.53	1.56	0.24	0.29	0.28	0.47	0.80	2
10	0.86	1.25	0.69	2.08	0.30	0.37	0.34	0.62	0.67	2
20	1.05	1.44	0.95	2.64	0.36	0.44	0.39	0.78	0.84	3
40	1.43	1.84	1.46	3.73	0.48	0.60	0.52	1.09	1.20	6
60	1.80	2.23	1.84	4.83	0.60	0.75	0.64	1.46	1.56	6
100	2.56	3.03	2.77	7.06	0.83	1.07	0.92	2.03	2.27	7
200	4.44	5.00	5.37	12.63	1.43	1.84	1.61	3.60	4.05	9

*Average prices refer to average normalized crop prices which were used in the deterministic analysis: Wheat= $3.59/bu.; Oats= $1.44/bu.; Barley= $2.15/bu.; Tame Hay= $35.96/ton.

**Subwatersheds were selected so as to provide a good cross-sectional representation of cases where various factors influencing feasibility were predominant.

Highest B/C ratio refers to the highest ratio at any of the three levels of improvement considered. For 2.02.01 and 2.04.01 this corresponded to level 3 whereas for all the remaining subwatersheds the level 2 improvement gave the largest ratios.

from any of the three improved designs considered. The results indicate that for the sample of subwatersheds evaluated an increase in the average prices by ten percent is not adequate to cause development works to become feasible. However, an increase of 20 percent in prices makes subwatershed 1.01.01 feasible for improvement. At these prices the benefits exceed the high cost of drainage development in this subwatershed. Increasing crop prices by 40 percent causes three additional subwatersheds to become feasible. Among these, 1.03.04 was initially not feasible because of low soil capability and a large proportion (47 percent) being sandy soils; 4.04.04 was associated with low capability soils; and in 5.03.00 a combination of cost and low soil capability were responsible for the initial results. The increase in crop prices by 40 percent correspond to the following prices: wheat = $5.03/bushel; oats = $2.02/bushel; barley = $3.01/bushel; and tame hay = $50.34/ton. This increase results in 57 percent of the subwatersheds which were initially not feasible becoming feasible for drainage improvement works.

The subwatersheds which still remain not feasible for improvements (2.02.01, 2.04.01 and 2.08.00) did not respond sufficiently at a 60 percent increase in price. At a 100 percent increase in the average prices 2.04.01 attained a benefit/cost ratio of 1.07. It was indicated that existing drainage in 2.04.01 and 2.08.00 were fairly good. It required a large increase in prices to make drainage improvement feasible in 2.04.01. Subwatershed 2.08.00 remains not feasible. At the 100 percent increase in prices the benefits generated from drainage development in 2.02.01 were still not adequate to offset the large costs.

The benefit/cost ratios for 1.01.02 and 2.01.02 increased at a faster rate than the increase in prices. For a 40 percent increase in prices the ratio for 1.01.02 increased from 1.05 to 1.84 - an increase of 75 percent. The ratio for 2.01.02 increased by about 140 percent to 3.73.

The results of the sensitivity analysis indicate that drainage improvement feasibility for areas in the Big Grass Watershed which were shown to be non-feasible in the analysis using average prices are not likely to be very responsive to increases in crop prices. Relatively large increases, such as by 40 percent, are required before a significant proportion of these subwatersheds become feasible for drainage works.

Chapter 11

STOCHASTIC SIMULATION OF BENEFITS FROM DRAINAGE DEVELOPMENTS

The deterministic version of the simulation model evaluates the impact of drainage development on the basis of the assumption that input variables are at their mean values. Accordingly, the values generated for the output variables are expected to estimate the population means. However, actual values for many input variables tend to show fluctuations about the means. If drainage development decision is taken on the basis of decision information generated by the deterministic simulation model then an ex-post analysis of benefits and costs after such a development will likely show values for benefits and costs which deviate from ex-ante estimates. This results from the fact that input variables assumed values which were different from their means.

The observed values for output variables will vary from one project period to another. Accordingly, decision-making can be enhanced if the single-valued estimates of decision variables (benefits, net benefits, drain design and benefit/cost ratio) at the optimum level of development are supplemented with information on the probability distribution of these variables. The stochastic simulation model is appropriate for generating information on probability distributions of decision variables. It was used in this study to simulate the important disturbances which cause fluctuations in the levels of the output variables.

The level of benefits from drainage development is influenced by numerous factors. Some of these exhibit random behaviour.

Random disturbances in storm events, crop prices and costs of production are expected to exert the most pronounced influence on the level of benefit. The data have shown that drain construction costs are more stable. These were assumed to be constant for all project periods or simulation runs.

For the present analysis the impact of drainage improvement was evaluated for 30 runs of the stochastic simulation model. For each run or project period (consisting of 15 years) storm data were generated for each day (April 1 to September 30) and crop prices and costs of production were generated for each year over the project life. Because of the extremely high computer cost for each stochastic simulation run it was not possible to conduct the analysis for more than one subwatershed. However, this is not considered a serious limitation since it is expected that decision variables in other subwatersheds would have similar statistical characteristics as the one evaluated. This results from the fact that the exogenous disturbances (storm events, crop prices and costs of production) will tend to produce similar relative changes in benefits from drainage improvement in the various subwatersheds.

The simulation runs were performed on subwatershed 2.01.02. A sample of the output information for one run (or one project period) is given in Appendix F. From the output data generated by the model for each run, the optimum drainage design, with respect to the outlet channel capacity, was determined from graphical analysis. The benefits (present value), net benefits, and benefit/cost ratio associated with the optimum drain design were estimated. These results are presented in Table 11.1. For all project periods the benefit/cost ratio exceeded

Table 11.1

Stochastic Simulation Benefit-Cost Analysis Results

For Subwatershed 2.01.02

Project Period	Optimum Capacity (c.f.s.)	Total Benefits at the Optimum ($1000)	Net Benefits at the Optimum ($1000)	Benefit/Cost Ratio at the Optimum
1	105	103	76	3.89
2	110	100	78	3.13
3	115	95	60	2.71
4	105	103	76	3.89
5	90	60	41	3.16
6	100	82	57	3.28
7	105	75	48	2.78
8	110	66	34	2.06
9	110	115	83	3.59
10	100	70	45	2.80
11	105	82	55	3.04
12	110	90	58	2.81
13	95	65	43	2.95
14	110	112	80	3.50
15	105	75	48	2.78
16	95	83	61	3.77
17	110	98	66	3.06
18	105	105	78	3.89
19	95	57	35	2.59
20	105	113	86	4.18
21	100	119	94	4.76
22	100	80	55	3.20
23	115	126	91	3.60
24	100	90	65	3.60
25	80	55	44	5.00
26	100	100	75	3.00
27	110	114	82	3.56
28	100	66	41	2.64
29	95	54	32	2.45
30	90	67	48	3.53

one thus making drainage improvement works feasible on the basis of the efficiency criterion.

The results for optimum drainage development for each of the 30 simulation runs were statistically analyzed. The mean, standard deviation, standard error and the 95 percent confidence interval for the various variables are given in Table 11.2. The expected values for the various decision variables from drainage development in subwatershed 2.01.02 are: $87,330 for benefits, $61,170 for net benefits, 102.5 c.f.s. for optimum drain outlet capacity and 3.31 for the benefit/cost ratio.

The confidence interval estimate for the optimum capacity indicate a relatively stable optimum. For this subwatershed 95 percent of all observed optima are expected to be narrowly dispersed about the mean. These fall within a range of 5.9 c.f.s. which corresponds to only about six percent of the mean design discharge. This finding suggests that drainage development works based on design information generated by the deterministic model have a high probability of being close to the true optimum. Alternatively, it can be said that the errors resulting from such decisions have a high probability of being small. Table 11.2 also indicates that 95 percent of all benefit/cost ratios will fall in the range 3.06 to 3.56. If drainage benefits which are realized in various project periods are estimated it is expected that 95 percent of these will be dispersed within a range of $15,780. This range corresponds to about 18 percent of the mean benefit. A similar measure of the dispersion of net benefits indicates that the range equals 22 percent of the mean value.

Table 11.2

Statistical Results for Decision Variables Derived
from Stochastic Simulation Analysis
for Subwatershed 2.01.02

Decision Variables	Mean Values	Standard Deviation	Standard Error	95 Percent Confidence Interval
Total Benefits ($1,000)	87.33	21.12	3.86	79.44 - 95.22
Net Benefits ($1,000)	61.17	18.27	3.34	54.34 - 68.00
Optimum Outlet Capacity (c.f.s)	102.50	7.96	1.45	99.53 - 105.47
Benefit/Cost Ratio	3.31	0.65	0.12	3.06 - 3.56

Note: Statistics were computed from the sample of optimum levels of the decision variables which were associated with the results for each of the 30 simulation runs. Benefits and net benefits are the discounted present values.

While the estimates presented in Table 11.2 indicate a stable optimum in terms of design discharge, small deviations from optimum design can cause relatively greater departure of projected benefits and net benefits from the true values realized. Accordingly, decision-makers may be interested in probable error associated with a given optimum drain design in terms of not being able to achieve specific levels of benefits. Estimates on the probable error associated with development decisions can be derived from the probability distributions of the decision variables. Figures 11.1 and 11.2 present graphs of the cumulative probabilities for reaching specific levels of benefits and net benefits, respectively, in subwatershed 2.01.02. If, for example, the decision criterion is benefit then Figure 11.1 shows that the probability of equalling or exceeding a benefit of $90,000 is 0.20. The probability of equalling or exceeding $80,000 is 0.95. If the decision criterion was net benefit and a value of less than $64,000 was considered a wrong decision then the probability of a wrong decision is 0.80. That is, the probability that a net benefit of at least $64,000 will be attained is 0.20.

It should be noted that the probability distributions given in Figures 11.1 and 11.2 are equilibrium values determined from marginal benefit and marginal cost functions. Thus the analysis could have been further refined to consider the impact of the bivariate distributions of the marginal functions on the probability distribution of benefit and other decision variables. However, this feature has been omitted from the present analysis since it introduces considerably greater complexities.

The stochastic simulation of drainage development in a particular subwatershed may not result in a global optimum for the watershed since the level of development can affect drainage in other subwatersheds. This interdependence among subwatersheds was considered in the deterministic analysis. To appropriately do the same with the stochastic model will require the application of a technique such as stagewise dynamic programming. The analysis in this study did not progress to the above since only one subwatershed was considered for stochastic analysis.

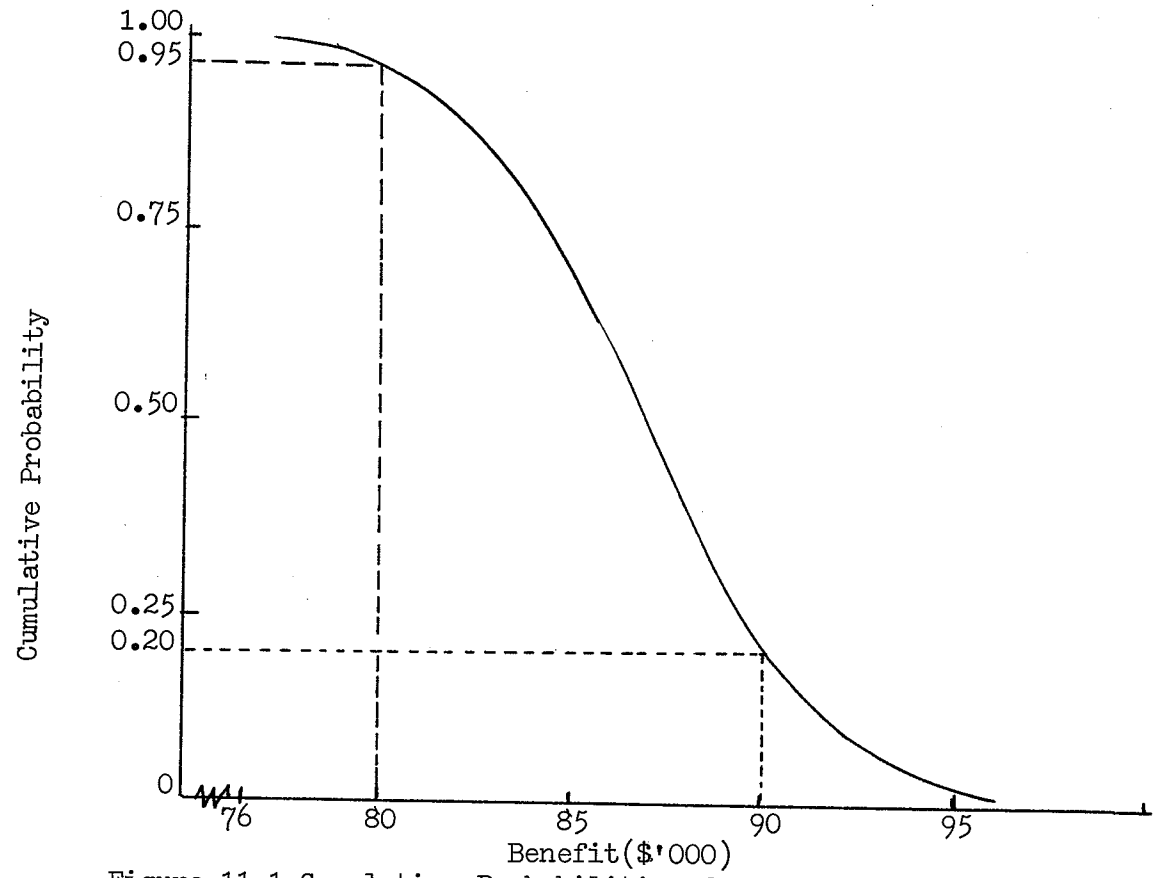


Figure 11.1 Cumulative Probabilities for Obtaining Various Levels of Benefits

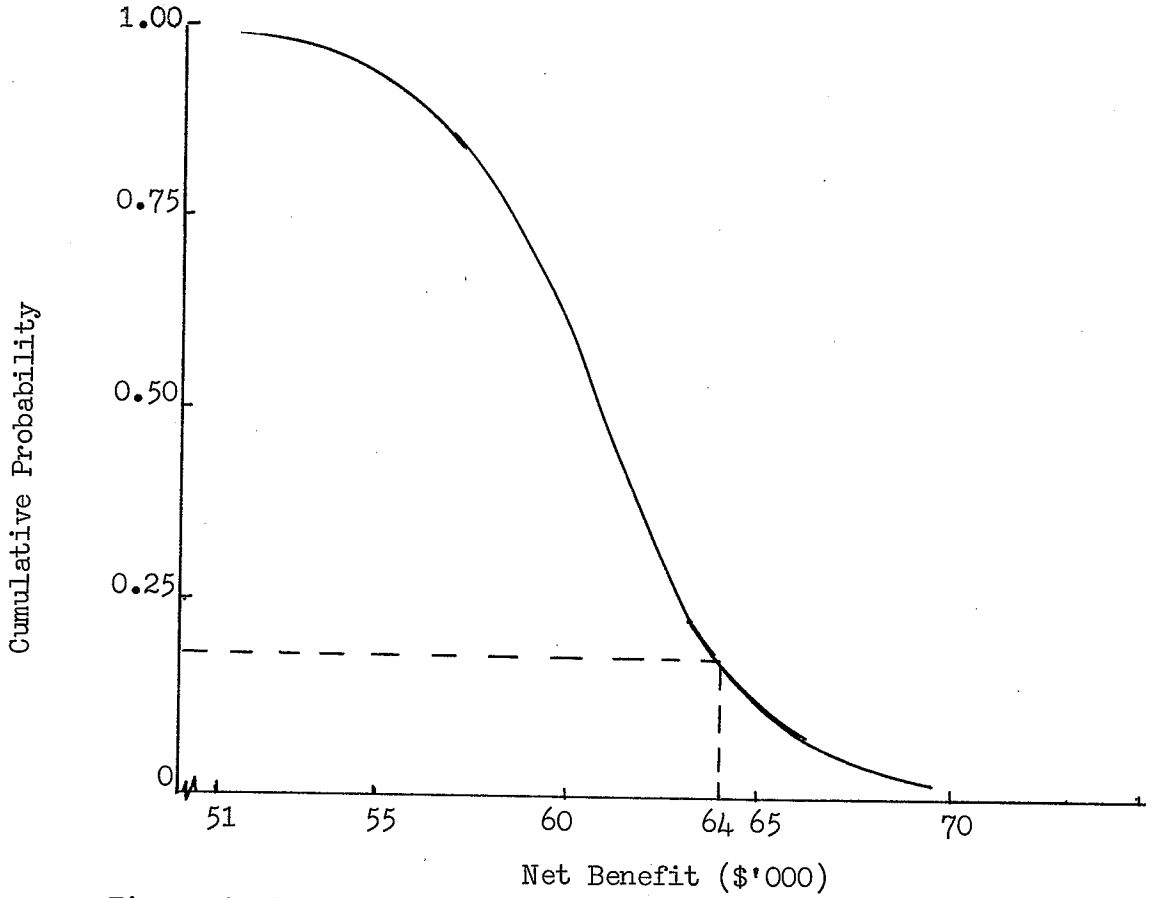


Figure 11.2 Cumulative Probabilities for Obtaining Various Levels of Net Benefits.

Chapter 12

SUMMARY AND CONCLUSIONS

This dissertation was concerned with the development of an analytical framework to evaluate the economic feasibility of public expenditure on agricultural drainage development. It was important that this framework should be able to provide decision-makers with information on the optimum level of development, the benefits and costs which are expected from optimum development and the land use adjustments which are necessary for increased efficiency in resource use. The model developed was applied to a watershed in Manitoba which currently experiences severe problems in agricultural production because of frequent occurrences of excess moisture. The selected watershed, the Big Grass Watershed, is an area of about four hundred square miles and is characterized by a rather complex pattern of soils, varied topography and hydraulic features.

The provision of improved drainage to agricultural lands results in crop damage avoided in areas where excess moisture is a significant problem. This is the major primary benefit. There are other benefits associated with drainage development which are expected to be of lesser magnitudes. These include the benefits due to reduced risk of crop losses, lower production costs, multiplier effects from higher levels of economic activity, and unmeasurable social benefits. While the benefits from drainage may be high, the costs associated with the provision of better protection for crops are also high. Proper resource allocation by the public sector for drainage development therefore calls for the construction of a model to provide data on the probable costs

and benefits for such projects.

A simulation model, based on benefit-cost analysis methodology, was developed to evaluate the impact of alternative levels of drainage development on the level of agricultural drainage benefit. The model dealt with relationships in engineering, hydrology, engineering design, agronomy and economics. Some of the important relationships embodied in the model are:

1. The effect of physical characteristics of the watershed, antecedent soil moisture, land use on the amount of runoff generated by a given storm.
2. The duration of excess moisture on the land from a given amount of storm runoff and for specific levels of drain design capacity.
3. The reduction in excess moisture duration which is caused by improved drainage.
4. The resulting improvement in agricultural productivity.
5. The economic benefits, the cost of drainage development and drainage feasibility.

The optimum level of development was determined by graphical analysis of the simulation results for alternative levels of drainage.

Because of the desire to obtain information on the statistical probability distribution of decision variables (benefit, net benefit, optimum drain design and benefit/cost ratio) a stochastic version of the simulation model was constructed in addition to a deterministic version. The deterministic version provided single-valued estimates whereas the stochastic version allowed for the random disturbances of the most influential stochastic variables - storm events, crop prices and costs of production. These two versions were introduced so as to avoid

excessive computer cost. The deterministic model was used to evaluate the entire watershed whereas the stochastic, which is costly to run, was used to evaluate only one subwatershed. The analysis of drainage improvement feasibility in this thesis proceeded in several steps. In the first step the computer model was used to generate preliminary results giving the impact of development of drainage for each subwatershed and at each design level considered. In the second step drainage development works are optimized for groups of subwatersheds. Groups are formed so as to (indirectly) allocate main channel reconstruction costs among subwatersheds which were feasible for improvements and also to form suitable areas for actual construction works.

In the application of the model to the Big Grass Watershed benefits and costs were evaluated from the stance of the Provincial economy. Benefits estimated by the model are the major primary benefit from agricultural drainage improvement-the crop damage avoided. This necessarily includes both reclamation and productivity enhancement benefits. Costs include the drain construction costs which is comprised of excavation and structure costs. The project life selected was 15 years and benefits and costs were discounted at a rate of eight percent.

The results of this study indicate that:

1. The analytical model developed is capable of evaluating drainage projects in watersheds where complex factors, which affect hydrology, drainage and agricultural production, are present.

2. Application of the model to the Big Grass Watershed showed that drainage improvement was feasible for only parts of the watershed.

3. Development of drainage in these areas to the optimum generates a total benefit of $2.7 million. Costs are $2.0 million. The overall benefit/cost ratio for drainage development in this watershed is 1.35.

4. Drainage improvement works are proposed for an area of 108 square miles (about 25 percent of the watershed) but 87 square miles are major works and the remainder are minor drainage improvements.

5. Optimum development and efficient resource use calls for land use adjustments. The acreages for field crops and tame hay in the Big Grass Watershed increased by 50 and 34 percent, respectively. As a result native grassland acreage was reduced by 35 percent and trees and bushes decreased by 54 percent.

6. The results of the stochastic analysis indicate that optimum in terms of drain design capacity is relatively stable. Errors in drainage design decisions on the basis of information from the model developed in this thesis are likely to be small. For the particular subwatershed evaluated 95 percent of all observed optima are expected to fall within a range of 5.9 c.f.s. which corresponds to six percent of the mean design discharge. The stochastic model also produced information on the probability distributions of other decision variables. Using any of these as a decision criterion the probability of wrong decisions can be estimated.

While the model developed in this study has proven to be well suited to evaluate drainage development feasibility there is nonetheless the need to further test and validate some of the hydrologic models. A well monitored watershed can provide better data (than currently

available) for testing the runoff functions and the model used for estimating precipitation excess.

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APPENDICES

APPENDIX A

SOIL AND LAND USE INFORMATION

Table A1 lists the data on soil characteristics and land use in the Big Grass Watershed. The soils within each subwatershed are categorized into homogenous soil groups on the basis of similarity in the following characteristics:

(i) soil capability for agriculture

(ii) soil productivity

(iii) hydrologic soil group

(iv) soil texture

Since soils at several different locations may be similar with respect the above characteristics these appear as different observations for the same group. For each observation information is provided on the following:

(i) land location - township, range, section and quarter-section

(ii) location within the quarter-section - whether the north, south, east or west half of the quarter-section and as a percentage of an 80 acre block (one-half of a quarter-section).

(iii) the present land use expressed as a percentage of 80 acres. The land use categories are:

(a) cropland, denoted A

(b) improved pasture and forage, denoted P

(c) native grassland, denoted K

(d) trees and unimproved land, denoted T

(e) all other categories, denoted O

Soil capability class 'O' refers to organic soils.

Table A1

Soil and Land Use Data for the Big Grass Watershed

SUBWATERSHED	SOIL GRP.	CAP	PROD	HSG	SOIL TEX.	TWP.	RGE.	SEC.	QTR.	% OF 80 AC.				LAND USE				
										N	S	E	W	A	P	K	T	O
01.01.01	01	5WP	F	C	CL	19	13	30	NW	50	80				60	70		
01.01.01	02	5WP	G	C	CL	19	14	23	NE			100	100		30	80	55	35
01.01.01	02	5WP	G	C	CL	19	13	30	SW			100	100	135	30	35		
01.01.01	02	5WP	G	C	CL	19	14	25	SW			100		30		55	15	
01.01.01	02	5WP	G	C	CL	19	14	26	SW			100		35			65	
01.01.01	03	5WP	H	C	CL	19	14	24	NW				100	70	25		5	
01.01.01	03	5WP	H	C	CL	19	14	25	NW			100	100			170	30	
01.01.01	04	5WP	I	C	CL	19	14	23	SE				100	35		15	50	
01.01.01	04	5WP	I	C	CL	19	13	19	NW			100		100				
01.01.01	04	5WP	I	C	CL	19	14	23	SW		100					20	80	
01.01.01	04	5WP	I	C	CL	19	14	24	NE			100	100			170	30	
01.01.01	04	5WP	I	C	CL	19	14	24	SE			100	100			200		
01.01.01	04	5WP	I	C	CL	19	14	24	SW				100	55		15	30	
01.01.01	04	5WP	I	C	CL	19	14	25	NE	100	100					170	30	
01.01.01	04	5WP	I	C	CL	19	14	25	SE	100	100					165	35	
01.01.01	04	5WP	I	C	CL	19	14	26	NE	100	100					200		
01.01.01	04	5WP	I	C	CL	19	14	26	NW			100	100			110	90	
01.01.01	04	5WP	I	C	CL	19	13	30	SE			40			35	5		
01.01.01	04	5WP	I	C	CL	19	13	19	NE			25	65	50			40	
01.01.01	05	0	I	C	CL	19	14	23	SW	100						60	40	
01.01.01	05	0	I	C	CL	19	14	25	SW				100	90		10		
01.01.01	06	6W	I	C	CL	19	13	30	SE				85	60	25			
01.01.01	06	6W	I	C	CL	19	13	19	NW				100	80		20		
01.01.01	06	6W	I	C	CL	19	13	19	SW			25	75			100		
01.01.01	07	4WP	G	C	CL	19	14	23	NW			100			90		10	
01.01.01	07	4WP	G	C	CL	19	14	26	SE			100	100	90	15	95		
01.01.01	07	4WP	G	C	CL	19	14	26	SW				100	55	15		30	
01.01.01	08	4WP	H	C	CL	19	14	24	NW			100		15		35	50	
01.01.01	09	4WP	I	C	CL	19	14	23	SE			100		40	20	20	20	
01.01.01	09	4WP	I	C	CL	19	14	24	SW			100		25		70	5	
01.01.02	01	0	H	C	CL	19	14	21	NE			100			45	50		5
01.01.02	02	0	H	D	HB	19	14	22	SW			100	100			50		150
01.01.02	03	3W	E	C	CL	19	14	20	NE			100		80	20			
01.01.02	03	3W	E	C	CL	19	14	21	NW				100	80	5	15		
01.01.02	04	3W	F	C	CL	19	14	21	SW	100	100			105	40	55		
01.01.02	05	3W	H	C	CL	19	14	21	SE				100			100		
01.01.02	06	4FW	E	CD	L	19	14	19	NE				100	100				
01.01.02	07	4FW	E	CD	CL	19	14	19	NW			60	5	65				
01.01.02	08	4FW	F	CD	L	19	14	19	SE	100	100			115	25	60		
01.01.02	09	4WP	E	C	CL	19	14	20	NE				100		100			
01.01.02	09	4WP	E	C	CL	19	14	20	NW			100	100		55		145	
01.01.02	09	4WP	E	C	CL	19	14	27	NE				100	90		10		
01.01.02	10	4WP	E	CD	L	19	14	19	NE			100		30	70			
01.01.02	11	4WP	F	C	CL	19	14	20	SW			100	100	45	105		50	
01.01.02	11	4WP	F	C	CL	19	14	20	SE			100	100	195	5			
01.01.02	12	5WP	E	C	L	19	14	21	NW			100		40	15	45		
01.01.02	13	5WP	E	C	CL	19	14	27	NW			100		35		25	40	
01.01.02	13	5WP	E	C	CL	19	14	27	NE			100		35		50	15	
01.01.02	14	5WP	F	C	CL	19	14	27	SW			100		70	30			
01.01.02	14	5WP	F	C	CL	19	14	27	SE			100	100	50	35	25	90	
01.01.02	15	5WP	G	C	CL	19	14	22	NE	100	100			150			50	
01.01.02	16	5WP	G	CD	CL	19	14	22	NW			100	100		15	105	45	35
01.01.02	17	5WP	H	C	CL	19	14	21	SE			100				100		
01.01.02	17	5WP	H	C	CL	19	14	22	SE			100			65		35	
01.01.02	17	5WP	H	C	CL	19	14	21	NE				100			100		
01.01.02	18	5WP	H	D	CL	19	14	22	SE				100		50	5	25	20
01.01.02	19	2W	E	BC	L	19	14	28	NW				100	100				
01.01.02	20	3FP	E	C	CL	19	14	28	NE			100		50		50		
01.01.02	21	3W	H	BC	L	19	14	28	SE			100	100	120	10	70		
01.01.02	22	3W	E	BC	L	19	14	28	SW	100	100			200				
01.01.02	22	3W	E	BC	L	19	14	28	NW			100		100				
01.01.02	22	3W	E	BC	L	19	14	28	NE				100	100				

Table A1 (continued)

Soil and Land Use Data for the Big Grass Watershed

SUBWATERSHED	SOIL GRP.	CAP	PROD	HSG	SOIL TEX.	TWP.	RGE.	SEC.	QTR.	% OF 80 AC.				LAND USE				
										N	S	E	W	A	P	K	T	O
01.01.03	01	2w	C	CD	CL	18	15	33	NE	100	100			145	55			
01.01.03	01	2W	C	CD	CL	19	15	12	SW			100	100	175	5	20		
01.01.03	01	2W	C	CD	CL	19	15	3	NW	100	100			20	110		70	
01.01.03	01	2W	C	CD	CL	19	15	3	SE	100	100			200				
01.01.03	01	2W	C	CD	CL	19	15	3	SW	100	100			170			30	
01.01.03	01	2W	C	CD	CL	19	15	11	SE	100	100			160			40	
01.01.03	02	2W	C	CD	C	19	15	3	NE	100	100			135			65	
01.01.03	02	2W	C	CD	C	19	15	2	NW		100			80	20			
01.01.03	02	2W	C	CD	C	19	15	10	SW	35	85			95	25			
01.01.03	03	2W	C	CD	L	19	15	11	SW			100		75		15	10	
01.01.03	04	2W	C	CD	C	19	15	10	SE				100	95	5			
01.01.03	05	2W	C	CD	CL	19	15	12	SE				50	50				
01.01.03	05	2W	C	CD	CL	19	15	2	NE	100	100			150	35		15	
01.01.03	06	2W	C	CD	S	18	15	34	NW			5	60	60			5	
01.01.03	07	2W	C	D	C	19	15	2	SW	100	100			170	30			
01.01.03	08	2W	D	CD	CL	18	15	33	NW	100	100			190	10			
01.01.03	08	2W	D	CD	CL	19	14	18	SW	75	30			65		40		
01.01.03	09	2W	D	D	C	19	15	2	SE			100	100	140	25		35	
01.01.03	10	2W	E	CD	CL	19	15	11	NE		75			45			30	
01.01.03	10	2W	E	CD	CL	19	15	12	NW	100	100			145		5	50	
01.01.03	10	2W	E	CD	CL	19	14	18	NW	100	100			160	30		10	
01.01.03	11	2W	E	CD	C	19	15	12	NE			50	100	150				
01.01.03	11	2W	E	CD	C	19	15	13	SE	100	100			115	20	65		
01.01.03	12	2W	E	D	L	19	15	1	SW				100	100				
01.01.03	13	2W	G	CD	L	19	14	19	SW				100	100				
01.01.03	13	2W	G	CD	L	19	14	19	NW			50	95	145				
01.01.03	14	3F	C	CD	C	19	15	10	SE			100		55	45			
01.01.03	15	3F	C	CD	L	19	15	11	SW				100	100				
01.01.03	16	3F	C	CD	L	19	15	2	NW	100				55	5		40	
01.01.03	17	3F	E	CD	L	19	15	11	NE	25				5		20		
01.01.03	18	3F	E	CD	CL	19	15	13	SW				30	30				
01.01.03	19	3FM	D	CD	L	19	15	1	NW			100	100	190	10			
01.01.03	20	3FM	E	CD	L	19	15	1	SW			100		60	40			
01.01.03	21	3M	E	CD	S	19	15	13	SW			70		40		30		
01.01.03	22	3M	G	AB	S	19	15	13	NE	100	100			160		10	30	
01.01.03	22	3M	G	AB	S	19	15	24	NE			40	5	45				
01.01.03	22	3M	G	AB	S	19	15	24	SE			100	50	150				
01.01.03	23	4FM	F	CD	L	19	14	19	SW			100		75	25			
01.01.05	01	2W	D	AB	C	19	15	14	NW			100		60		10	30	
01.01.05	02	2W	D	CD	C	19	15	11	NW			100	100	15	100		60	25
01.01.05	02	2W	D	CD	C	19	15	14	SW			100		75	25			
01.01.05	03	2W	D	CD	L	19	15	23	NW			70	70	120		20		
01.01.05	03	2W	D	CD	L	19	15	23	SW			100		100				
01.01.05	04	2W	E	CD	L	19	15	14	NE				100	55		20	25	
01.01.05	04	2W	E	CD	L	19	15	14	SE				100	90	10			
01.01.05	05	2W	E	CD	C	19	15	22	NE			75		40	35			
01.01.05	05	2W	E	CD	C	19	15	11	NE				75	45	20		10	
01.01.05	06	2W	F	CD	L	19	15	23	NE			70	70	120	20			
01.01.05	07	3F	D	CD	L	19	15	10	NE			100	100	95				105
01.01.05	07	3F	D	CD	L	19	15	14	NW				100	85			15	
01.01.05	07	3F	D	CD	L	19	15	15	SE	100	100			150	20			30
01.01.05	07	3F	D	CD	L	19	15	15	NE	100	100			95	10		95	
01.01.05	07	3F	D	CD	L	19	15	15	NW			60		40	20			
01.01.05	07	3F	D	CD	L	19	15	22	SW			70		70				
01.01.05	07	3F	D	CD	L	19	15	22	SE			100	70	135			35	
01.01.05	07	3F	D	CD	L	19	15	14	SW				100	55	25			20
01.01.05	08	3M	G	AB	C	19	15	23	SE	100	100			155	25		20	
01.01.05	09	3F	D	CD	S	19	15	23	SW				100	100				
01.01.05	10	3F	E	CD	L	19	15	11	NE			25		10		15		
01.01.05	10	3F	E	CD	L	19	15	13	SW				75	50	10	15		
01.01.05	10	3F	E	CD	L	19	15	14	SE			100		80	5	15		
01.01.05	11	3M	E	AB	C	19	15	14	NE			100		80	20			
01.01.05	12	3M	E	CD	L	19	15	13	SW			25		20	5			

Table A1 (continued)

Soil and Land Use Data for the Big Grass Watershed

SUBWATERSHED	SOIL GRP.	CAP	PROD	HSG	SOIL TEX.	TWP.	RGE.	SEC.	QTR.	% OF 80 AC.				LAND USE				
										N	S	E	W	A	P	K	T	O
05.06.00	11	4WP	H	C	CL	18	12	16	NW			100	100	85	25		90	
05.06.00	11	4WP	H	C	CL	18	12	17	NE			100		30	10		60	
05.06.00	11	4WP	H	C	CL	18	12	18	NE			100		45			55	
05.06.00	11	4WP	H	C	CL	18	12	19	SE			100		100				
05.06.00	11	4WP	H	C	CL	18	12	20	SW			100	100	95			105	
05.06.00	11	4WP	H	C	CL	18	12	20	SE			100		90			10	
05.06.00	12	4WP	I	C	CL	18	12	17	NW	100	100				15		185	
05.06.00	13	5FM	H	AB	CL	18	12	17	NE				100	15	20		65	
05.06.00	13	5FM	H	AB	CL	18	12	20	SE				100	75			25	
05.07.00	01	2X	E	C	CL	18	12	14	NE			30	90	90		5	25	
05.07.00	01	2X	E	C	CL	18	12	14	SE			90	85	130			45	
05.07.00	01	2X	E	C	CL	18	12	14	SW	55	10			50		15		
05.07.00	01	2X	E	C	CL	18	12	14	NW			90	60	115			35	
05.08.00	01	2X	E	C	CL	18	12	11	NE			100	50	100			50	
05.08.00	01	2X	E	C	CL	18	12	12	NW				95	75	20			
05.08.00	02	3F	E	B	L	18	12	12	NW			80		80				
05.08.00	03	3F	E	B	CL	18	12	12	NE	60				55			5	
06.01.00	01	0	J	D	B	17	11	14	NW			100	100			70		130
06.01.00	01	0	J	D	B	17	11	14	SE			70	45					115
06.01.00	01	0	J	D	B	17	11	23	SW			60	100			70		90
06.01.00	01	0	J	D	B	17	11	23	NW				60			60		
06.01.00	01	0	J	D	B	17	11	14	NE			5	60					65
06.01.00	01	0	J	D	B	17	11	14	SW	50								50
06.01.00	02	0	J	D	HB	17	11	15	NE	100	50				40	80		30
06.01.00	02	0	J	D	HB	17	11	22	NE			100	100	70		90		40
06.01.00	02	0	J	D	HB	17	11	22	SE			100	100		10	170		20
06.01.00	03	0	F	C	CL	17	11	15	NW	40				40				
06.01.00	04	0	J	C	HB	17	11	27	SE			25	75	55	45			
06.01.00	05	2X	F	C	CL	17	11	20	NE	50	100			20		130		
06.01.00	05	2X	F	C	CL	17	11	20	SE	100	50			20		130		
06.01.00	05	2X	F	C	CL	17	11	21	NW	100	100			130	10	60		
06.01.00	05	2X	F	C	CL	17	11	21	NE	100	100			150	50			
06.01.00	05	2X	F	C	CL	17	11	21	SE	100	100			155		45		
06.01.00	05	2X	F	C	CL	17	11	21	SW	100	100			15		185		
06.01.00	05	2X	F	C	CL	17	11	22	NW				100	100				
06.01.00	05	2X	F	C	CL	17	11	22	SW				100	100				
06.01.00	05	2X	F	C	CL	17	11	27	SW	100	100			200				
06.01.00	05	2X	F	C	CL	17	11	28	NE	100	100			165	35			
06.01.00	05	2X	F	C	CL	17	11	28	NW			100	100	10	130	5	55	
06.01.00	05	2X	F	C	CL	17	11	28	SW	100					100			
06.01.00	05	2X	F	C	CL	17	11	28	SE			100	100	105	95			
06.01.00	05	2X	F	C	CL	17	11	29	NE	100	100						200	
06.01.00	05	2X	F	C	CL	17	11	29	SE	100				60			40	
06.01.00	05	2X	F	C	CL	17	11	29	NW			100	40			100	40	
06.01.00	05	2X	F	C	CL	17	11	31	NE			100	100	20	85	95		
06.01.00	05	2X	F	C	CL	17	11	31	SE	70	5			70			5	
06.01.00	05	2X	F	C	CL	17	11	32	SW	100	90			80			110	
06.01.00	05	2X	F	C	CL	17	11	32	NW			30	75	90			15	
06.01.00	05	2X	F	C	CL	17	11	32	SE			30	70	75	5	20		
06.01.00	05	2X	F	C	CL	17	11	20	NW		50			40		10		
06.01.00	05	2X	F	C	CL	17	11	20	SW	40				40				
06.01.00	05	2X	F	C	CL	17	11	27	NW				75	75				
06.01.00	05	2X	F	C	CL	17	11	29	SW	50				40		10		
06.01.00	06	4L	F	C	CL	17	11	28	SW		100				100			
06.01.00	06	4L	F	C	CL	17	11	27	NW			25		25				
06.01.00	06	4L	F	C	CL	17	11	29	SE		50			30			20	
06.01.00	07	5W	F	C	CL	17	11	22	NW			100		55	45			
06.01.00	07	5W	F	C	CL	17	11	22	SW			100		50	30	20		
06.02.00	01	2X	E	C	CL	18	12	11	SE	50				25			25	
06.02.00	01	2X	E	C	CL	18	12	12	NW		30			30				
06.02.00	02	2X	F	C	CL	18	11	6	NW			100	100	85	30		85	
06.02.00	02	2X	F	C	CL	18	11	6	SW	100	50			40			110	
06.02.00	02	2X	F	C	CL	18	11	6	SE				100	70	15		15	

Table A1 (continued)

Soil and Land Use Data for the Big Grass Watershed

SUBWATERSHED	SOIL GRP.	CAP	PROD	HSG	SOIL TEX.	TWP.	RGE.	SEC.	QTR.	% OF 80 AC.				LAND USE				
										N	S	E	W	A	P	K	T	O
06.02.00	02	2X	F	C	CL	18	12	7	SE			100	100	200				
06.02.00	02	2X	F	C	CL	18	12	1	NE			100	100	60	25		115	
06.02.00	02	2X	F	C	CL	18	12	12	SW				60	30			30	
06.02.00	02	2X	F	C	CL	18	12	1	NW			50		50				
06.02.00	03	2X	F	B	CL	18	12	12	NE	40				25		10	5	
06.02.00	04	2X	F	C	L	18	12	1	SW			5		5				
06.02.00	04	2X	F	C	L	18	12	1	SE	80	5			50	35			
06.02.00	05	2X	G	C	CL	18	11	6	NE				100		100			
06.02.00	05	2X	G	C	CL	18	12	12	SE		100			85			15	
06.02.00	06	3F	F	B	L	18	12	12	NE		100			100				
06.02.00	06	3F	F	B	L	18	12	12	SE	100				100				
06.02.00	07	3F	F	C	CL	18	12	12	SW			100		60			40	
06.02.00	08	4WP	F	C	L	18	11	6	SE			100		40	60			
06.02.00	09	4WP	G	C	CL	18	11	7	SE				100	50			50	
06.02.00	09	4WP	G	C	CL	18	11	6	NE			100		30	40		30	
06.02.00	10	3FW	G	C	CL	18	11	7	SE			100		100				

*** NO. OF RECORDS= 2220

Table A2

Present Land Use in the Big Grass Watershed

SWS NO.	CROPS		FORAGE		PASTURE		TREES		OTHER		AREA
	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES
1.01.01	772	24.5	276	8.7	1512	47.9	568	18.0	28	0.9	3156
1.01.02	1564	45.8	552	16.2	732	21.5	396	11.6	168	4.9	3412
1.01.03	3280	78.4	396	9.5	164	3.9	344	8.2	0	0	4184
1.01.05	1628	62.7	348	13.4	196	7.6	280	10.8	144	5.5	2596
1.01.07	184	76.7	32	13.3	0	0	24	10.0	0	0	240
1.02.00	1240	57.1	88	4.1	120	5.5	724	33.3	0	0	2172
1.03.01	408	23.7	344	20.0	600	34.9	368	21.4	0	0	1720
1.03.02	232	25.8	12	1.3	416	46.2	240	26.7	0	0	900
1.03.03	1120	21.2	892	16.9	1308	24.8	1752	33.2	208	3.9	5280
1.03.04	584	11.1	480	9.1	1352	25.6	2756	52.2	108	2.0	5280
1.04.00	988	30.2	528	16.2	1396	42.7	356	10.9	0	0	3268
1.05.00	1028	41.4	608	24.5	368	14.8	480	19.3	0	0	2484
1.06.00	776	23.1	456	13.6	1036	30.9	1088	32.4	0	0	3356
2.01.01	1808	69.1	116	4.4	88	3.4	500	19.1	104	4.0	2616
2.01.02	1144	57.9	132	6.7	352	17.8	348	17.6	0	0	1976
2.01.03	1092	51.1	680	31.8	108	5.1	256	11.0	0	0	2136
2.01.04	668	52.1	184	14.4	60	4.7	368	28.8	0	0	1280

Table A2 (continued)

Present Land Use in the Big Grass Watershed

SWS NO.	CROPS		FORAGE		PASTURE		TREES		OTHER		AREA
	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES
2.02.01	1800	75.3	104	4.3	40	1.7	400	16.7	48	2.0	2392
2.02.02	1292	67.3	184	9.6	192	10.0	252	13.1	0	0	1920
2.02.03	1088	56.7	180	9.4	216	11.2	436	22.7	0	0	1920
2.02.04	2380	74.4	168	5.2	144	4.5	508	15.9	0	0	3200
2.03.00	492	43.9	48	4.3	244	21.8	316	28.2	20	1.8	1120
2.04.01	1680	50.9	40	1.2	856	25.9	492	14.9	232	7.1	3300
2.04.02	1324	28.1	412	8.7	1556	33.0	1172	24.9	248	5.3	4712
2.04.03	2968	67.6	248	5.6	488	11.1	648	14.8	40	0.9	4392
2.04.04	2752	69.5	236	6.0	236	6.0	736	18.5	0	0	3960
2.05.00	416	55.9	84	11.3	16	2.2	200	26.9	28	3.7	744
2.06.01	428	12.4	96	2.8	1716	49.7	812	23.5	400	11.6	3452
2.06.02	1564	40.7	388	10.1	1060	27.6	584	15.2	244	6.4	3840
2.06.03	1960	79.2	404	16.3	24	1.0	88	3.5	0	0	2476
2.07.00	740	45.6	228	14.0	48	3.0	588	36.2	20	1.2	1624
2.08.00	1320	77.8	212	12.5	28	1.7	136	8.0	0	0	1696
2.09.00	792	65.1	120	9.9	44	3.6	260	21.4	0	0	1216
2.10.00	1604	39.4	628	15.4	104	2.6	1732	42.6	0	0	4068

Table A2 (continued)

Present Land Use in the Big Grass Watershed

SWS NO.	CROPS		FORAGE		PASTURE		TREES		OTHER		AREA
	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES
2.11.00	608	32.7	92	5.0	780	41.9	380	20.4	0	0	1860
3.01.00	428	78.1	0	0	80	14.6	40	7.3	0	0	548
3.02.00	660	63.5	80	7.7	132	12.7	168	16.1	0	0	1040
3.03.00	468	40.6	224	19.4	60	5.2	356	30.9	44	3.9	1152
3.04.01	580	25.0	932	40.1	544	23.4	268	11.5	0	0	2324
3.04.02	1400	37.5	344	9.2	428	11.5	1564	41.8	0	0	3736
3.04.03	932	31.0	132	4.4	1236	41.1	676	22.5	32	1.0	3008
3.04.04	1296	48.9	436	16.5	692	26.1	224	8.0	0	0	2648
3.04.05	540	41.7	44	3.4	404	31.2	308	23.7	0	0	1296
3.04.06	16	4.4	116	32.2	108	30.0	112	31.1	8	2.3	360
3.05.00	212	66.3	0	0	88	27.5	20	6.2	0	0	320
3.06.01	1832	59.2	360	11.6	484	15.6	420	13.6	0	0	3096
3.06.02	1364	42.7	772	24.2	168	5.3	888	27.8	0	0	3192
3.06.03	1138	26.6	660	15.4	1136	26.5	1326	31.0	20	0.5	4280
3.06.04	1176	51.9	152	6.7	164	7.2	720	31.7	56	2.5	2268
3.06.05	1496	72.9	356	17.3	28	1.4	172	8.4	0	0	2052
3.06.06	816	61.1	312	23.4	8	0.6	200	14.9	0	0	1336
3.06.07	672	77.8	104	12.0	0	0	88	10.2	0	0	864
3.06.08	1996	52.8	348	9.2	460	12.2	976	25.8	0	0	3780
3.06.09	1976	65.9	308	10.3	180	6.0	536	17.8	0	0	3000
3.06.10	688	49.9	344	24.9	44	3.2	304	22.0	0	0	1380
3.06.11	1828	60.4	448	14.8	214	7.1	534	17.7	0	0	3024

Table A2 (continued)

Present Land Use in the Big Grass Watershed

SWS NO.	CROPS		FORAGE		PASTURE		TREES		OTHER		AREA
	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES
3.06.12	120	16.8	412	57.5	56	7.8	128	17.9	0	0	716
3.06.13	196	31.0	188	29.7	72	11.4	176	27.8	0	0	632
3.06.14	2952	55.5	536	10.1	696	13.1	1136	21.3	0	0	5320
3.06.15	572	92.9	8	1.3	28	4.5	8	1.3	0	0	616
3.06.16	300	63.0	84	17.6	16	3.4	28	5.9	48	10.1	476
3.07.01	1388	82.6	112	6.7	52	3.1	128	7.6	0	0	1680
3.07.02	916	40.0	184	8.0	228	10.0	960	42.0	0	0	2288
4.01.00	1112	76.0	28	1.9	208	14.2	116	7.9	0	0	1464
4.02.00	1224	50.3	60	4.9	28	2.3	496	40.5	24	2.0	1224
4.03.00	944	83.4	72	6.2	36	3.2	80	7.0	0	0	1132
4.04.01	1196	34.8	72	2.1	792	23.0	1208	35.1	172	5.0	3440
4.04.02	380	34.8	0	0	204	18.7	508	46.5	0	0	1092
4.04.03	144	3.8	116	3.1	2908	77.0	340	9.0	268	7.1	3776
4.04.04	444	12.6	200	5.7	1012	28.8	1552	44.1	312	8.8	3520
4.04.05	8	0.2	200	5.2	396	10.3	3236	84.3	0	0	3840
4.04.06	276	9.9	208	7.4	1336	47.7	980	35.0	0	0	2800
4.05.00	784	88.7	20	2.3	24	2.7	56	6.3	0	0	884
4.06.00	1728	38.4	208	4.6	64	1.4	2504	55.6	0	0	4504
4.07.01	2488	58.4	184	4.3	252	5.9	1336	31.4	0	0	4260
4.07.02	1452	47.5	112	3.7	140	4.6	1352	44.2	0	0	3056
4.08.00	1256	56.3	176	7.9	0	0	800	35.8	0	0	2232
4.09.00	828	89.2	20	2.2	36	3.9	44	4.7	0	0	928

Table A2 (continued)

Present Land Use in the Big Grass Watershed

SWS NO.	CROPS		FORAGE		PASTURE		TREES		OTHER		AREA
	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES	PERCENT	ACRES
4.10.00	1700	65.8	24	0.9	24	0.9	832	32.2	4	0.2	2584
5.01.01	2156	96.3	12	0.5	56	2.5	16	0.7	0	0	2240
5.01.02	2338	48.1	586	12.1	640	13.2	1272	26.2	24	0.4	4860
5.02.01	1668	87.8	44	2.3	92	4.8	96	5.1	0	0	1900
5.02.02	1244	74.0	144	8.6	32	1.9	260	15.5	0	0	1680
5.03.00	1920	46.4	644	15.6	404	9.8	1152	27.8	20	0.4	4140
5.04.00	1692	60.8	352	12.7	196	7.1	540	19.4	0	0	2780
5.05.00	1124	48.5	228	9.8	40	1.7	928	40.0	0	0	2320
5.06.00	1360	61.6	84	3.8	48	2.2	716	32.2	0	0	2208
5.07.00	308	75.5	0	0	16	3.9	84	20.6	0	0	408
5.08.00	248	80.5	16	5.2	0	0	44	14.3	0	0	308
6.01.00	1668	39.8	624	14.9	1080	25.8	388	9.3	432	10.3	4192
6.02.00	988	59.7	244	14.7	8	0.5	416	25.1	0	0	1656

INPUT DATA FOR THE RUNOFF AND PE SUBMODELS

The input data used in the runoff and precipitation excess submodels are given in Table A3. It consists of hydrology data, drain capacities, location and distances from the precipitation recording stations for each subwatershed. The subwatersheds appear in the logical sequence in which runoff is estimated and traced through the system. All tributaries entering the system in the various subwatersheds are identified so that their contributing flows through the subwatersheds are aggregated to derive total discharge. The data for each subwatershed are presented in two sections. The section identification is given by the first column. Section one gives the following information (sequentially from left to right):

(i) subwatershed number

(ii) outflow tributary number

(iii) inflow tributary number

(iv) L

(v) H

(vi) A

(vii) runoff curve number (CN1, CN2, CN3)

(viii) an indicator (x) to denote whether another inflow tributary enters the system in the particular subwatershed (otherwise blank)

(ix) an indicator (E) to denote that the subwatershed is located on the escarpment (otherwise blank).

The first section of data for each subwatershed occupies as many rows as there are inflow tributaries into that subwatershed. The information listed above will be repeated with only the inflow tributary number being changed.

The second section of the data for each subwatershed is distinguished from the first section by the number in the first column. Section one is identified with a '1' and section two with a '2'. The data contained in section two are:

(i) subwatershed number

(i) outflow tributary number

(iii) capacities at the outlet of each subwatershed - the existing and three improved designs

(iv) the distance from the mid-point of the subwatershed to each of the precipitation recording stations.

First order tributaries were numbered in the '100' series. Similarly, second, third and fourth order tributaries were numbered in the '200', '300' and '400' series, respectively. The first order tributaries were of the smallest order and consequently had no channels flowing into them. But first order tributaries discharged into second order tributaries and the latter became the inflow into the third order tributaries which in turn flowed in the main channel, identified as '400'. Generally, the hydrologic model traced runoff for a portion of the watershed in the following sequence:

(i) estimating runoff along all first order tributaries up to the

point where these enter second order tributaries and then storing the results

(ii) estimating runoff along all second order tributaries; adding in the inflow from first order tributaries; and storing the results

(iii) estimating runoff along all third order tributaries and adding in the inflow from the second order tributaries.

Because the subwatersheds are presented in the logical sequence necessary, the first and second order tributary numbers were not required to be unique and are not. An inflow tributary number '0' indicates that there are no inflow tributaries into the particular subwatershed.

Table A3

Input Data for the Runoff and PE Submodels

1	3.06.20 131	0	495.0	3.28	67 83 93	2.50	E			
2	3.06.20 131		600.0	600.0	600.0 600.0	24.8	28.0	20.0	11.5	
1	3.06.10 131	0	650.0	7.81	58 76 89	2.16				
2	3.06.10 131		8.0	8.0	8.0 8.0	20.8	23.5	22.5	10.8	
1	3.06.21 132	0	395.0	2.03	76 89 96	1.38	E			
2	3.06.21 132		600.0	600.0	600.0 600.0	24.3	27.0	20.0	10.5	
1	3.06.11 132	0	580.0	8.28	58 76 89	4.72				
2	3.06.11 132		180.0	180.0	180.0 180.0	20.8	22.5	22.5	10.3	
1	3.06.05 141	0	183.5	4.68	67 83 93	3.21				
2	3.06.05 141		100.0	100.0	100.0 100.0	17.0	21.8	26.8	15.0	
1	3.06.06 142	0	179.5	4.21	66 82 92	2.09				
2	3.06.06 142		100.0	100.0	100.0 100.0	17.5	22.0	26.0	14.3	
1	3.06.07 143	0	122.0	3.28	64 81 92	1.35				
2	3.06.07 143		100.0	100.0	100.0 100.0	17.5	21.5	25.8	14.0	
1	3.06.18 144	0	437.0	2.80	63 80 91	4.13	E			
2	3.06.18 144		494.0	494.0	494.0 494.0	23.3	29.0	22.5	14.0	
1	3.06.08 144	0	707.0	10.00	58 76 89	5.91				
2	3.06.08 144		29.0	197.0	369.0 538.0	19.0	23.0	24.5	12.8	
1	3.04.06 145	0	4.2	1.25	62 79 91	0.56				
2	3.04.06 145		20.0	43.0	66.0 90.0	14.0	16.5	28.5	15.0	
1	3.04.05 161	0	21.0	2.50	63 80 91	2.02				
2	3.04.05 161		20.0	75.0	130.0 195.0	13.5	15.3	29.3	15.8	
1	3.03.00 162	0	8.6	1.75	44 64 81	1.80				
2	3.03.00 162		20.0	46.0	78.0 98.0	11.8	7.0	35.0	20.5	
1	3.06.22 201	0	1025.0	7.20	63 80 91	5.50	E			
2	3.06.22 201		670.0	670.0	670.0 670.0	25.8	28.5	18.3	9.8	
1	3.06.15 201	0	1074.8	8.64	70 85 94	0.96				
2	3.06.15 201		700.0	700.0	700.0 700.0	23.5	25.5	19.5	8.8	
1	3.06.13 202	0	75.0	2.34	47 67 83	0.99				
2	3.06.13 202		22.0	22.0	22.0 22.0	19.0	20.3	24.0	10.5	
1	3.06.19 203	0	1050.0	5.93	68 84 93	5.88	E			
2	3.06.19 203		720.0	720.0	720.0 720.0	25.5	29.0	20.5	12.8	
1	3.06.09 203 131	X	1300.0	11.86	58 76 89	4.69				
1	3.06.09 203 132		1300.0	11.86	58 76 89	4.69				
2	3.06.09 203		350.0	350.0	350.0 350.0	19.8	23.0	23.8	12.0	
1	3.06.12 203	0	1306.0	20.13	52 71 86	1.12				
2	3.06.12 203		12.0	336.0	642.0 949.0	17.5	19.0	25.3	11.8	
1	3.06.17 204	0	810.0	14.37	63 80 91	24.25	E			
2	3.06.17 204		950.0	950.0	950.0 950.0	28.3	32.5	21.0	15.3	
1	3.06.04 204	0	1060.0	21.55	62 79 91	3.54				
2	3.06.04 204		110.0	110.0	110.0 110.0	18.0	23.0	26.8	15.5	
1	3.06.03 204 141	X	1107.0	27.80	54 73 87	6.69				
1	3.06.03 204 142	X	1107.0	27.80	54 73 87	6.69				
1	3.06.03 204 143	X	1107.0	27.80	54 73 87	6.69				
1	3.06.03 204 144	X	1107.0	27.80	54 73 87	6.69				
1	3.06.03 204 145		1107.0	27.80	54 73 87	6.69				
2	3.06.03 204		178.0	646.0	1143.0 1614.0	15.3	18.0	27.8	14.3	
1	3.07.02 205	0	35.0	2.96	52 71 86	3.57				
2	3.07.02 205		48.0	122.0	196.0 269.0	16.8	15.8	27.0	12.8	
1	3.07.01 205	0	55.0	5.61	60 78 90	2.63				
2	3.07.01 205		28.0	80.0	236.0 392.0	14.5	11.8	30.3	15.8	
1	3.04.04 206	0	50.0	2.00	60 78 40	4.14				
2	3.04.04 206		20.0	111.0	203.0 294.0	12.8	16.5	29.8	16.5	
1	3.04.03 206 161		80.0	5.25	58 76 89	4.70				
2	3.04.03 206		17.0	93.0	133.0 173.0	11.5	14.3	31.5	17.8	
1	3.04.02 206	0	115.0	7.75	57 75 88	5.89				
2	3.04.02 206		92.0	298.0	533.0 771.0	10.8	11.5	32.8	18.8	
1	3.04.01 206 162		119.0	10.75	59 77 89	3.63				
2	3.04.01 206		93.0	369.0	652.0 928.0	11.3	9.0	33.5	19.3	
1	3.02.00 207	0	5.0	1.50	45 65 82	1.63				
2	3.02.00 207		11.0	29.0	47.0 63.0	13.3	7.3	34.5	20.0	
1	3.01.00 208	0	1.4	1.50	50 69 84	0.86				
2	3.01.00 208		25.0	47.0	82.0 112.0	14.3	7.8	35.0	19.3	
1	3.06.23 317	0	1025.0	4.64	75 88 95	6.63	E			

Table A3 (continued)

Input Data for the Runoff and PE Submodels

2	3.06.23 317			900.0 900.0 900.0 900.0	27.3	29.0	16.8	8.8
1	3.06.16 317 201			1074.8 5.64 66 82 92	0.74			
2	3.06.16 317			775.0 775.0 775.0 775.0	24.0	25.8	18.8	7.8
1	3.06.14 317 202		X	1242.8 14.05 59 77 89	8.31			
1	3.06.14 317 203			1242.8 14.05 59 77 89	8.31			
2	3.06.14 317			605.0 713.0 822.0 930.0	20.8	21.8	22.0	8.8
1	3.06.02 317 204			1276.0 18.05 58 76 89	4.99			
2	3.06.02 317			290.01047.01804.02561.0	15.8	16.0	27.8	13.8
1	3.06.01 317 205		X	1305.0 22.45 58 76 89	4.84			
1	3.06.01 317 206		X	1305.0 22.45 58 76 89	4.84			
1	3.06.01 317 207			1305.0 22.45 58 76 89	4.84			
2	3.06.01 317			240.01081.01923.02764.0	13.0	10.8	31.8	17.3
1	3.05.00 317 208			1307.0 23.45 67 83 93	0.50			
2	3.05.00 317			288.01209.02231.03100.0	14.0	8.8	33.0	18.5
1	1.01.06 201	0		870.0 4.40 67 83 93	4.63	E		
2	1.01.06 201			750.0 750.0 750.0 750.0	30.5	30.0	12.0	3.3
1	1.01.05 201	0		998.0 8.60 62 79 91	4.06			
2	1.01.05 201			100.0 100.0 100.0 100.0	29.3	27.0	14.3	1.0
1	1.01.07 201	0		1021.0 9.60 46 66 82	0.38			
2	1.01.07 201			1171.0 393.0 450.0 525.0	29.3	26.0	15.3	2.8
1	1.01.04 307	0		1020.0 6.80 63 80 91	14.75	E		
2	1.01.04 307			1090.01090.01090.01090.0	30.5	31.0	11.5	5.3
1	1.01.03 307	0		1246.2 12.60 67 83 93	6.54			
2	1.01.03 307			850.0 850.0 850.0 850.0	27.3	25.5	15.8	1.5
1	1.01.02 307 201			1272.5 16.60 64 81 92	5.33			
2	1.01.02 307			58.0 440.0 822.01208.0	27.0	23.5	19.0	5.8
1	1.01.01 307	0		1281.6 19.60 66 82 92	4.93			
2	1.01.01 307			102.0 496.0 896.01257.0	25.8	20.0	22.0	9.5
1	4.04.03 201	0		6.0 3.00 68 84 93	5.90			
2	4.04.03 201			45.0 66.0 87.0 109.0	24.3	12.5	37.8	24.5
1	4.06.00 202	0		42.2 5.20 55 74 88	7.04			
2	4.06.00 202			40.0 170.0 299.0 429.0	20.8	10.8	34.0	20.3
1	4.05.00 203	0		14.0 2.00 62 79 91	1.38			
2	4.05.00 203			29.0 55.0 82.0 118.0	19.5	8.0	37.3	23.5
1	4.07.02 204	0		6.0 2.00 38 58 76	4.77			
2	4.07.02 204			34.0 50.0 142.0 235.0	21.5	13.3	30.3	16.8
1	4.07.01 204	0		45.0 7.18 57 75 88	6.66			
2	4.07.01 204			30.0 161.0 292.0 423.0	18.8	8.8	34.3	20.3
1	4.08.00 205	0		47.2 4.30 57 75 88	3.49			
2	4.08.00 205			48.0 122.0 195.0 269.0	17.0	7.0	35.8	21.3
1	4.02.00 206	0		10.4 1.69 51 70 85	1.89			
2	4.02.00 206			20.0 49.0 109.0 186.0	17.3	4.8	40.3	26.0
1	4.04.06 320	0		23.0 2.00 63 80 91	4.50			
2	4.04.06 320			14.0 96.0 178.0 260.0	24.0	15.5	30.0	16.8
1	4.04.05 320	0		40.0 4.00 55 74 88	6.00			
2	4.04.05 320			11.0 161.0 311.0 460.0	23.8	14.0	32.8	19.3
1	4.04.04 320	0		50.0 6.00 60 78 90	5.50			
2	4.04.04 320			21.0 217.0 413.0 610.0	24.0	13.0	35.5	22.0
1	4.04.02 320 201			60.0 8.00 60 78 90	1.71			
2	4.04.02 320			12.0 226.0 440.0 654.0	22.3	10.8	36.5	23.0
1	4.04.01 320	0		81.5 13.75 62 79 91	5.38			
2	4.04.01 320			20.0 277.0 533.0 790.0	20.8	8.8	37.8	24.5
1	4.03.00 320 202		X	83.0 17.17 64 81 92	1.69			
1	4.03.00 320 203		X	83.0 17.17 64 81 92	1.69			
1	4.03.00 320 204		X	83.0 17.17 64 81 92	1.69			
1	4.03.00 320 205		X	83.0 17.17 64 81 92	1.69			
1	4.03.00 320 206			83.0 17.17 64 81 92	1.69			
2	4.03.00 320			227.0 734.01241.01747.0	17.3	5.0	38.8	24.8
1	1.02.00 306	0		12.0 3.00 48 68 84	3.39			
2	1.02.00 306			20.0 94.0 168.0 242.0	25.3	18.0	25.8	13.0
1	2.06.03 308	0		35.6 2.00 68 84 93	3.87			
2	2.06.03 308			40.0 124.0 208.0 287.0	26.3	23.5	17.8	3.8
1	2.06.02 308	0		60.0 5.00 66 82 92	6.02			
2	2.06.02 308			61.0 204.0 345.0 481.0	24.5	20.5	21.0	7.0
1	2.06.01 308	0		73.0 8.50 63 80 91	5.39			
2	2.06.01 308			38.0 213.0 400.0 577.0	22.5	17.3	24.8	11.0

Table A3 (continued)

Input Data for the Runoff and PE Submodels

1	2.10.00 309	0	17.0 3.43 32 52 71	6.36				
2	2.10.00 309		19.0 142.0 264.0 387.0	23.5	16.3	27.8	14.5	
1	2.05.00 310	0	2.8 1.30 54 73 87	1.16				
2	2.05.00 310		11.0 55.0 80.0 102.0	20.5	14.5	27.0	13.3	
1	2.04.05 311	0	1068.0 7.18 75 88 95	10.38	E			
2	2.04.05 311		2741.02741.02741.02741.0	29.0	29.5	14.0	6.3	
1	2.04.04 311	0	1225.2 10.77 63 80 91	6.19				
2	2.04.04 311		356.0 477.0 598.0 720.0	25.3	24.0	18.0	4.0	
1	2.04.03 311	0	1259.4 13.58 66 82 92	6.86				
2	2.04.03 311		288.0 493.0 724.0 927.0	23.0	21.3	20.0	6.0	
1	2.04.02 311	0	1278.0 16.70 64 81 92	7.36				
2	2.04.02 311		89.0 398.0 678.0 951.0	20.5	18.0	23.3	9.3	
1	2.04.01 311	0	1294.2 19.51 63 80 91	5.16				
2	2.04.01 311		251.0 429.0 752.01098.0	19.5	15.0	27.0	12.5	
1	2.03.00 312	0	10.5 1.48 63 80 91	1.75				
2	2.03.00 312		25.0 115.0 142.0 172.0	18.0	13.0	28.8	14.3	
1	2.08.00 313	0	14.4 2.77 46 66 82	2.65				
2	2.08.00 313		65.0 110.0 166.0 222.0	18.3	11.5	30.0	16.0	
1	2.02.05 314	0	831.6 4.30 75 88 95	3.88	E			
2	2.02.05 314		4311.04311.04311.04311.0	26.5	27.8	16.3.	6.5	
1	2.02.04 314	0	940.0 7.60 63 80 91	5.00				
2	2.02.04 314		424.0 424.0 424.0 424.0	24.0	24.0	18.3	5.5	
1	2.02.03 314	0	1014.6 10.60 63 80 91	3.00				
2	2.02.03 314		75.0 254.0 433.0 612.0	20.8	19.3	22.3	8.0	
1	2.02.02 314	0	1028.8 13.70 60 78 90	3.00				
2	2.02.02 314		51.0 260.0 469.0 679.0	18.5	16.0	25.5	11.5	
1	2.02.01 314	0	1053.0 17.20 60 78 90	3.74				
2	2.02.01 314		176.0 391.0 606.0 820.0	16.8	11.8	30.0	15.5	
1	2.07.00 315	0	13.6 1.98 42 62 79	2.54				
2	2.07.00 315		29.0 77.0 146.0 215.0	17.3	9.5	32.0	18.0	
1	2.01.04 316	0	60.0 2.00 58 76 89	2.00				
2	2.01.04 316		7.0 7.0 7.0 7.0	22.3	22.5	20.3	7.0	
1	2.01.03 316	0	165.0 3.00 60 78 90	3.34				
2	2.01.03 316		7.0 85.0 237.0 382.0	19.8	19.5	23.3	9.3	
1	2.01.02 316	0	175.0 6.00 57 75 88	3.09				
2	2.01.02 316		53.0 125.0 296.0 465.0	17.5	15.8	26.5	12.0	
1	2.01.01 316	0	190.0 10.00 62 79 91	4.09				
2	2.01.01 316		7.0 216.0 424.0 633.0	15.5	11.3	30.5	16.0	
1	4.09.00 318	0	3.0 1.50 60 78 90	1.45				
2	4.09.00 318		30.0 67.0 118.0 169.0	16.5	5.0	38.0	23.8	
1	5.06.00 319	0	50.0 3.60 57 75 88	3.45				
2	5.06.00 319		19.0 102.0 186.0 269.0	14.5	5.0	37.0	22.5	
1	5.05.00 321	0	41.6 2.60 55 74 88	3.63				
2	5.05.00 321		19.0 75.0 197.0 275.0	13.3	3.8	37.8	23.5	
1	4.01.00 322	0	8.0 1.87 66 82 92	2.29				
2	4.01.00 322		25.0 83.0 142.0 200.0	15.3	2.8	40.3	26.3	
1	5.04.00 323	0	60.0 2.72 54 73 87	4.34				
2	5.04.00 323		19.0 107.0 212.0 322.0	12.0	3.3	39.0	24.3	
1	5.03.00 324	0	72.4 6.60 52 71 86	6.47				
2	5.03.00 324		31.0 166.0 293.0 418.0	10.8	3.3	39.5	24.8	
1	5.02.02 325	0	50.0 2.00 55 74 88	2.63				
2	5.02.02 325		20.0 87.0 154.0 222.0	9.3	4.5	39.8	25.0	
1	5.02.01 325	0	71.0 5.10 62 79 91	2.97				
2	5.02.01 325		34.0 146.0 258.0 370.0	10.8	2.5	43.0	28.3	
1	5.01.02 326	0	55.0 3.60 57 75 88	7.59				
2	5.01.02 326		30.0 162.0 282.0 400.0	8.3	6.3	38.3	24.0	
1	5.01.01 326	0	78.0 7.80 62 79 91	3.50				
2	5.01.01 326		46.0 230.0 413.0 580.0	10.0	3.8	43.8	29.3	
1	1.05.00 303	0	13.1 3.40 62 79 91	3.88				
2	1.05.00 303		25.0 124.0 223.0 322.0	30.3	24.3	20.0	9.8	
1	1.04.00 304	0	13.0 3.20 66 82 92	5.11				
2	1.04.00 304		25.0 135.0 244.0 354.0	28.3	22.5	21.0	9.3	
1	1.03.04 305	0	25.0 3.83 47 67 83	8.38				
2	1.03.04 305		20.0 116.0 213.0 309.0	34.5	26.8	22.8	15.3	
1	1.03.03 305	0	50.0 7.16 55 74 88	8.25				
2	1.03.03 305		20.0 176.0 332.0 488.0	28.8	21.5	24.8	13.5	

Table A3 (continued)

Input Data for the Runoff and PE Submodels

1	1.06.00	400	303	X	5.0	1.52	64	81	92	5.24	
1	1.06.00	400	304		5.0	1.52	64	81	92	5.24	
2	1.06.00	400			30.0	106.0	177.0	253.0		31.0	24.3	21.3	11.5
1	1.03.02	400	305		6.2	3.21	66	82	92	1.41	
2	1.03.02	400			60.0	207.0	354.0	475.0		28.5	21.5	23.0	11.5
1	1.03.01	400	0		14.0	9.36	66	82	92	1.41	
2	1.03.01	400			130.0	334.0	541.0	752.0		26.5	19.5	24.3	11.8
1	2.11.00	400	307	X	14.0	4.90	59	77	89	2.91			
1	2.11.00	400	308	X	14.0	4.90	59	77	89	2.91			
1	2.11.00	400	309		14.0	4.90	59	77	89	2.91			
2	2.11.00	400			270.0	713.0	1178.0	1641.0		23.5	17.3	25.5	11.8
1	2.09.00	400	310	X	37.0	9.50	42	62	79	1.90			
1	2.09.00	400	311	X	37.0	9.50	42	62	79	1.90			
1	2.09.00	400	312	X	37.0	9.50	42	62	79	1.90			
1	2.09.00	400	313	X	37.0	9.50	42	62	79	1.90			
1	2.09.00	400	314		37.0	9.50	42	62	79	1.90			
2	2.09.00	400			564.0	1254.0	1900.0	2546.0		19.5	13.5	28.8	14.8
1	4.10.00	400	315	X	88.0	17.90	55	74	88	4.04			
1	4.10.00	400	316	X	88.0	17.90	55	74	88	4.04			
1	4.10.00	400	317	X	88.0	17.90	55	74	88	4.04			
1	4.10.00	400	318		88.0	17.90	55	74	88	4.04			
2	4.10.00	400			1348.0	1348.0	1348.0	1348.0		15.5	6.3	36.0	21.5
1	5.07.00	400	319	X	98.0	19.10	64	81	92	0.64			
1	5.07.00	400	320	X	98.0	19.10	64	81	92	0.64			
1	5.07.00	400	321		98.0	19.10	64	81	92	0.64			
2	5.07.00	400			1358.0	1358.0	1358.0	1358.0		14.3	2.3	39.8	25.5
1	5.08.00	400	322		100.0	19.90	60	78	90	0.48			
2	5.08.00	400			1360.0	1360.0	1360.0	1360.0		13.8	1.3	40.8	26.5
1	6.02.00	400	323	X	106.0	21.90	62	79	91	2.59			
1	6.02.00	400	324		106.0	21.90	62	79	91	2.59			
2	6.02.00	400			1366.0	1366.0	1366.0	1366.0		13.3	1.0	47.0	28.0
1	6.01.00	400	325	X	124.0	28.30	66	82	92	6.59			
1	6.01.00	400	326		124.0	28.30	66	82	92	6.59			
2	6.01.00	400			1384.0	1384.0	1384.0	1384.0		12.5	5.8	42.3	32.5

APPENDIX B

Table B1

Goodness of Fit (chi-square) Test for the Monthly Distributions of Daily Storm Frequencies Recorded at Grass River with that at Brandon

DATA:
(1) Grass River = 18 years (1958 - 75)
(2) Brandon = 80 years
(3) Oi = observed relative daily storm frequencies at Grass River
(4) Ei = expected daily storm frequencies = frequencies observed at Brandon
(5) N = number of events (days)

(A) Test for the distribution for the month of April

Range of Precip (ins.)	Relative Frequency		$\frac{N(Oi-Ei)}{Ei}$
	Ei (Brandon)	Oi (Grass River)	
0 - .1	.902	.893	.046
.1 - .2	.036	.037	.011
.2 - .3	.020	.021	.044
.3 - .4	.014	.012	.160
.4 - .5	.010	.008	.137
.5 - .7	.009	.014	1.573
.7 - 2.5	.010	.018	3.763

$$\chi^2(6, 0.05) = 12.59; \quad \hat{\chi}^2 = \sum \frac{N(O_i - E_i)^2}{E_i} = 6.13 \; \therefore \; \hat{\chi}^2 < \chi^2$$

(B) Test for the distribution for the month of May

Range of Precip (ins.)	Relative Frequencies		$\frac{N(Oi-Ei)^2}{Ei}$
	Ei (Brandon)	Oi (Grass River)	
0 - .1	.855	.842	.111
.1 - .2	.055	.057	.031
.2 - .3	.124	.125	.018
.3 - .4	.017	.025	1.923
.4 - .5	.014	.023	2.707
.5 - .6	.009	.015	2.203
.6 - .9	.013	.008	.949
.9 - 3.5	.012	.006	1.621

$$\chi^2(7, 0.05) = 14.07 \; ; \; \hat{\chi}^2 = \sum \frac{N(O_i - E_i)^2}{E_i} = 9.56 \; \therefore \; \hat{\chi}^2 < \chi^2$$

Table B1 (continued)

(C) Test for the distribution for the month of June

Range of Precip (ins.)	Relative Frequency		N (Oi-Ei) / Ei
	Ei (Brandon)	Oi (Grass River)	
0 - .1	.809	.830	.276
.1 - .2	.054	.049	.255
.2 - .3	.035	.027	1.021
.3 - .4	.024	.014	2.304
.4 - .5	.014	.018	.423
.5 - .6	.014	.006	2.551
.6 - .7	.010	.008	.137
.7 - 1.0	.015	.028	6.028
1.0 - 1.4	.012	.016	.683
1.4 - 4.5	.011	.006	1.236

$$\chi^2(9,0.05) = 16.92\ ;\ \hat{\chi}^2 = \sum \frac{N(O_i - E_i)^2}{E_i} = 14.92\ ;\ \therefore\ \hat{\chi}^2 < \chi^2$$

(D) Test for the distribution for the month of July

Range of Precip (ins.)	Relative Frequency		N (Oi-Ei) / Ei
	Ei (Brandon)	Oi (Grass River)	
0 - .1	.818	.808	.070
.1 - .2	.051	.065	1.928
.2 - .3	.033	.047	3.296
.3 - .4	.028	.027	.007
.4 - .5	.017	.006	3.297
.5 - .6	.010	.015	1.253
.6 - .8	.017	.015	.102
.8 - 1.2	.015	.004	4.496
1.2 - 3.0	.010	.014	.746

$$\chi^2(8,0.05) = 15.51\ ;\ \hat{\chi}^2 = \sum \frac{N(O_i - E_i)^2}{E_i} = 15.20\ ;\ \therefore\ \hat{\chi}^2 < \chi^2$$

(E) Test for the distribution for the month of August

Range of Precip (ins.)	Relative Frequency		N (Oi-Ei) / Ei
	Ei (Brandon)	Oi (Grass River)	
0 - .1	.845	.831	.114
.1 - .2	.046	.049	.089
.2 - .3	.028	.032	.301
.3 - .4	.019	.025	1.119
.4 - .5	.010	.019	3.626
.5 - .6	.014	.008	1.215
.6 - .8	.015	.014	.023
.8 - 1.2	.013	.020	1.779
1.2 - 3.5	.011	.004	2.166

$$\chi^2(8,0.05) = 15.51\ ;\ \hat{\chi}^2 = \sum \frac{N(O_i - E_i)^2}{E_i} = 10.43\ ;\ \therefore\ \hat{\chi}^2 < \chi^2$$

Conclusion for chi-square goodness of fit tests:

The results of the chi-square tests which examined the goodness of fit of the distribution of daily storm frequencies observed at Grass River with the frequency distributions at Brandon indicate that the distributions are statistically similar at the 5 percent level of significance for each of the months.

Computing Runoff Curve Numbers

The soil, soil cover and hydrologic characteristics of the soils in a subwatershed (or hydrologic) unit influence the amount of runoff resulting from a storm. Since these factors are usually varied it is desirable that the runoff curve number computed for the subwatershed be weighted on the basis of the land area for each soil-cover complex A complex is comprised of the following characteristics: hydrologic soil group-land cover (land use) - land treatment - hydrologic condition.

For each of the various complexes Table 9.4 gives the runoff curve number for antecedent moisture condition II - that is, CN II for AMC II. Curve numbers derived for AMC II are suitable for estimating runoff under moderate soil saturation condition.

The computation of CN II is demonstrated using the hypothetical example in Table B2. It is assumed that the distribution of hydrologic soil group is as follows:

(i) hydrologic soil group A = 20 percent of the subwatershed

(ii) hydrologic soil group C = 50 percent of the subwatershed

(iii) hydrologic soil group CD = 30 percent of the subwatershed

The land use or cover as a fraction of the respective soil group is given in the fourth column. The fifth column gives the hydrologic condition and the sixth gives the CN II values (from Table 9.4)

for the respective complexes. The weighted CN II value for the first complex is:

Group A - cropland (row crop) - good hydrologic condition

= (0.20 * 0.40 * 78)

= 6.24

The other value in Table B2 are computed similarly. The CN II value for the subwatershed is 81. The corresponding CN I and CN III values are 64 and 92, respectively. These are derived from Table 9.5 and are applicable for runoff estimation under dry and saturated conditions, respectively.

Table B2

Compution of the CN value for a Hydrologic Unit

Hydrologic Soil Group		Land Use				
Group Type	Proportion of the Subwatershed	Type	Proportion of the Soil Group	Hydrologic Condition	CN II	CN II (Weighted)
B	0.20	Cropland	0.40	good	78	6.24
		Forage	0.30	good	72	4.32
		Pasture	0.20	poor	79	3.16
		Trees	0.10	fair	60	1.20
C	0.50	Cropland	0.60	good	85	25.50
		Forage	0.20	good	81	8.10
		Pasture	0	poor	86	0
		Trees	0.20	fair	73	7.30
CD	0.30	Cropland	0.75	good	87	19.54
		Forage	0.05	poor	87	1.31
		Pasture	0.05	poor	87	1.31
		Trees	0.15	fair	75	3.38
						81.38

CN II = 81; CN I = 64; CN III = 92

APPENDIX C

DRAINAGE IMPROVEMENT COSTS

Drainage improvement costs were estimated separately for each of the subwatersheds in the Big Grass Watershed since the levels of development were non-uniform. For example, the level of protection provided by the level four design in one subwatershed may be different from the level four protection in another subwatershed.

The cost estimates given in Table C1 are the total costs for each component of the system for improvement from existing condition. For the majority of drainage channels in the Big Grass Watershed this meant total re-construction since there was no salvage from the existing system. Estimates includes the following costs:

(i) excavation

(ii) culverts, bridges

(iii) gradient control structures

(iv) right of way

(v) 15 percent contingency

Table C1

Drainage Development Costs

SUBWATERSHED	OUTLET CAPACITIES IN C.F.S.				DRAINAGE IMPROVEMENT COSTS ($ 1000)								
					LEVEL 2			LEVEL 3			LEVEL 4		
	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	MAIN	COLLECT-ION	ON-FARM	MAIN	COLLECT-ION	ON-FARM	MAIN	COLLECT-ION	ON-FARM
01.01.01	102.	496.	896.	1257.	3718.	277.	110.	5268.	440.	129.	6502.	546.	138.
01.01.02	58.	440.	822.	1208.	2197.	415.	128.	3388.	455.	150.	4471.	490.	162.
01.01.03	850.	850.	850.	850.	0.	422.	212.	0.	540.	438.	0.	635.	555.
01.01.05	100.	230.	388.	496.	1357.	537.	170.	1696.	691.	197.	2029.	826.	223.
01.01.07	1173.	393.	450.	525.	1140.	55.	17.	1236.	70.	21.	1364.	78.	24.
01.02.00	20.	94.	168.	242.	196.	121.	91.	286.	314.	114.	372.	410.	114.
01.03.01	130.	334.	541.	752.	603.	369.	91.	885.	439.	109.	1167.	480.	127.
01.03.02	60.	207.	354.	475.	565.	158.	60.	879.	201.	72.	1131.	245.	85.
01.03.03	20.	176.	332.	488.	1320.	726.	273.	1765.	998.	328.	2040.	1219.	382.
01.03.04	20.	94.	162.	225.	1056.	726.	273.	1412.	998.	328.	1632.	1219.	382.
01.04.00	25.	135.	244.	354.	429.	410.	203.	530.	522.	422.	649.	616.	530.
01.05.00	25.	124.	223.	322.	394.	369.	182.	488.	470.	194.	597.	563.	207.
01.06.00	30.	106.	177.	253.	193.	725.	171.	278.	808.	202.	386.	933.	217.
02.01.01	7.	216.	424.	633.	2662.	178.	46.	3477.	288.	150.	4428.	406.	166.
02.01.02	53.	125.	296.	465.	94.	177.	54.	1324.	249.	94.	1737.	300.	115.
02.01.03	7.	85.	237.	382.	49.	187.	52.	1482.	266.	91.	1766.	322.	110.
02.01.04	7.	67.	127.	184.	0.	264.	35.	0.	461.	60.	0.	618.	74.
02.02.01	176.	391.	606.	820.	2674.	292.	81.	3018.	334.	97.	3605.	419.	113.
02.02.02	51.	260.	469.	679.	1434.	203.	69.	1712.	258.	83.	2061.	296.	97.
02.02.03	75.	254.	433.	612.	1699.	203.	69.	1937.	258.	83.	2248.	333.	97.
02.03.00	25.	115.	142.	172.	205.	111.	60.	278.	108.	60.	339.	153.	85.
02.04.01	251.	429.	757.	1098.	2738.	384.	151.	3839.	521.	211.	4696.	591.	227.
02.04.02	89.	398.	678.	951.	1616.	618.	216.	2265.	715.	259.	2845.	854.	302.
02.04.03	288.	493.	724.	927.	1999.	745.	233.	2439.	875.	279.	2910.	1033.	327.
02.04.04	356.	477.	598.	720.	776.	0.	10.	933.	0.	12.	1101.	0.	13.
02.05.00	11.	55.	80.	102.	104.	127.	36.	208.	237.	39.	230.	186.	44.
02.06.01	38.	213.	400.	577.	1919.	362.	108.	2566.	493.	170.	3043.	618.	216.
02.06.02	61.	204.	345.	481.	956.	428.	173.	1363.	525.	266.	1998.	685.	285.
02.06.03	40.	124.	208.	287.	1022.	363.	107.	1311.	448.	134.	1643.	549.	143.
02.07.00	29.	77.	146.	215.	178.	110.	83.	260.	285.	104.	338.	373.	104.
02.08.00	65.	110.	166.	222.	343.	205.	101.	424.	261.	108.	519.	313.	115.
02.09.00	564.	1254.	1900.	2546.	7330.	292.	75.	10195.	351.	83.	13825.	418.	95.
02.10.00	19.	142.	264.	387.	472.	451.	223.	583.	574.	464.	714.	678.	253.
02.11.00	270.	713.	1178.	1641.	1140.	456.	124.	1560.	569.	139.	2090.	677.	155.
03.01.00	25.	47.	82.	112.	113.	74.	20.	155.	106.	20.	191.	116.	24.
03.02.00	11.	29.	47.	63.	78.	106.	67.	129.	126.	112.	167.	152.	131.
03.03.00	20.	46.	78.	98.	194.	168.	48.	248.	222.	60.	296.	292.	91.
03.04.01	93.	369.	652.	928.	2274.	397.	125.	2703.	559.	155.	3175.	691.	175.
03.04.02	92.	298.	533.	771.	1511.	476.	194.	1808.	675.	233.	2213.	760.	272.
03.04.03	17.	93.	133.	173.	375.	341.	115.	474.	398.	150.	586.	469.	161.
03.04.04	20.	111.	203.	294.	93.	283.	71.	1201.	517.	111.	1307.	654.	142.

Table C1 (continued)

Drainage Development Costs

SUBWATERSHED	OUTLET CAPACITIES IN C.F.S.				DRAINAGE IMPROVEMENT COSTS ($ 1000)								
					LEVEL 2			LEVEL 3			LEVEL 4		
	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	MAIN	COLLECT-ION	ON-FARM	MAIN	COLLECT-ION	ON-FARM	MAIN	COLLECT-ION	ON-FARM
03.04.05	20.	75.	130.	185.	178.	110.	83.	260.	285.	104.	338.	323.	104.
03.04.06	20.	43.	66.	90.	117.	50.	20.	148.	65.	20.	180.	80.	20.
03.05.00	288.	1209.	2231.	3100.	697.	92.	58.	1045.	104.	69.	1362.	115.	81.
03.06.01	240.	1081.	1923.	2764.	4410.	410.	203.	6006.	522.	422.	7870.	616.	530.
03.06.02	290.	1047.	1804.	2561.	3728.	415.	208.	4813.	530.	430.	6150.	625.	540.
03.06.03	178.	646.	1143.	1614.	4817.	698.	161.	7076.	871.	217.	8851.	1157.	256.
03.06.04	110.	470.	779.	1071.	1407.	30.	17.	1791.	40.	26.	2223.	54.	31.
03.06.08	29.	197.	369.	538.	802.	192.	48.	112.	217.	51.	1415.	305.	53.
03.06.12	12.	336.	642.	949.	1345.	152.	43.	1794.	210.	43.	2267.	253.	60.
03.06.13	22.	63.	97.	116.	167.	162.	35.	212.	192.	35.	257.	211.	35.
03.06.14	605.	713.	822.	930.	1999.	230.	61.	2100.	346.	70.	2300.	450.	80.
03.07.01	28.	80.	236.	392.	511.	271.	98.	1146.	467.	147.	1452.	666.	177.
03.07.02	48.	122.	196.	269.	391.	355.	131.	794.	495.	170.	955.	562.	196.
04.01.00	25.	83.	142.	200.	178.	110.	83.	260.	285.	104.	338.	373.	104.
04.02.00	20.	49.	109.	186.	33.	121.	65.	343.	169.	91.	512.	235.	97.
04.03.00	222.	734.	1241.	1747.	2403.	80.	73.	3420.	106.	88.	4530.	122.	103.
04.04.01	20.	277.	533.	790.	1363.	661.	158.	1734.	776.	206.	2214.	860.	230.
04.04.02	12.	226.	440.	654.	500.	214.	75.	754.	269.	83.	979.	329.	92.
04.04.03	45.	66.	87.	109.	768.	552.	173.	974.	710.	224.	1171.	865.	242.
04.04.04	21.	217.	413.	610.	736.	661.	158.	1064.	776.	206.	1307.	860.	230.
04.04.05	11.	161.	311.	460.	761.	612.	173.	1097.	767.	224.	1532.	903.	250.
04.04.06	14.	96.	178.	260.	405.	572.	155.	677.	733.	181.	809.	859.	194.
04.05.00	29.	55.	82.	118.	35.	42.	72.	173.	79.	78.	228.	102.	78.
04.06.00	40.	170.	299.	429.	42.	384.	107.	353.	558.	122.	483.	704.	135.
04.07.01	30.	161.	292.	423.	2139.	955.	253.	2749.	1116.	288.	3519.	1300.	315.
04.07.02	34.	50.	142.	235.	28.	256.	71.	235.	372.	81.	322.	469.	90.
04.08.00	48.	122.	195.	269.	1222.	296.	131.	1370.	375.	146.	1622.	352.	156.
04.09.00	30.	67.	118.	169.	385.	225.	60.	510.	277.	75.	626.	339.	86.
04.10.00	1105.	2529.	3953.	5377.	0.	280.	75.	0.	310.	85.	0.	400.	103.
05.01.01	46.	230.	413.	580.	1695.	363.	104.	2586.	456.	155.	3409.	613.	166.
05.01.02	30.	162.	282.	400.	743.	946.	190.	975.	1258.	266.	1190.	1588.	285.
05.02.01	34.	146.	258.	370.	802.	275.	95.	1237.	369.	121.	1657.	483.	138.
05.02.02	20.	87.	154.	222.	298.	321.	83.	359.	412.	106.	426.	533.	121.
05.03.00	31.	166.	293.	418.	2591.	413.	229.	3141.	581.	274.	3584.	692.	343.
05.04.00	19.	107.	212.	322.	164.	389.	126.	853.	614.	176.	1164.	860.	189.
05.05.00	19.	75.	197.	275.	93.	283.	71.	1201.	517.	111.	1307.	654.	142.
05.06.00	19.	102.	186.	269.	93.	283.	71.	1201.	517.	111.	1307.	654.	152.
05.07.00	1308.	2922.	4536.	6150.	0.	92.	58.	0.	104.	69.	0.	115.	81.
05.08.00	1231.	2908.	4584.	6261.	0.	80.	45.	0.	95.	60.	0.	103.	70.
06.01.00	300.	2407.	4514.	6621.	0.	552.	173.	0.	710.	224.	0.	860.	230.
06.02.00	1470.	3163.	4857.	6550.	0.	270.	70.	0.	300.	80.	0.	400.	105.

Table C2

Average Agricultural Prices

Year	Farm[1] Input Price Index	Average Farm Prices			
		Wheat ($/Bu)	Oats ($/Bu)	Barley ($/Bu)	Tame Hay ($/Ton)
1970	131.0	1.45	0.50	0.80	16.50
1971	135.9	1.37	0.53	0.78	16.50
1972	145.2	1.86	0.90	1.26	20.00
1973	162.9	4.30	1.63	2.51	30.00
1974	190.7	4.00	1.53	2.22	35.00
1975	217.0	3.50	1.44	2.28	37.00
1976	229.3	2.75	1.25	1.75	40.00
Average[2] (normalized) Prices (1970-76)		3.59	1.44	2.15	35.96

Source: Yearbook of Manitoba Agriculture: 1976

1. Farm input price index is based, 1961 = 100, and does not include the cost of land.

2. To compute average normalized prices the values for the various years are first converted to constant 1976 dollars according to the equation:

$$\text{Price for year } t \text{ in 1976 dollars} = \left[\text{Price } (t) * \frac{\text{Price Index 1976)}}{\text{Price Index } (t)}\right]$$

Where: t = year.

Table C3

Cost of Production For Wheat, Oats and Barley - 1976

COSTS	WHEAT	OATS	BARLEY
Operating Costs		($ /acre)	
1. Seed[1]	$ 7.20	$ 4.90	$ 5.95
2. Fertilizer[2]	4.40	2.78	4.41
3. Herbiside[3]	2.05	2.05	2.05
4. Repairs	2.50	2.50	2.50
5. Fuel	3.00	3.00	3.00
6. Miscellaneous	2.50	2.50	2.50
7. Interest on operating costs (11% for 6 months)	1.19	0.98	1.12
Total Operating Costs	$22.84	$18.71	$21.53
Fixed Costs			
1. Depreciation			
Machinery	$ 7.50	$ 7.50	$ 7.50
Buildings	1.00	1.00	1.00
2. Investment			
Machinery	3.75	3.75	3.75
Buildings	1.00	1.00	1.00
3. Taxes	2.00	2.00	2.00
Total Fixed Costs	$15.25	$15.25	$15.25
Total Production Costs /acre	$38.00	$34.00	$37.75

SOURCE: Manitoba Dept. of Agriculture, Economics Branch.

NOTE:

(i) Costs exclude land, labor, management and crop insurance charges.

(ii) Estimates were adjusted as follows:

1. Seed: (a) Wheat 90 lbs/acre @ 8¢ /lb.
(b) Oats 70 lbs/acre @ 7¢ /lb.
(c) Barley 85 lbs/acre @ 7¢ /lb.

2. Fertilizer:

(a) Present Application

Crop	Application Rate		
	N	P	K
Wheat	6.17	19.27	0.16
Oats	6.57	9.67	0.08
Barley	9.32	16.33	0.32

(b) Prices
11 - 48 - 0 @ $10.00 /100 lbs.
34 - 0 - 0 @ 6.00 /100 lbs.
0 - 0 - 62 @ 5.00 /100 lbs.

3. Herbicides: Avadex and MCPA
= 25% of normal application
(i.e. 0.25 * $8.20)

Table C3(cont'd)

Cost of Production for Tame Hay - 1976

A. ESTABLISHMENT YEAR

		($ /acre)
1. Cost of Seeding Forage and Nurse Crop		
Machinery	$	4.00
Fertilizer		4.40
Chemical		0.90
Seeding Costs	$	9.30
2. Specific Forage Costs		
Seed: 6 lbs alfalta @ $1.00 /lb		6.00
3 lbs brome @ $0.50 /lb		1.50
fertilizer: 50 lbs 11-48-0 in fall @ $0.10 /lb		5.00
application		.65
Specific Forage Costs	$	13.65
Total Establishment Year Costs		
- 0.5 * Seeding cost (balance charged to nurse crop)	$	4.65
- Specific forage cost		13.65
- Tax on land		2.00
- Interest (11% for 4 years on remaining balance 4 equal payments)		5.55
Total Establishment Year Costs (to be spread in equal amounts over four years)	$	25.85

B. CROPPING YEARS

1. Fertilizer 21 lbs 34-0-0 @ $6.00 /100 lbs	$	2.66
2. Application: 14 lbs 11-48-0 @ $10.00 /100 lbs		1.00
2. Taxes		2.00
3. Share of establishment year cost		6.46
	$	12.12
4. Harvesting cost per ton	$	8.50

Total Annual Cost = $(12.12 + $8.50Y)
Where: Y = yield in tons

SOURCE: Manitoba Department of Agriculture

NOTE: Estimates were adjusted to reflect a lower level of fertilizer application - 44 lbs of 11-48-0 only in the establishment year.

Table C4

Price Index of Farm Inputs (1971 = 100)

Year	Farm Input Price Index
1946	40.7
1947	43.9
1948	50.4
1949	52.8
1950	54.8
1951	59.7
1952	63.1
1953	61.4
1954	60.6
1955	62.2
1956	64.4
1957	66.4
1958	68.3
1959	70.4
1960	72.3
1961	73.6
1962	78.9
1963	81.4
1964	81.2
1965	84.0
1966	88.7
1967	89.5
1968	92.4
1969	95.8
1970	96.4
1971	100.0
1972	106.8
1973	119.9
1974	140.3
1975	159.7
1976	168.5

Source: Yearbook of Manitoba Agriculture.

Note: Index does not include the cost of land.

Table C5

The Chi-square Goodness of Fit Test for a Normal Distribution in the Deflated Price Series: Wheat, 1950 - 76

Price Range	Observed Frequency (Oi)	Expected Frequency (Ei)	$\frac{(Oi - Ei)^2}{Ei}$
0.63 - 1.13 1.13 - 1.63	5	4.24	0.014
1.63 - 2.13	10	9.21	0.005
2.13 - 2.63	9	9.21	0.068
2.63 - 3.13 3.13 - 3.63	4	4.24	0.136
			0.223

$\bar{X}$ = \$2.13 /BU: S = \$0.50

$\hat{\chi}^2$ = 0.223 ; $\chi^2(1, 0.05) = 3.84$

Since $\hat{\chi}^2 < \chi^2$ it can be concluded that the distribution of the annual deflated price of wheat is approximately normal.

Table C6

The Chi-square Goodness of Fit Test for a Normal Distribution in the Deflated Price Series: Oats, 1950 - 75

Price Range	Observed Frequency (Oi)	Expected Frequency (Ei)	$\frac{(Oi - Ei)^2}{Ei}$
0.20 - 0.42 0.42 - 0.64	4	4.24	0.014
0.64 - 0.86	13	9.21	1.118
0.86 - 1.08	6	9.21	1.559
1.08 - 1.30 1.30 - 1.52	4	4.24	0.014
			2.705

$\bar{x}$ = \$0.86 /BU; S = \$0.22

$\hat{\chi}^2 = 2.705$; $\chi^2(1, 0.05) = 3.84$

Since $\hat{\chi}^2 < \chi^2$ it can be concluded that the distribution of annual deflated price of oats is approximately normal.

Table C7

The Chi-square Goodness of Fit Test for a Normal Distribution in the Deflated Price Series: Barley, 1950 - 76

Price Range	Observed Frequency (Oi)	Expected Frequency (Ei)	$\frac{(Oi - Ei)^2}{Ei}$
0.22 - 0.58 0.58 - 0.94	4	4.24	0.014
0.94 - 1.30	13	9.21	1.118
1.30 - 1.66	6	9.21	1.559
1.66 - 2.02 2.02 - 2.38	4	4.21	0.014
			2.705

$\bar{X}$ = \$1.30 /BU; S = \$0.36

$\hat{\chi}^2$ = 2.705; $\chi^2(1,0.05)$ = 3.84

Since $\hat{\chi}^2 < \chi^2$ it can be concluded that the distribution of annual deflated price of barley is approximately normal.

Table C8

The Chi-square Goodness of Fit Test for a Normal Distribution in the Deflated Price Series: Tame Hay, 1950 - 76

Price Range	Observed Frequency (Oi)	Expected Frequency (Ei)	$\frac{(Oi - Ei)^2}{Ei}$
10.76 - 13.69 13.69 - 16.62	5	4.24	0.730
16.62 - 19.55	9	9.21	0.510
19.55 - 22.48	7	9.21	0.005
22.48 - 25.41 25.41 - 28.34	6	4.21	0.136
			1.38

$\bar{X}$ = \$19.55 /ton; S = \$2.93

$\hat{\chi}^2$ = 1.38; $\chi^2(1,0.05)$ = 3.84

Since $\hat{\chi}^2 < \chi^2$ it can be concluded that the distribution of annual deflated price of tame hay is approximately normal.

Table C9

The Chi-square Goodness of Fit Test for a Normal Distribution in the Annual Change of the Farm Input Price Index (1971 = 100)

Price Range	Observed Frequency (Oi)	Expected Frequency (Ei)	$\frac{(Oi - Ei)^2}{Ei}$
- 4.00 - (- 1.72) - 1.72 - 0.56	3	3.34	0.035
0.56 - 2.84	12	9.55	0.629
2.84 - 5.12	9	9.55	0.032
5.12 - 7.40 7.40 - 9.08	4	3.34	0.130
			0.826

Observation period: 1946 - 1976, excluding 1973 - 75.

$\bar{x} = 2.84$; $S = 2.28$

$\hat{\chi}^2 = 0.826$; $\chi^2(1, 0.05) = 3.84$

Since $\hat{\chi}^2 < \chi^2$ it can be concluded that the distribution of annual change in the farm input price index is approximately normal.

APPENDIX D

Table D1

Probability of Daily Storm Events for the Months

April to September at Brandon*

Precip. Range (ins.)	Probability in Percent					
	April	May	June	July	August	Sept.
0.0	82.12	73.88	64.64	68.66	73.26	77.02
0.0 - 0.1	8.09	11.66	16.27	13.18	11.19	10.85
0.1 - 0.2	3.60	5.51	5.42	5.13	4.62	3.70
0.2 - 0.3	1.96	2.41	3.53	3.26	2.79	2.27
0.3 - 0.4	1.40	1.71	2.45	2.76	1.86	1.09
0.4 - 0.5	.96	1.43	1.44	1.71	1.04	1.30
0.5 - 0.6	.64	.89	.96	1.01	1.36	.65
0.6 - 0.7	.24	.58	.56	8.55	.70	.69
0.7 - 0.8	.44	.35	.48	.81	.77	.73
0.8 - 0.9	.12	.35	.44	.54	.31	.03
0.9 - 1.0	.12	.38	.60	.27	.50	.52
1.0 - 1.2	.08	.23	.60	.73	.50	.40
1.2 - 1.4	.08	.11	.32	.15	.35	.08
1.4 - 1.6	.08	.27	.24	.42	.31	.16
1.6 - 1.8	0	.03	.24	.11	.07	.08
1.8 - 2.0	0	.07	.20	.19	.15	.08
2.0 - 2.5	.04	0	.40	.11	.07	0
2.5 - 3.0	0	.03	.40	.03	.03	0
3.0 - 3.5	0	.03	0	0	.03	0
3.5 - 4.0	0	0	0	0	0	0
4.0 - 4.5	0	0	.40	0	0	0
4.5 - 5.0	0	0	0	0	0	0

* Probability is estimated from 80 years of recorded precipitation data at Brandon (CDA) station. Observation period is 1890 - 1972, with three years missing.

Note: Range 0.0 includes trace precipitation - that is, 0.001 recordings.

Talbe D2

Probability of Daily Storm Events for the Months

April to September at Grass River*

Precip. Range (Ins.)	Relative Frequencies					
	April	May	June	July	August	Sept.
0.0	80.3	75.1	70.1	70.0	71.5	77.8
0.0 – 0.1	9.0	9.1	12.9	10.8	11.6	9.4
0.1 – 0.2	3.7	5.7	4.9	6.5	4.9	5.6
0.2 – 0.3	2.1	2.5	2.7	4.7	3.2	1.7
0.3 – 0.4	1.2	2.5	1.4	2.7	2.5	2.1
0.4 – 0.5	.8	2.3	1.8	.6	1.9	.8
0.5 – 0.6	.8	1.5	.6	1.5	.8	.6
0.6 – 0.7	.6	.4	.8	.9	.6	.2
0.7 – 0.8	.2	.2	1.4	.6	.8	1.0
0.8 – 0.9	.2	.2	.4	.4	.8	.2
0.9 – 1.0	.6	.2	1.0	0	.4	0
1.0 – 1.2	.4	.2	.4	0	.8	.2
1.2 – 1.4	.2	.2	1.2	.4	.2	0
1.4 – 1.6	0	0	.2	.4	0	.2
1.6 – 1.8	0	0	.4	0	0	0
1.8 – 2.0	0	0	0	.4	0	0
2.0 – 2.5	0	0	0	0	.2	.2
2.5 – 3.0	0	0	0	.2	0	0
3.0 – 3.5	0	0	0	0	0	0
3.5 – 4.0	0	0	0	0	0	0
4.0 – 4.5	0	0	0	0	0	0
4.5 – 5.0	0	0	0	0	0	0

* Probability is estimated from 18 years of recorded precipitation data at Grass River. Observation period is 1958 – 1975.

Note: Range 0.0 includes trace precipitation – that is, 0.001 recordings.

Table D3

Probability of Daily Storm Events for the Months

May to September at Riding Mountain*

Precip. Range (ins.)	May	June	July	August	September
0.0	68.06	61.32	58.46	62.28	70.44
0.0 - 0.1	14.44	13.74	18.72	16.13	11.31
0.1 - 0.2	6.94	7.38	8.21	6.45	6.68
0.2 - 0.3	3.06	3.82	5.64	4.22	2.57
0.3 - 0.4	1.39	2.80	2.56	2.48	1.29
0.4 - 0.5	1.11	2.80	1.03	.99	.77
0.5 - 0.6	.28	1.53	1.03	1.49	.77
0.6 - 0.7	1.39	1.53	.77	.99	1.80
0.7 - 0.8	.83	.51	.51	.50	1.29
0.8 - 0.9	.28	.51	0	1.24	.77
0.9 - 1.0	.28	.51	.77	.74	.51
1.0 - 1.2	.56	1.27	.77	.50	.26
1.2 - 1.4	.83	.25	.26	.74	.51
1.4 - 1.6	0	.76	.26	.50	0
1.6 - 1.8	.28	0	0	0	0
1.8 - 2.0	0	0	.51	0	.26
2.0 - 2.5	.28	.76	.26	.25	.51
2.5 - 3.0	0	.51	.26	.25	.26
3.0 - 3.5	0	0	0	0	0
3.5 - 4.0	0	0	0	0	0
4.0 - 4.5	0	0	0	0	0
4.5 - 5.0	0	0	0	.25	0

* Probability is estimated from 18 years of recorded precipitation data at Riding Mountain. Observation period is 1958 - 1975.

Note: Range 0.0 includes trace precipitation - that is, 0.001 recordings.

CONDITIONAL PROBABILITIES

The conditional probabilities for various storm events at Riding Mountain and Plumas given daily events at Grass River are presented in Tables D4 and D5, respectively. The empirical conditional probability distributions were estimated for each of the relevant months using daily storm data of the respective stations for the period 1958-75. In addition to conditional probability of storm events at Riding Mountain or Plumas given a storm at Grass River, Tables D4 and D5 also provide other probability measures. Each element in the tables contains four values. These are as follows:

(i) the top value gives the number of joint storm events for the observation period and of magnitudes which are indicated on the horizontal and vertical axes.

(ii) the second value is the conditional probability (in percent) of the particular event at the posterior station given the event at the prior station. Here Grass River is the prior station and Riding Mountain (Table D4) or Plumas (Table D5) are the conditional stations.

(iii) the third value is the conditional probability when it is assumed that Grass River is the conditional station and Plumas or Riding Mountain is the prior station.

(iv) the last value is the total probability of the joint event.

In this study the probability measure of primary interest is identified by item (ii).

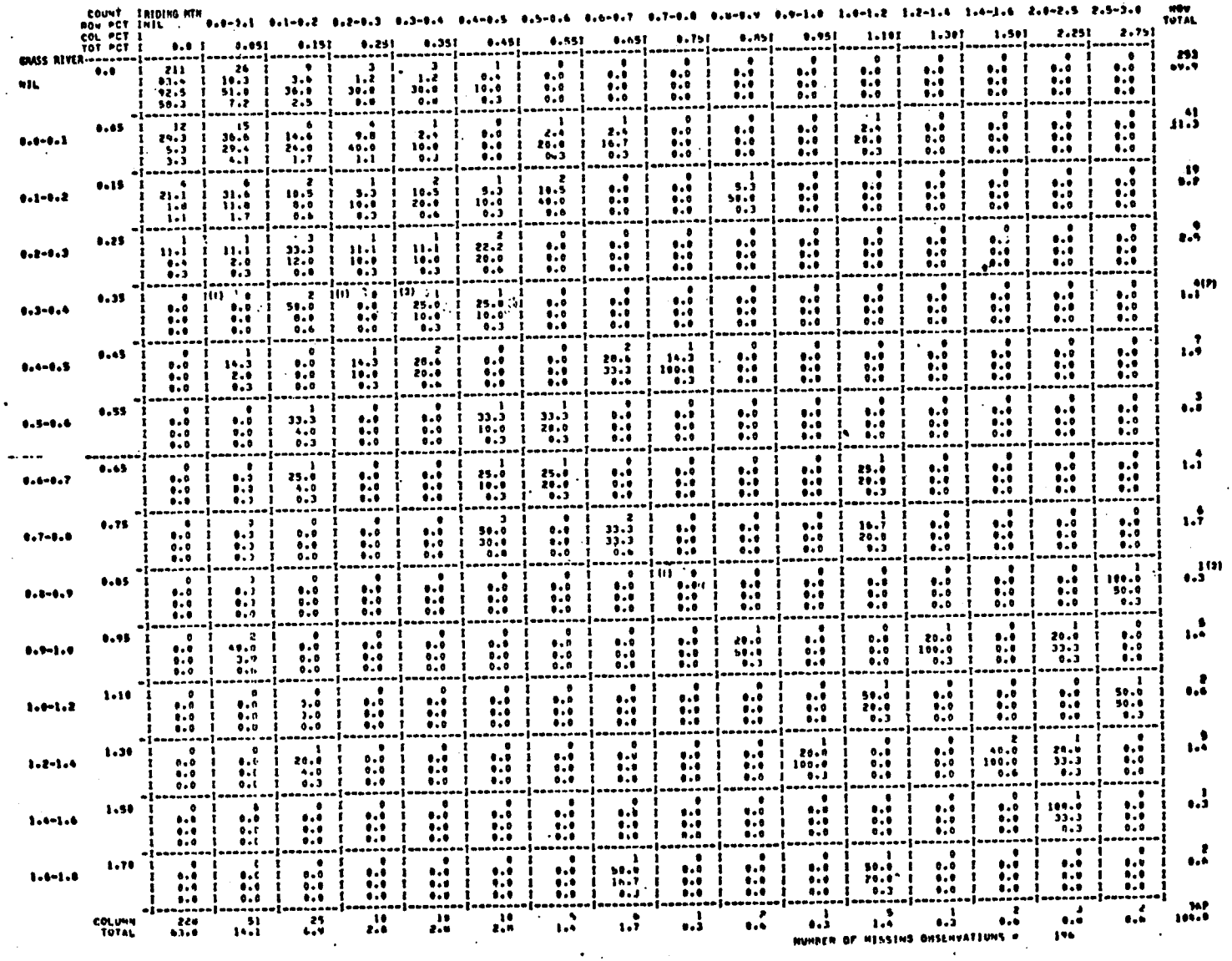
Table D4

Conditional Probability Distributions for Daily Storm Events at Grass River and Riding Mountain: May

GRASS RIVER	COUNT / ROW PCT / COL PCT / TOT PCT	RIDING MTN NIL	0.0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0	1.0-1.2	1.2-1.4	2.0-2.5	ROW TOTAL
	0.0	240	28	6	2	2	0	0	0	0	0	0	0	0	0	278
NIL		86.3	10.1	2.2	0.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	75.7
		93.0	54.9	25.0	22.2	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		65.4	7.6	1.6	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.05	10	13	10	0	0	0	0	0	0	0	1	0	0	0	34
0.0-0.1		29.4	38.2	29.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	9.3
		3.9	25.5	41.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	
		2.7	3.5	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	
	0.15	6	5	2	4	0	2	1	1	1	0	0	0	1	1	23
0.1-0.2		26.1	21.7	8.7	17.4	0.0	8.7	4.3	4.3	4.3	0.0	0.0	0.0	0.0	4.3	6.3
		2.3	9.8	8.3	44.4	0.0	33.3	100.0	33.3	33.3	0.0	0.0	0.0	0.0	100.0	
		1.6	1.4	0.5	1.1	0.0	0.5	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.3	
	0.25	0	1	1	0	1	1	0	1	2	0	0	0	0	0	7
0.2-0.3		0.0	14.3	14.3	0.0	14.3	14.3	0.0	14.3	28.6	0.0	0.0	0.0	0.0	0.0	1.9
		0.0	2.0	4.2	0.0	20.0	16.7	0.0	33.3	66.7	0.0	0.0	0.0	0.0	0.0	
		0.0	0.3	0.3	0.0	0.3	0.3	0.0	0.3	0.5	0.0	0.0	0.0	0.0	0.0	
	0.35	2	1	2	1	1	2	0	0	0	1	0	0	0	0	10
0.3-0.4		20.0	10.0	20.0	10.0	10.0	20.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	2.7
		0.8	2.0	8.3	11.1	20.0	33.3	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	
		0.5	0.3	0.5	0.3	0.3	0.5	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	
	0.45	0	2	2	1	1	0	0	0	0	0	0	1	1	0	6
0.4-0.5		0.0	25.0	25.0	12.5	12.5	0.0	0.0	0.0	0.0	0.0	0.0	12.5	12.5	0.0	2.2
		0.0	3.9	8.3	11.1	20.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	50.0	0.0	
		0.0	0.5	0.5	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	
	0.55	0	1	0	1 [1]	0	1 [2]	0	0	0	0	0	0	1	0	4[7]
0.5-0.6		0.0	25.0	0.0	25.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	1.1
		0.0	2.0	0.0	11.1	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	
		0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	
	0.75	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
0.7-0.8		0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	
	0.85	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
0.8-0.9		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.3
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	
	1.30	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
1.2-1.4		0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
		0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	COLUMN TOTAL	258	51	24	9	5	6	1	3	3	1	1	2	2	1	367
		70.3	13.9	6.5	2.5	1.4	1.6	0.3	0.8	0.8	0.3	0.3	0.5	0.5	0.3	100.0

Table D4 (continued)

Conditional Probability Distributions for Daily Storm Events at Grass River and Riding Mountain: June



GRASS RIVER \ RIDING MTN	NIL	0.0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0	1.0-1.2	1.2-1.4	1.4-1.6	2.0-2.5	2.5-3.0	ROW TOTAL
NIL	211 83.4 92.5 58.3	26 10.3 51.0 7.2	9 3.6 36.0 2.5	3 1.2 30.0 0.8	3 1.2 30.0 0.8	1 0.4 10.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	253 69.9
0.0-0.1	12 29.3 5.3 3.3	15 36.6 29.4 4.1	6 14.6 24.0 1.7	4 9.8 40.0 1.1	1 2.4 10.0 0.3	0 0.0 0.0 0.0	1 2.4 20.0 0.3	1 2.4 16.7 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 2.4 20.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	41 11.3
0.1-0.2	4 21.1 1.8 1.1	6 31.6 11.8 1.7	2 10.5 8.0 0.6	1 5.3 10.0 0.3	2 10.5 20.0 0.6	1 5.3 10.0 0.3	2 10.5 40.0 0.6	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 5.3 50.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	19 5.2
0.2-0.3	1 11.1 0.4 0.3	1 11.1 2.0 0.3	3 33.3 12.0 0.8	1 11.1 10.0 0.3	1 11.1 10.0 0.3	2 22.2 20.0 0.6	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	9 2.5
0.3-0.4	0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	2 50.0 8.0 0.6	(1) 0 0.0 0.0 0.0	(2) 1 25.0 10.0 0.3	1 25.0 10.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	4(P) 1.1
0.4-0.5	0 0.0 0.0 0.0	1 14.3 2.0 0.3	0 0.0 0.0 0.0	1 14.3 10.0 0.3	2 28.6 20.0 0.6	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 28.6 33.3 0.6	1 14.3 100.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	7 1.9
0.5-0.6	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 33.3 4.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 33.3 10.0 0.3	1 33.3 20.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	3 0.8
0.6-0.7	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 25.0 4.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 25.0 10.0 0.3	1 25.0 20.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 25.0 20.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	4 1.1
0.7-0.8	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 10.0 0.3	0 0.0 0.0 0.0	2 33.3 33.3 0.6	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 16.7 20.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	6 1.7
0.8-0.9	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 50.0 0.3	1(2) 0.3
0.9-1.0	0 0.0 0.0 0.0	2 40.0 3.9 0.6	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 20.0 50.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 20.0 100.0 0.3	0 0.0 0.0 0.0	1 20.0 33.3 0.3	0 0.0 0.0 0.0	5 1.4
1.0-1.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 20.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 50.0 0.3	0 0.0 0.0 0.0	2 0.6
1.2-1.4	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 20.0 4.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 20.0 100.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 40.0 100.0 0.6	1 20.0 33.3 0.3	0 0.0 0.0 0.0	3 0.8
1.4-1.6	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 33.3 0.3	0 0.0 0.0 0.0	1 0.3
1.6-1.8	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 16.7 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 20.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 0.6
COLUMN TOTAL	226 63.0	51 14.1	25 6.9	10 2.8	10 2.8	10 2.8	5 1.4	6 1.7	1 0.3	2 0.6	1 0.3	5 1.4	1 0.3	2 0.6	2 0.6	2 0.6	360 100.0

NUMBER OF MISSING OBSERVATIONS = 196

Conditional Probability Distributions for Daily Storm Events at Grass River and Riding Mountain: July

GRASS RIVER	COUNT / ROW PCT / COL PCT / TOT PCT	RIDING MTN NIL 0.0	0.0-0.1 0.05	0.1-0.2 0.15	0.2-0.3 0.25	0.3-0.4 0.35	0.4-0.5 0.45	0.5-0.6 0.55	0.6-0.7 0.65	0.7-0.8 0.75	0.9-1.0 0.95	1.0-1.2 1.10	1.2-1.4 1.30	1.4-1.6 1.50	1.6-2.0 1.90	2.0-2.5 2.25	2.5-3.0 2.75	ROW TOTAL
NIL	0.0	195 76.5 89.0 52.4	40 15.7 58.0 10.8	10 3.9 30.3 2.7	3 1.2 15.8 0.8	5 2.0 50.0 1.3	0 0.0 0.0 0.0	2 0.8 66.7 0.5	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	255 68.5
0.0-0.1	0.05	13 31.0 5.9 3.5	12 28.6 17.4 3.2	10 23.8 30.3 2.7	5 11.9 26.3 1.3	1 2.4 10.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 2.4 33.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	42 11.3
0.1-0.2	0.15	7 28.0 3.2 1.9	10 40.0 14.5 2.7	6 24.0 18.2 1.6	2 8.0 10.5 0.5	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	25 6.7
0.2-0.3	0.25	3 17.6 1.4 0.8	4 23.5 5.8 1.1	4 23.5 12.1 1.1	3 17.6 15.8 0.8	1 5.9 10.0 0.3	1 5.9 33.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 5.9 100.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	17 4.6
0.3-0.4	0.35	1 9.1 0.5 0.3	1 9.1 1.4 0.3	2 18.2 6.1 0.5	1 9.1 5.3 0.3	2 18.2 20.0 0.5	1 9.1 33.3 0.3	1 9.1 33.3 0.3	1 9.1 33.3 0.3	0 0.0 0.0 0.0	1 9.1 33.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	11 3.0
0.4-0.5	0.45	0 0.0 0.0 0.0	1 33.3 1.4 0.3	1 33.3 3.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 33.3 33.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	3 0.8
0.5-0.6	0.55	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 14.3 5.3 0.3	1 14.3 10.0 0.3	1 14.3 33.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 14.3 50.0 0.3	1 14.3 33.3 0.3	2 28.6 66.7 0.5	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	7 1.9
0.6-0.7	0.65	0 0.0 0.0 0.0	1 33.3 1.4 0.3	0 0.0 0.0 0.0	1 33.3 5.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	1 33.3 50.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	3 (1) 0.8
0.7-0.8	0.75	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 5.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 (1) 0.3
0.8-0.9	0.85	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 100.0 0.3	0 0.0 0.0 0.0	1 (1) 0.3
1.2-1.4	1.30	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 5.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 100.0 0.3	0 0.0 0.0 0.0	2 0.5
1.4-1.6	1.50	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 33.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 100.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 0.5
1.8-2.0	1.90	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 33.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 100.0 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 0.5
2.5-3.0	2.75	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 5.3 0.3	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 0.3
	COLUMN TOTAL	219 58.9	69 18.5	33 8.9	19 5.1	10 2.7	3 0.8	3 0.8	3 0.8	2 0.5	3 0.8	3 0.8	1 0.3	1 0.3	1 0.3	1 0.3	1 0.3	372 100.0

Conditional Probability Distributions for Daily Storm Events at Grass River and Riding Mountain: August

GRASS RIVER / NIL	RIDING MTN / NIL	0.0	0.0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0	1.0-1.2	1.2-1.4	1.4-1.6	2.0-2.5	2.5-3.0	>4.5	ROW TOTAL
0.0	COUNT	218	35	8	3	1	0	1	2	1	0	0	0	0	0	0	0	0	269
	ROW PCT	81.0	13.0	3.0	1.1	0.4	0.0	0.4	0.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	72.3
	COL PCT	95.2	56.5	33.3	17.6	11.1	0.0	16.7	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOT PCT	58.6	9.4	2.2	0.8	0.3	0.0	0.3	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.05	COUNT	8	17	9	3	0	0	0	0	0	0	0	1	1	0	0	0	0	39
	ROW PCT	20.5	43.6	23.1	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	2.6	0.0	0.0	0.0	0.0	10.5
	COL PCT	3.5	27.4	37.5	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	100.0	0.0	0.0	0.0	0.0	
	TOT PCT	2.2	4.6	2.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	
0.15	COUNT	1	5	3	3	4	2	0	0	0	0	0	0	0	0	0	0	0	18
	ROW PCT	5.6	27.8	16.7	16.7	22.2	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8
	COL PCT	0.4	8.1	12.5	17.6	44.4	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOT PCT	0.3	1.3	0.8	0.8	1.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.25	COUNT	1	2	1	4	2	0	2	0	0	1	0	0	0	0	0	0	0	13
	ROW PCT	7.7	15.4	7.7	30.8	15.4	0.0	15.4	0.0	0.0	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5
	COL PCT	0.4	3.2	4.2	23.5	22.2	0.0	33.3	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOT PCT	0.3	0.5	0.3	1.1	0.5	0.0	0.5	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.35	COUNT	1	1	0	1	0	0	1	2	0	1	0	0	0	0	0	0	0	8
	ROW PCT	12.5	12.5	0.0	12.5	0.0	0.0	12.5	25.0	0.0	12.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
	COL PCT	0.4	1.6	0.0	5.9	0.0	0.0	16.7	50.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOT PCT	0.3	0.3	0.0	0.3	0.0	0.0	0.3	0.5	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.45	COUNT	0	2	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	7
	ROW PCT	0.0	28.6	14.3	14.3	14.3	14.3	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
	COL PCT	0.0	3.2	4.2	5.9	11.1	25.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOT PCT	0.0	0.5	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.55	COUNT	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	3
	ROW PCT	0.0	0.0	0.0	0.0	33.3	33.3	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
	COL PCT	0.0	0.0	0.0	0.0	11.1	25.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOT PCT	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.65	COUNT	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2
	ROW PCT	0.0	0.0	0.0	50.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	COL PCT	0.0	0.0	0.0	5.9	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOT PCT	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.75	COUNT	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	1	4
	ROW PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	25.0	0.0	25.0	0.0	0.0	0.0	25.0	1.1
	COL PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	33.3	0.0	50.0	0.0	0.0	0.0	100.0	
	TOT PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.3	0.0	0.0	0.0	0.3	
0.85	COUNT	0	0	2	0	0	0	0	0	(1) 0	0	0	0	0	0	0	1	0	3
	ROW PCT	0.0	0.0	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.8
	COL PCT	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	
	TOT PCT	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	
0.95	COUNT	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2
	ROW PCT	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.5
	COL PCT	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	
	TOT PCT	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	
1.10	COUNT	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	2
	ROW PCT	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	COL PCT	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	TOT PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
1.30	COUNT	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
	ROW PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.3
	COL PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	
	TOT PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	
2.25	COUNT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
	ROW PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.3
	COL PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
	TOT PCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	
COLUMN TOTAL		229	62	24	17	9	4	6	4	2	5	3	1	2	1	1	1	1	372
		61.6	16.7	6.5	4.6	2.4	1.1	1.6	1.1	0.5	1.3	0.8	0.3	0.5	0.3	0.3	0.3	0.3	100.0

NUMBER OF MISSING OBSERVATIONS = NA

Table D4 (continued)

Conditional Probability Distributions for Daily Storm Events at Grass River and Riding Mountain: September

GRASS RIVER	COUNT / ROW PCT / COL PCT / TOT PCT	RIDING MTN INIL 0.0	0.0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0	1.0-1.2	1.2-1.4	1.4-2.0	2.0-2.5	2.5-3.0	ROW TOTAL
NIL	0.0	222	23	5	1	1	0	0	1	1	0	0	0	0	0	0	0	254
		87.4	9.1	2.0	0.4	0.4	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.7
		94.5	56.1	23.8	14.3	20.0	0.0	0.0	16.7	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		67.1	6.9	1.5	0.3	0.3	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0-0.1	0.05	9	13	5	1	1	0	1	0	0	0	0	0	0	0	0	0	30
		30.0	43.3	16.7	3.3	3.3	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1
		3.8	31.7	23.8	14.3	20.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		2.7	3.9	1.5	0.3	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.1-0.2	0.15	3	4	9	2	2	0	0	1	0	0	0	1	0	0	0	0	22
		13.6	18.2	40.9	9.1	9.1	0.0	0.0	4.5	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	6.6
		1.3	9.8	42.9	28.6	40.0	0.0	0.0	16.7	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	
		0.9	1.2	2.7	0.6	0.6	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	
0.2-0.3	0.25	0	0	1	1	0	0	0	1	1	0	0	0	1	0	0	0	5
		0.0	0.0	20.0	20.0	0.0	0.0	0.0	20.0	20.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	1.5
		0.0	0.0	4.8	14.3	0.0	0.0	0.0	16.7	25.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	
		0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	
0.3-0.4	0.35	0	1	0	1	0	1	0	1	2	1	0	0	0	0	0	0	7
		0.0	14.3	0.0	14.3	0.0	14.3	0.0	14.3	28.6	14.3	0.0	0.0	0.0	0.0	0.0	0.0	2.1
		0.0	2.4	0.0	14.3	0.0	100.0	0.0	16.7	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	
0.4-0.5	0.45	1	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	4
		25.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	1.2
		0.4	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	
		0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	
0.5-0.6	0.55	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	2
		0.0	0.0	0.0	50.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
		0.0	0.0	0.0	14.3	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.6-0.7	0.65	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
		0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
		0.0	0.0	0.0	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.7-0.8	0.75	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	1	3
		0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	33.3	33.3	0.9
		0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	100.0	100.0	
		0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.3	
0.8-0.9	0.85	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	3
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.9
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	
1.0-1.2	1.10	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.3
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	
1.4-1.6	1.50	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.3
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	
COLUMN TOTAL		235	41	21	7	5	1	2	6	4	2	1	1	1	1	2	1	331
		71.0	12.4	6.3	2.1	1.5	0.3	0.6	1.8	1.2	0.6	0.3	0.3	0.3	0.3	0.6	0.3	100.0

NUMBER OF MISSING OBSERVATIONS = 227

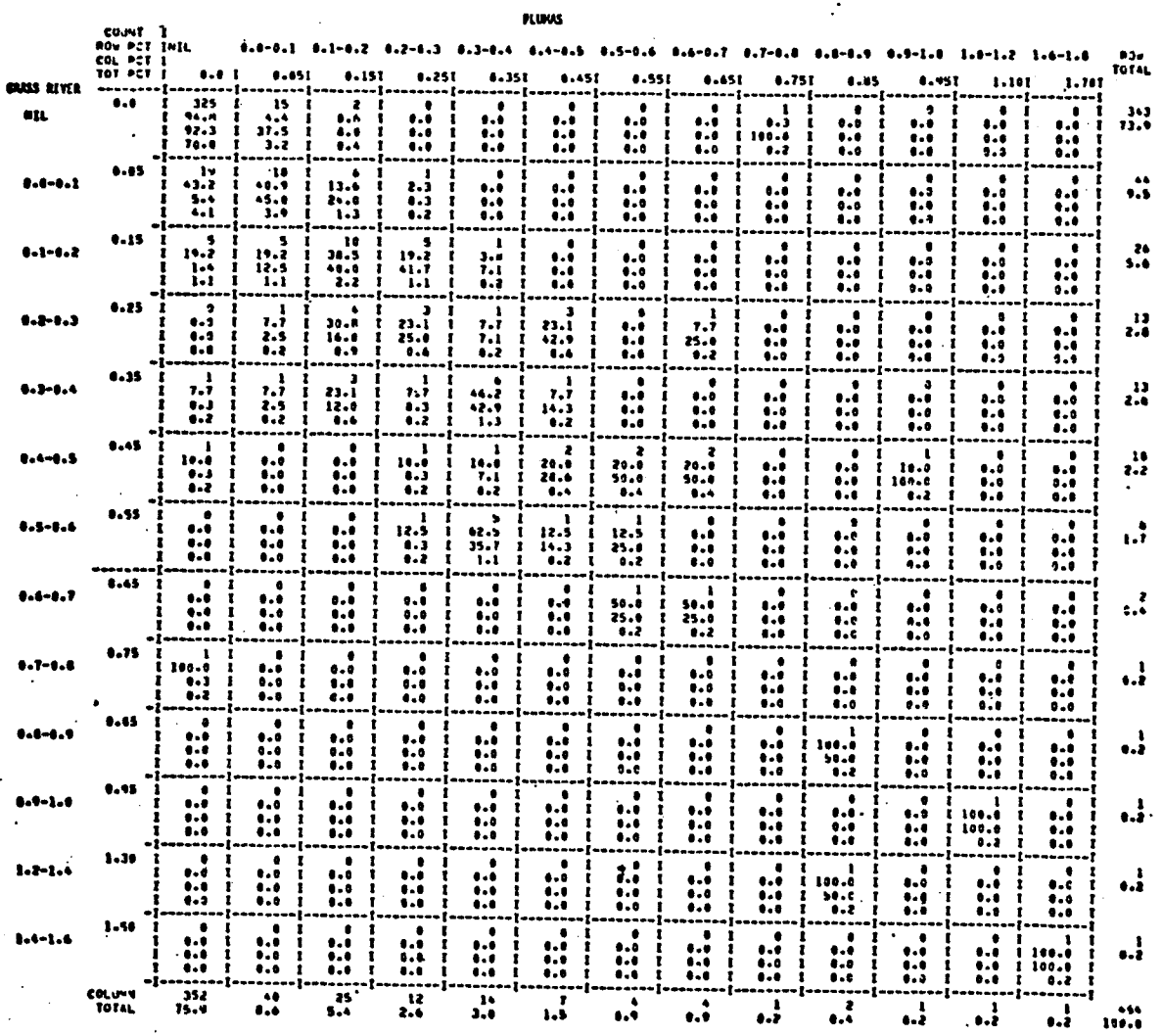
Table D5

Conditional Probability Distributions for Daily Storm Events at Grass River and Plumas: April

GRASS RIVER	COUNT / ROW PCT / COL PCT / TOT PCT	PLUMAS NIL 0.0	0.0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0	1.0-1.2	ROW TOTAL
NIL		335	7	3	0	0	0	0	0	0	0	0	0	345
		97.1	2.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.3
		97.4	21.2	18.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		80.0	1.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0-0.1		8	20	4	1	0	1	0	0	0	1	1	36	
		22.2	55.6	11.1	2.8	0.0	2.8	0.0	0.0	0.0	0.0	2.8	2.8	8.6
		2.3	60.6	25.0	10.0	0.0	50.0	0.0	0.0	0.0	0.0	100.0	33.3	
		1.9	4.8	1.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.2	
0.1-0.2		0	3	7	1	0	0	1	0	0	0	0	0	12
		0.0	25.0	58.3	8.3	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	2.9
		0.0	9.1	43.8	10.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.7	1.7	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	
0.2-0.3		1	2	1	6	0	0	0	0	0	0	0	0	10
		10.0	20.0	10.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4
		0.3	6.1	6.3	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.2	0.5	0.2	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.3-0.4		0	1	1	0	3	0	0	0	0	0	0	0	5
		0.0	20.0	20.0	0.0	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
		0.0	3.0	6.3	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.2	0.2	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.4-0.5		0	0	0	2	0	1	0	0	0	0	0	0	3
		0.0	0.0	0.0	66.7	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.7
		0.0	0.0	0.0	20.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.5	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	
0.5-0.6		0	0	0	0	0	0	2	0	0	0	0	0	2
		0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.5
		0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	
0.6-0.7		0	0	0	0	0	0	1	0	1	0	0	0	2
		0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	50.0	0.0	0.0	0.0	0.5
		0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	100.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	
0.7-0.8		0	0	0	0	0	0	0	0	0	1	0	0	1
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.2
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	
0.8-0.9		0	0	0	0	0	0	0	1	0	0	0	1	2
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	50.0	0.5
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	33.3	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	
0.9-1.0		0	0	0	0	0	0	0	(1) 0	0	0	0	1	1 [2]
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.2
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	
COLUMN TOTAL		344	33	16	10	3	2	4	1	1	1	1	3	419
		82.1	7.9	3.8	2.4	0.7	0.5	1.0	0.2	0.2	0.2	0.2	0.7	100.0

Table D5 (continued)

Conditional Probability Distributions for Daily Storm Events at Grass River and Plumas: May



GRASS RIVER		PLUMAS: NIL	0.0–0.1	0.1–0.2	0.2–0.3	0.3–0.4	0.4–0.5	0.5–0.6	0.6–0.7	0.7–0.8	0.8–0.9	0.9–1.0	1.0–1.2	1.6–1.8	ROW TOTAL
NIL	0.0	325	15	2	0	0	0	0	0	1	0	0	0	0	343
		94.8	4.4	0.6	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	73.9
		92.3	37.5	8.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	
		70.0	3.2	0.4	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	
0.0–0.1	0.05	19	18	6	1	0	0	0	0	0	0	0	0	0	44
		43.2	40.9	13.6	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5
		5.4	45.0	24.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		4.1	3.9	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.1–0.2	0.15	5	5	10	5	1	0	0	0	0	0	0	0	0	26
		19.2	19.2	38.5	19.2	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6
		1.4	12.5	40.0	41.7	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		1.1	1.1	2.2	1.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.2–0.3	0.25	2	1	4	3	1	3	0	1	0	0	0	0	0	13
		0.3	7.7	30.8	23.1	7.7	23.1	0.0	7.7	0.0	0.0	0.0	0.0	0.0	2.8
		0.6	2.5	16.0	25.0	7.1	42.9	0.0	25.0	0.0	0.0	0.0	0.0	0.0	
		0.4	0.2	0.9	0.6	0.2	0.6	0.0	0.2	0.0	0.0	0.0	0.0	0.0	
0.3–0.4	0.35	1	1	3	1	6	1	0	0	0	0	0	0	0	13
		7.7	7.7	23.1	7.7	46.2	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8
		0.3	2.5	12.0	8.3	42.9	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.2	0.2	0.6	0.2	1.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.4–0.5	0.45	1	0	0	1	1	2	2	2	0	0	1	0	0	10
		10.0	0.0	0.0	10.0	10.0	20.0	20.0	20.0	0.0	0.0	100.0	0.0	0.0	2.2
		0.3	0.0	0.0	0.3	7.1	28.6	50.0	50.0	0.0	0.0	100.0	0.0	0.0	
		0.2	0.0	0.0	0.2	0.2	0.4	0.4	0.2	0.0	0.0	0.2	0.0	0.0	
0.5–0.6	0.55	0	0	0	1	5	1	1	0	0	0	0	0	0	8
		0.0	0.0	0.0	12.5	62.5	12.5	12.5	0.0	0.0	0.0	0.0	0.0	0.0	1.7
		0.0	0.0	0.0	8.3	35.7	14.3	25.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.2	1.1	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	
0.6–0.7	0.65	0	0	0	0	0	0	1	1	0	0	0	0	0	2
		0.0	0.0	0.0	0.0	0.0	0.0	50.0	50.0	0.0	0.0	0.0	0.0	0.0	0.4
		0.0	0.0	0.0	0.0	0.0	0.0	25.0	25.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	
0.7–0.8	0.75	1	0	0	0	0	0	0	0	0	0	0	0	0	1
		100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
		0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.8–0.9	0.85	0	0	0	0	0	0	0	0	0	1	0	0	0	1
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.2
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	
0.9–1.0	0.95	0	0	0	0	0	0	0	0	0	0	1	0	0	1
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.2
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	
1.2–1.4	1.30	0	0	0	0	0	0	0	0	1	0	0	0	0	1
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.2
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	
1.4–1.6	1.50	0	0	0	0	0	0	0	0	0	0	0	0	1	1
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.2
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	
COLUMN TOTAL		352	48	25	12	14	7	4	4	1	2	1	1	1	464
		75.9	8.6	5.4	2.6	3.0	1.5	0.9	0.9	0.2	0.4	0.2	0.2	0.2	100.0

Table D5 (continued)

Conditional Probability Distributions for Daily Storm Events at Grass River and Plumas: June

PLUMAS

GRASS RIVER	COUNT / ROW PCT / COL PCT / TOT PCT	NIL 0.0	0.0-0.1 0.05	0.1-0.2 0.15	0.2-0.3 0.25	0.3-0.4 0.35	0.4-0.5 0.45	0.5-0.6 0.55	0.6-0.7 0.65	0.7-0.8 0.75	0.8-0.9 0.85	0.9-1.0 0.95	1.0-1.2 1.10	1.2-1.4 1.30	ROW TOTAL
NIL	0.0	301	26	4	3	0	0	0	0	0	0	0	0	0	334
		90.1	7.8	1.2	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	69.6
		99.1	40.6	18.2	18.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		62.7	5.4	0.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.0-0.1	0.05	22	23	4	0	1	1	0	0	0	1	0	0	0	52
		42.3	44.2	7.7	0.0	1.9	1.9	0.0	0.0	0.0	1.9	0.0	0.0	0.0	10.8
		6.6	35.9	18.2	0.0	11.1	16.7	0.0	0.0	0.0	16.7	0.0	0.0	0.0	
		4.6	4.8	0.8	0.0	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	
0.1-0.2	0.15	6	10	9	5	0	2	1	0	1	0	0	0	0	34
		17.6	29.4	26.5	14.7	0.0	5.9	2.9	0.0	2.9	0.0	0.0	0.0	0.0	7.1
		1.8	15.6	40.9	31.3	0.0	20.0	33.3	0.0	20.0	0.0	0.0	0.0	0.0	
		1.3	2.1	1.9	1.0	0.0	0.4	0.2	0.0	0.2	0.0	0.0	0.0	0.0	
0.2-0.3	0.25	4	3	4	5	2	2	0	0	0	0	0	1	0	21
		19.0	14.3	19.0	23.8	9.5	9.5	0.0	0.0	0.0	0.0	0.0	4.8	0.0	4.4
		1.2	4.7	18.2	31.3	22.2	20.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	
		0.8	0.6	0.8	1.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.2	0.0	
0.3-0.4	0.35	1	1	1	1	5	2	0	0	0	1	1	1	0	14
		7.1	7.1	7.1	7.1	35.7	14.3	0.0	0.0	0.0	7.1	7.1	7.1	0.0	2.9
		0.3	0.6	4.5	6.3	55.6	20.0	0.0	0.0	0.0	16.7	50.0	20.0	0.0	
		0.2	0.2	0.2	0.2	1.0	0.4	0.0	0.0	0.0	0.2	0.2	0.2	0.0	
0.4-0.5	0.45	0	1	0	1	0	1	0	0	0	0	0	0	0	3
		0.0	33.3	0.0	33.3	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
		0.0	1.6	0.0	6.3	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.2	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.5-0.6	0.55	0	0	0	0	0	0	1	2	2	0	1	0	0	6
		0.0	0.0	0.0	0.0	0.0	0.0	16.7	33.3	33.3	0.0	16.7	0.0	0.0	1.3
		0.0	0.0	0.0	0.0	0.0	0.0	33.3	66.7	40.0	0.0	50.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.4	0.0	0.2	0.0	0.0	
0.6-0.7	0.65	0	0	0	0	0	1	1	0	1	1	0	1	0	4
		0.0	0.0	0.0	0.0	0.0	25.0	25.0	0.0	25.0	25.0	0.0	25.0	0.0	0.8
		0.0	0.0	0.0	0.0	0.0	10.0	33.3	0.0	20.0	16.7	0.0	50.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.2	0.2	0.0	0.2	0.0	
0.7-0.8	0.75	0	0	0	0	1	0	0	1	0	0	0	0	1	3
		0.0	0.0	0.0	0.0	33.3	0.0	0.0	33.3	0.0	0.0	0.0	0.0	33.3	0.6
		0.0	0.0	0.0	0.0	11.1	0.0	0.0	33.3	0.0	0.0	0.0	0.0	100.0	
		0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2	
0.8-0.9	0.85	0	0	0	0	0	1	0	0	0	0	0	1	0	2
		0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.4
		0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	
1.2-1.4	1.30	0	0	0	0	0	0	0	0	1	0	0	1	0	2
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	50.0	0.0	0.4
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	20.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.0	
1.4-1.6	1.50	0	0	0	0	0	0	0	0	0	1	0	1	0	2
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	50.0	0.0	0.4
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	20.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	
1.8-2.0	1.90	0	0	0	0	0	0	0	0	0	2	0	0	0	2
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.4
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	
2.5-3.0	2.75	0	0	0	1	0	0	0	0	0	0	0	0	0	1
		0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
		0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
COLUMN TOTAL		334	64	22	16	9	10	3	3	5	4	2	5	1	480
		69.6	13.3	4.6	3.3	1.9	2.1	0.6	0.6	1.0	1.3	0.4	1.0	0.2	100.0

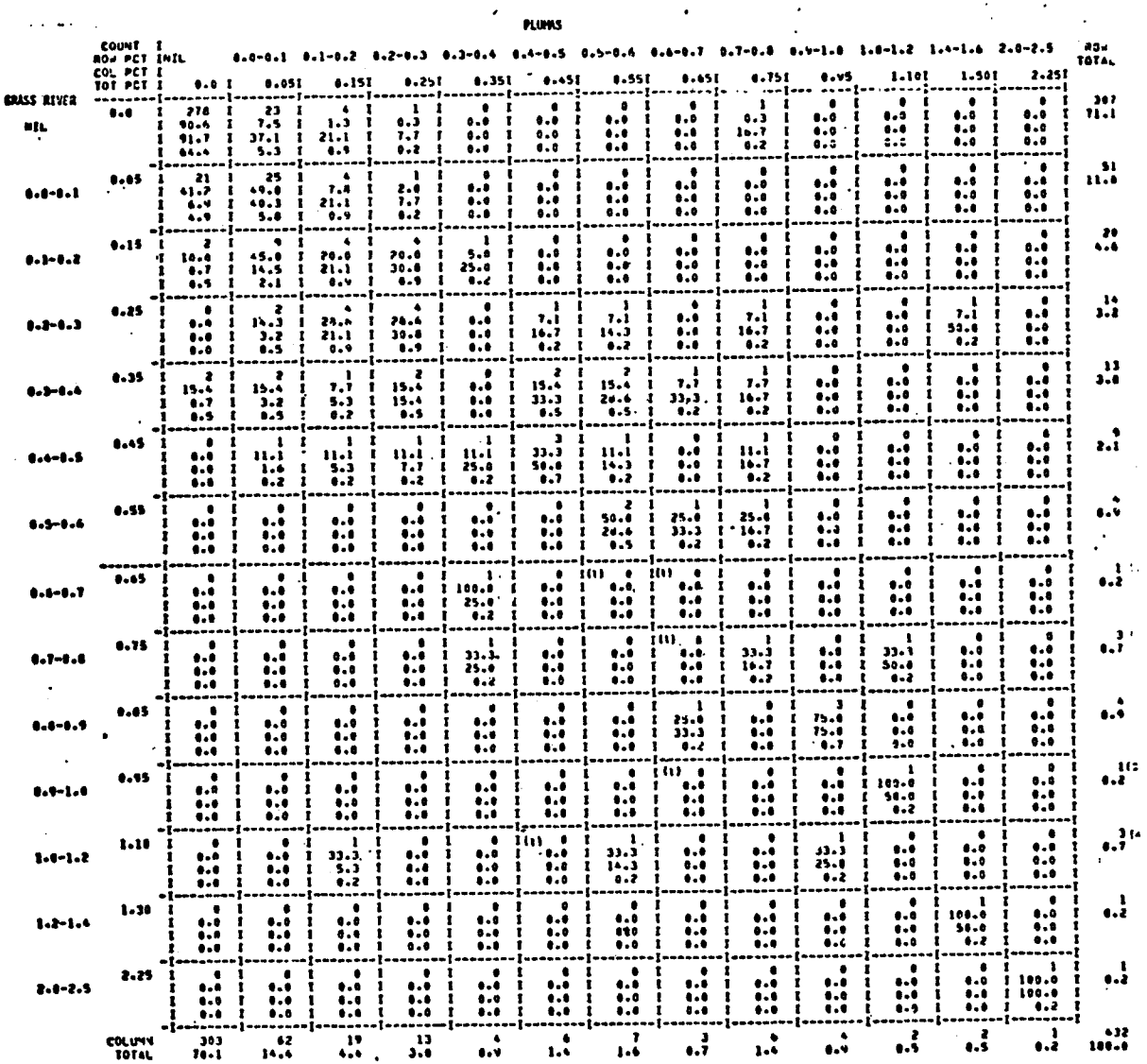
Table D5 (continued)

Conditional Probability Distributions for Daily Storm Events at Grass River and Plumas: July

GRASS RIVER	COLUMN / ROW PCT / COL PCT / TOT PCT	PLUMAS: NIL	0.0	0.0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	0.9-1.0	1.0-1.2	1.2-1.4	1.4-1.6	2.0-2.5	ROW TOTAL
NIL	0.0	317 93.5 91.1 64.4	20 5.9 35.7 4.2	1 0.3 6.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 0.3 20.0 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	339 71.2
0.0-0.1	0.05	33 91.7 9.6 6.9	22 37.9 39.3 4.6	4 6.9 26.7 0.8	1 1.7 6.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 1.7 100.0 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	58 12.2
0.1-0.2	0.15	1 4.8 0.3 0.2	9 42.9 16.1 1.9	6 28.6 40.0 1.3	4 19.0 26.7 0.8	1 4.8 14.3 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	21 4.4
0.2-0.3	0.25	0 0.0 0.0 0.0	3 21.4 5.4 0.6	2 14.3 13.3 0.4	4 28.6 26.7 0.8	3 21.4 42.9 0.6	2 14.3 33.3 0.4	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	14 2.9
0.3-0.4	0.35	0 0.0 0.0 0.0	1 14.3 1.8 0.2	2 28.6 13.3 0.4	2 28.6 13.3 0.4	2 28.6 28.6 0.4	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	7 1.5
0.4-0.5	0.45	0 0.0 0.0 0.0	1 11.1 1.8 0.2	0 0.0 0.0 0.0	2 22.2 13.3 0.4	0 0.0 0.0 0.0	2 22.2 33.3 0.4	2 22.2 40.0 0.4	1 11.1 100.0 0.2	1 11.1 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	9 1.9
0.5-0.6	0.55	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 33.3 6.7 0.2	0 0.0 0.0 0.0	1 33.3 16.7 0.2	1 33.3 20.0 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	3 0.6
0.6-0.7	0.65	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 33.3 6.7 0.2	0 0.0 0.0 0.0	1 33.3 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 33.3 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	3 0.6
0.7-0.8	0.75	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 20.0 16.7 0.2	2 40.0 100.0 0.4	0 0.0 0.0 0.0	2 40.0 33.3 0.4	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	5 1.1
0.8-0.9	0.85	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 20.0 0.2	0 0.0 0.0 0.0	1 50.0 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 0.4
0.9-1.0	0.95	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 20.0 14.3 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 20.0 16.7 0.2	3 60.0 75.0 0.6	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	5 1.1
1.0-1.2	1.10	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 100.0 33.3 0.4	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 0.4
1.2-1.4	1.30	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 20.0 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 20.0 16.7 0.2	0 0.0 0.0 0.0	2 40.0 66.7 0.4	1 20.0 100.0 0.2	0 0.0 0.0 0.0	5 1.1
1.4-1.6	1.50	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 25.0 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 0.2
1.6-1.8	1.70	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 50.0 33.3 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 0.4
	COLUMN TOTAL	358 73.1	56 11.8	15 3.2	15 3.2	7 1.5	6 1.3	5 1.1	1 0.2	6 1.3	2 0.4	1 0.2	6 1.3	4 0.8	3 0.6	1 0.2		479 100.0

Table D5 (continued)

Conditional Probability Distributions for Daily Storm Events at Grass River and Plumas: August



GRASS RIVER	COUNT / ROW PCT / COL PCT / TOT PCT	PLUMAS NIL	0.0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-1.0	1.0-1.2	1.2-1.5	1.5-2.5	ROW TOTAL
		0.0	0.05	0.15	0.25	0.35	0.45	0.55	0.65	0.75	0.9	1.10	1.50	2.25	
NIL	0.0	278 90.6 91.7 64.4	23 7.5 37.1 5.3	4 1.3 21.1 0.9	1 0.3 7.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 0.3 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	307 71.1
0.0-0.1	0.05	21 41.2 6.9 4.9	25 49.0 40.3 5.8	4 7.8 21.1 0.9	1 2.0 7.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	51 11.8
0.1-0.2	0.15	2 10.0 0.7 0.5	9 45.0 14.5 2.1	4 20.0 21.1 0.9	4 20.0 30.8 0.9	1 5.0 25.0 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	20 4.6
0.2-0.3	0.25	0 0.0 0.0 0.0	2 14.3 3.2 0.5	4 28.6 21.1 0.9	4 28.6 30.8 0.9	0 0.0 0.0 0.0	1 7.1 16.7 0.2	1 7.1 14.3 0.2	0 0.0 0.0 0.0	1 7.1 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 7.1 50.0 0.2	0 0.0 0.0 0.0	14 3.2
0.3-0.4	0.35	2 15.4 0.7 0.5	2 15.4 3.2 0.5	1 7.7 5.3 0.2	2 15.4 15.4 0.5	0 0.0 0.0 0.0	2 15.4 33.3 0.5	2 15.4 28.6 0.5	1 7.7 33.3 0.2	1 7.7 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	13 3.0
0.4-0.5	0.45	0 0.0 0.0 0.0	1 11.1 1.6 0.2	1 11.1 5.3 0.2	1 11.1 7.7 0.2	1 11.1 25.0 0.2	3 33.3 50.0 0.7	1 11.1 14.3 0.2	0 0.0 0.0 0.0	1 11.1 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	9 2.1
0.5-0.6	0.55	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	2 50.0 28.6 0.5	1 25.0 33.3 0.2	1 25.0 16.7 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	4 0.9
0.6-0.7	0.65	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 25.0 0.2	0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 0.2
0.7-0.8	0.75	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 33.3 25.0 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	1 33.3 16.7 0.2	0 0.0 0.0 0.0	1 33.3 50.0 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	3 0.7
0.8-0.9	0.85	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 25.0 33.3 0.2	0 0.0 0.0 0.0	3 75.0 75.0 0.7	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	4 0.9
0.9-1.0	0.95	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 50.0 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1[1] 0.2
1.0-1.2	1.10	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 33.3 5.3 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	(1) 0 0.0 0.0 0.0	1 33.3 14.3 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 33.3 25.0 0.2	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	3[1] 0.7
1.2-1.4	1.30	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 50.0 0.2	0 0.0 0.0 0.0	1 0.2
2.0-2.5	2.25	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	0 0.0 0.0 0.0	1 100.0 100.0 0.2	1 0.2
	COLUMN TOTAL	303 70.1	62 14.4	19 4.4	13 3.0	4 0.9	6 1.4	7 1.6	3 0.7	6 1.4	4 0.9	2 0.5	2 0.5	1 0.2	432 100.0

Table D5 (continued)

Conditional Probability Distributions for Daily Storm Events at Grass River and Plumas: September

GRASS RIVER	COUNT / ROW PCT / COL PCT / TOT PCT	PLUMAS: NIL	0.0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	0.7-0.8	0.8-0.9	1.0-1.2	2.0-2.5	ROW TOTAL
0.0		292	16	1	0	0	0	0	0	0	0	0	0	309
		96.5	5.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	79.0
NIL		96.1	39.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		74.7	4.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.05		10	16	6	1	0	0	0	0	0	0	0	0	33
		30.3	48.5	18.2	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4
0.0-0.1		3.3	39.0	30.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		2.6	4.1	1.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.15		2	9	7	4	1	0	0	0	0	0	0	0	23
		8.7	39.1	30.4	17.4	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9
0.1-0.2		0.7	22.0	35.0	57.1	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
		0.5	2.3	1.8	1.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0.25		0	0	5	1	0	0	0	1	0	0	0	0	7
		0.0	0.0	71.4	14.3	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	1.8
0.2-0.3		0.0	0.0	25.0	14.3	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	
		0.0	0.0	1.3	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	
0.35		0	0	1	0	2	1	2	0	1	1	0	0	8
		0.0	0.0	12.5	0.0	25.0	12.5	25.0	0.0	12.5	12.5	0.0	0.0	2.0
0.3-0.4		0.0	0.0	5.0	0.0	50.0	33.3	40.0	0.0	50.0	50.0	0.0	0.0	
		0.0	0.0	0.3	0.0	0.5	0.3	0.5	0.0	0.3	0.3	0.0	0.0	
0.45		0	0	0	1	1	1	0	0	0	0	0	0	3
		0.0	0.0	0.0	33.3	33.3	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.8
0.4-0.5		0.0	0.0	0.0	14.3	25.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	
0.55		0	0	(1) 0	0	0	0	2	0	0	0	0	0	2 (3)
		0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.5
0.5-0.6		0.0	0.0	0.0	0.0	0.0	0.0	40.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	
0.65		0	0	0	0	0	1	0	0	0	0	0	0	1
		0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
0.6-0.7		0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	
0.75		0	0	0	0	0	0	1	0	1	1	0	0	4
		0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	25.0	25.0	0.0	0.0	1.0
0.7-0.8		0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	50.0	50.0	100.0	0.0	
		0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.3	0.3	0.0	
2.25		0	0	0	0	0	0	0	0	0	0	1	1	1
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	0.3
0.8-2.5		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	
COLUMN TOTAL		304	41	20	7	4	3	5	1	2	2	1	1	391
		77.7	10.5	5.1	1.8	1.0	0.8	1.3	0.3	0.5	0.5	0.3	0.3	100.0

APPENDIX E

Table E1

Results of Regression Analysis to Determine
Crop Damage Relationship From PE

	Linear Regression Coefficients For									
	Wheat				Oats				Barley	
	Clay Loam		Loam		Clay Loam		Loam	Sand	Clay Loam	
	Stubble	Fallow	Stubble	Fallow	Stubble	Fallow	Stubble	Stubble	Stubble	Fallow
Dependent Variable										
Yield (bushels)										
Independent Variables										
PE5	- .070		.073+			- .048	.260*		- .103	- .070
PE6	- .071*	- .039**	- .050	- .020	- .091**	- .152**	- .035	- .093*	- .068**	- .101*
PE7	.079**	.043**	.040	.047*	.104**	.116**	.095*		.046	.032
PE8		- .025**	.040+	- .019	- .020+	- .012	.019	- .019	- .029*	- .028+
N	.459*			3.340**	.301	-2.58	2.772**		0.189	
N^2		.059*	- .018*	- .099	- .006		- .170**		.003	
P	.314*	.278*			1.220**	.621**	- .028		1.084**	1.305**
P^2		.012		.028	- .035**			- .007**	- .033**	- .023**
NP	- .030**	- .087**					- .214		.146**	
PROD	.718*	.669**	2.974**	2.306**	.890**	1.292**	.522	1.44	2.067**	2.338
NPP				- .007*		.005	.007		- .005**	
Constant	- 2.83	5.68	-57.9	-38.8	-6.10	-17.06	7.47	-25.17	-36.45	-46.58
Statistics:										
R^2	0.37	0.16	0.55	0.30	0.28	0.44	0.32	0.27	0.40	0.51
F Ratio	5.79**	6.72**	6.75**	7.43**	15.00**	12.40**	5.29**	5.52**	6.59**	6.40**
S.E.	7.31	8.80	4.98	7.65	15.25	14.81	14.09	12.53	11.57	12.52
No. of Observations	76	282	38	148	325	86	124	65	117	51

Note: Statistical significance of coefficients and equations: ** = 1 percent level; * = 5 percent level; + = 10 percent level

Other coefficients and equations are not considered statistically significant. Variables for which no coefficient is given failed to enter the equation since they provided no significant improvement in explanatory power.

APPENDIX F

STOCHASTIC SIMULATION RESULTS

FOR SUBWATERSHED 2.01.02 FOR

ONE PERIOD

LAND USE TABLE FOR SUBWATERSHED 02.01.02

GROUP NO.	CAPABILITY	PRODUCTIVITY	HYDROLOGIC SOIL GROUP	SOIL TEXT	LAND USE IN ACRES: CEREAL CROP	FORAGE CROP	NATURAL GRASSLAND	TREES + SHRUBS	OTHER	GROUP LAND USE NET RETURNS
1.	4WP	5.	C	CL	0.	0.	40.	40.	0.	516.
2.	4WP	6.	C	CL	512.	24.	52.	132.	0.	10751.
3.	4WP	7.	C	S	4.	4.	0.	32.	0.	149.
4.	5FM	6.	C	S	64.	0.	16.	0.	0.	1382.
5.	5FM	7.	AB	S	80.	8.	24.	48.	0.	1668.
6.	5W	7.	AB	S	96.	0.	64.	0.	0.	2171.
7.	5W	7.	AB	CL	12.	80.	12.	56.	0.	2047.
8.	5WP	7.	C	CL	24.	0.	112.	24.	0.	1571.
9.	3FM	5.	AB	S	168.	8.	0.	0.	0.	4290.
10.	3FM	5.	C	S	120.	0.	32.	8.	0.	3314.
11.	3FM	6.	AB	S	64.	8.	0.	8.	0.	1393.

TOTAL NET RETURN INFORMATION FOR EACH SOIL GROUP WITHIN SUBWATERSHED 02.01.02

GROUP NO.	SOIL TEXT.	PRODUCTIVITY	ACREAGE	RECOMMENDED LAND USE	NET RETURNS TO PUBLIC DRAINS	NET RETURNS TO ALL DRAINS	FARM LAND DEVELOPMENT COST	DRAINAGE IMPROVEMENT COST	
1.	CL	5.	80.	-	-->	516. ¢--	0.	0.	FOR LEVEL-1
				A	1695.	1721.	4000.	219.	FOR LEVEL-2
				A	1780.	1824.	4000.	381.	FOR LEVEL-3
*				A	1791.	1846.	4000.	466.	FOR LEVEL-4
2.	CL	6.	720.	-	-->	10751. ¢--	0.	0.	FOR LEVEL-1
				A	14061.	14291.	11720.	1968.	FOR LEVEL-2
				A	14823.	15223.	11720.	3425.	FOR LEVEL-3
				A	14925.	15414.	11720.	4190.	FOR LEVEL-4
3.	S	7.	40.	-	-->	149. ¢--	0.	0.	FOR LEVEL-1
				A	273.	286.	2580.	109.	FOR LEVEL-2
				A	273.	286.	2580.	109.	FOR LEVEL-3
				A	273.	286.	2580.	109.	FOR LEVEL-4
4.	S	6.	80.	-	-->	1382. ¢--	0.	0.	FOR LEVEL-1
				-	1382.	1382.	0.	0.	FOR LEVEL-2
				-	1382.	1382.	0.	0.	FOR LEVEL-3
				-	1382.	1382.	0.	0.	FOR LEVEL-4
5.	S	7.	160.	-	-->	1668. ¢--	0.	0.	FOR LEVEL-1
				A	1788.	1839.	4360.	437.	FOR LEVEL-2
				A	1788.	1839.	4360.	437.	FOR LEVEL-3
				A	1788.	1839.	4360.	437.	FOR LEVEL-4
6.	S	7.	160.	-	-->	2171. ¢--	0.	0.	FOR LEVEL-1
				-	2171.	2171.	0.	0.	FOR LEVEL-2
				-	2171.	2171.	0.	0.	FOR LEVEL-3
				-	2171.	2171.	0.	0.	FOR LEVEL-4
7.	CL	7.	160.	-	-->	2047. ¢--	0.	0.	FOR LEVEL-1
				P	3769.	3820.	4720.	437.	FOR LEVEL-2
				P	4050.	4139.	4720.	761.	FOR LEVEL-3
				P	4085.	4194.	4720.	931.	FOR LEVEL-4
8.	CL	7.	160.	-	-->	1571. ¢--	0.	0.	FOR LEVEL-1
				A	2446.	2497.	4160.	437.	FOR LEVEL-2
				A	2615.	2704.	4160.	761.	FOR LEVEL-3
				A	2638.	2747.	4160.	931.	FOR LEVEL-4
9.	S	5.	176.	-	-->	4290. ¢--	0.	0.	FOR LEVEL-1
				-	4290.	4290.	0.	0.	FOR LEVEL-2
				-	4290.	4290.	0.	0.	FOR LEVEL-3
				-	4290.	4290.	0.	0.	FOR LEVEL-4
10.	S	5.	160.	-	-->	3314. ¢--	0.	0.	FOR LEVEL-1
				A	3541.	3593.	1280.	437.	FOR LEVEL-2
				A	3541.	3593.	1280.	437.	FOR LEVEL-3
				A	3541.	3593.	1280.	437.	FOR LEVEL-4
11.	S	6.	80.	-	-->	1393. ¢--	0.	0.	FOR LEVEL-1
				-	1393.	1393.	0.	0.	FOR LEVEL-2
				-	1393.	1393.	0.	0.	FOR LEVEL-3
				-	1393.	1393.	0.	0.	FOR LEVEL-4

MATRIX OF VARIOUS CAPITAL AND MAINTENANCE COSTS OF THE DRAINAGE SYSTEM FOR SUBWATERSHED 02.01.02

	TOTAL CAPITAL COSTS FOR DRAINAGE IMPROVEMENT TO THIS LEVEL.	CAPITAL COSTS FOR MAIN AND COLLECTION CHANNEL IMPROVEMENT TO THIS LEVEL.	CAPITAL COSTS FOR ON-FARM DRAINAGE IMPROVEMENT TO THIS LEVEL.	TOTAL ANNUAL MAINTENANCE COSTS FOR THIS LEVEL OF DRAINAGE IMPROVEMENT.	PRESENT VALUE OF ALL COSTS FOR MAIN & COLLECTION CHANNELS.	PRESENT VALUE OF ALL COSTS FOR ON-FARM DRAINAGE.	PRESENT VALUE OF ALL COSTS FOR THE TOTAL DRAINAGE SYSTEM.
LEVEL-2	26645.	22600.	4045.	2029.	35815.	8199.	44014.
LEVEL-3	134512.	128200.	6312.	4784.	162669.	12795.	175464.
LEVEL-4	176302.	168800.	7502.	6035.	212747.	15208.	227955.

YEAR NO.	INFLATION RATE	FARM INPUT PRICE INDEX		WHEAT (-----	OATS BUSHELS	BARLEY -----)	FORAGE (-----	NAT GRASSLAND TONS -------)
1	11.93	180.43	CROP PRICES IN $/ABOVE UNITS	3.61	1.45	2.18	33.91	33.91
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	40.69	36.41	40.42	12.97	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	9.09	9.09
2	1.03	181.45	CROP PRICES IN $/ABOVE UNITS	4.93	2.03	3.12	41.71	41.71
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	40.92	36.62	40.65	13.05	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	9.15	9.15
3	4.76	186.22	CROP PRICES IN $/ABOVE UNITS	5.17	2.13	3.29	43.47	43.47
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	41.99	37.58	41.71	13.39	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	9.39	9.39
4	3.79	190.01	CROP PRICES IN $/ABOVE UNITS	5.05	2.08	3.19	43.03	43.03
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	42.85	38.34	42.56	13.66	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	9.58	9.58
5	1.37	191.38	CROP PRICES IN $/ABOVE UNITS	4.62	1.89	2.88	40.62	40.62
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	43.16	38.62	42.87	13.76	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	9.65	9.65
6	6.75	198.13	CROP PRICES IN $/ABOVE UNITS	5.21	2.14	3.29	44.56	44.56
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	44.68	39.98	44.38	14.25	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	9.99	9.99
7	7.09	205.21	CROP PRICES IN $/ABOVE UNITS	4.60	1.87	2.83	41.47	41.47
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	46.28	41.41	45.97	14.75	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	10.34	10.34

8	4.46	209.67	CROP PRICES IN $/ABOVE UNITS	3.55	1.40	2.07	35.62	35.62
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	47.28	42.31	46.97	15.08	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	10.57	10.57
9	-.15	209.52	CROP PRICES IN $/ABOVE UNITS	4.16	1.67	2.51	39.21	39.21
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	47.25	42.28	46.93	15.06	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	10.56	10.56
10	5.88	215.41	CROP PRICES IN $/ABOVE UNITS	4.29	1.72	2.58	40.36	40.36
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	48.57	43.47	48.25	15.49	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	10.86	10.86
11	10.06	225.47	CROP PRICES IN $/ABOVE UNITS	4.45	1.78	2.68	42.02	42.02
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	50.84	45.50	50.50	16.21	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	11.36	11.36
12	5.17	230.64	CROP PRICES IN $/ABOVE UNITS	6.20	2.55	3.93	52.65	52.65
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	52.01	46.54	51.66	16.58	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	11.62	11.62
13	2.58	233.22	CROP PRICES IN $/ABOVE UNITS	4.46	1.78	2.67	42.61	42.61
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	52.59	47.06	52.24	16.77	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	11.75	11.75
14	1.47	234.69	CROP PRICES IN $/ABOVE UNITS	7.47	3.10	4.83	60.34	60.34
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	52.92	47.36	52.57	16.87	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	11.83	11.83
15	3.44	238.13	CROP PRICES IN $/ABOVE UNITS	4.74	1.90	2.85	44.59	44.59
			CONSTANT COSTS OF PRODUCTION IN $/ACRE	53.70	48.06	53.34	17.12	0.00
			YEILD DEPENDENT COSTS OF PRODUCTION IN $/ABOVE UNITS	0.00	0.00	0.00	12.00	12.00

SIMULATED ANNUAL BENEFITS FOR SUBWATERSHED 02.01.02

YEAR	LEVEL-2	LEVEL-3	LEVEL-4
1	38735.33	48789.98	51386.72
2	-459.19	-459.19	-459.19
3	-6589.76	-6589.76	-6589.76
4	403.46	563.88	563.88
5	3479.21	3667.59	3667.59
6	351.68	351.68	351.68
7	24953.35	31319.31	33425.62
8	9422.65	9422.65	9422.65
9	16454.62	20514.81	21516.13
10	19787.79	22977.08	24100.50
11	7126.22	7298.23	7298.23
12	13359.89	14785.15	14785.15
13	12217.54	16135.81	17225.95
14	24284.21	25809.80	25809.80
15	49257.28	59998.04	62459.82

PRESENT DISCOUNTED TOTAL BENEFITS
FOR SUBWATERSHED 02.01.02

FRM LEVEL	TO LEVEL	DISCOUNTED TOTAL BENEFIT
1	2	106824.91
1	3	129589.57
1	4	135421.13
2	3	22764.66
3	4	5831.56

MATRIX OF SIMULATED BENEFIT/COST RATIOSFOR SUBWATERSHED02.01.02

IMPROVEMENT FROM-LEVEL	TO-LEVEL	BENEFIT/COST RATIO
1	2	2.4271
1	3	.7386
1	4	.5941
2	3	.1732
3	4	.1111

SIMULATED ANNUAL BENEFITS FOR SUBWATERSHED 02.01.02

YEAR	LEVEL-2	LEVEL-3	LEVEL-4
1	4612.29	4612.29	4612.29
2	27781.30	33135.64	34230.35
3	14637.10	14688.16	14688.16
4	13158.84	13158.84	13158.84
5	10475.38	10749.48	10844.59
6	13595.02	13595.02	13595.02
7	12391.94	15053.22	15428.84
8	585.76	1965.64	2260.61
9	7507.40	8854.32	8854.32
10	4891.14	4891.14	4891.14
11	30587.17	46492.08	51514.31
12	23487.61	24629.82	24629.82
13	6520.02	9836.70	10832.36
14	26157.66	26157.66	26157.66
15	9767.73	11761.13	12031.12

PRESENT DISCOUNTED TOTAL BENEFITS
FOR SUBWATERSHED 02.01.02

FRM LEVEL	TO LEVEL	DISCOUNTED TOTAL BENEFIT
1	2	115472.69
1	3	132385.25
1	4	136372.22
2	3	16912.56
3	4	3986.96

MATRIX OF SIMULATED BENFFIT/COST RATIOSFOR SUBWATERSHED02.01.02

IMPROVEMENT FROM-LEVEL	TO-LEVEL	BENEFIT/COST RATIO
1	2	2.6236
1	3	.7545
1	4	.5982
2	3	.1287
3	4	.0760

APPENDIX G

TABLE G1

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 01.01.01

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	496.	896.	1257.
B/C RATIO	.672	.571	.488
INCREMENTAL B/C RATIO	.672	.313	.124
PRESENT VALUE OF BENEFITS ($)	273054.	322703.	338827.
PRESENT VALUE OF COSTS ($)	406447.	564890.	694785.
ANNUAL BENEFITS ($)	31901.	37701.	39585.
COSTS:			
CAPITAL: TOTAL ($)	328550.	470000.	589581.
PUBLIC ($)	319000.	458800.	577600.
ON-FARM ($)	9550.	11200.	11981.
ANNUAL MAINTENANCE ($)	9101.	11086.	12291.
LAND USE			
CEREAL CROPS (AC.)	2524.	2524.	2524.
TAME HAY (AC.)	420.	420.	420.
NATIVE HAY (AC.)	152.	152.	152.
UNIMPROVED (AC.)	32.	32.	32.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 102. C.F.S.

SUBWATERSHED AREA = 3156. ACRES

PRESENT LAND USE (ACRES): A = 772.; P = 276.; K = 1512.; T = 568.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 01.01.02

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	440.	822.	1208.
B/C RATIO	1.048	.885	.755
INCREMENTAL B/C RATIO	1.048	.434	.171
PRESENT VALUE OF BENEFITS ($)	340765.	391655.	408550.
PRESENT VALUE OF COSTS ($)	325068.	442337.	541403.
ANNUAL BENEFITS ($)	39811.	45757.	47731.
COSTS:			
CAPITAL: TOTAL ($)	251434.	358900.	451772.
PUBLIC ($)	240000.	345500.	437300.
ON-FARM ($)	11434.	13400.	14472.
ANNUAL MAINTENANCE ($)	8603.	9748.	10472.
LAND USE			
CEREAL CROPS (AC.)	2272.	2272.	2272.
TAME HAY (AC.)	892.	892.	892.
NATIVE HAY (AC.)	80.	80.	80.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 58. C.F.S.

SUBWATERSHED AREA = 3412. ACRES

PRESENT LAND USE (ACRES): A = 1564.; P = 552.; K = 732.; T = 396.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 01.03.01

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	334.	541.	752.
B/C RATIO	1.022	1.086	1.052
INCREMENTAL B/C RATIO	1.022	1.419	.748
PRESENT VALUE OF BENEFITS ($)	82103.	103939.	111798.
PRESENT VALUE OF COSTS ($)	80357.	95748.	106254.
ANNUAL BENEFITS ($)	9592.	12143.	13061.
COSTS:			
CAPITAL: TOTAL ($)	45873.	54648.	60523.
PUBLIC ($)	36900.	43900.	48000.
ON-FARM ($)	8973.	10748.	12523.
ANNUAL MAINTENANCE ($)	4029.	4802.	5343.
LAND USE			
CEREAL CROPS (AC.)	1344.	1344.	1344.
TAME HAY (AC.)	376.	376.	376.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 130. C.F.S.

SUBWATERSHED AREA = 1720. ACRES

PRESENT LAND USE (ACRES): A = 408.; P = 344.; K = 600.; T = 368.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 01.03.02

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	207.	354.	475.
B/C RATIO	.505	.489	.430
INCREMENTAL B/C RATIO	.505	.453	.205
PRESENT VALUE OF BENEFITS ($)	52976.	73984.	82072.
PRESENT VALUE OF COSTS ($)	104809.	151181.	190678.
ANNUAL BENEFITS ($)	6189.	8643.	9588.
COSTS:			
CAPITAL: TOTAL ($)	78300.	115200.	146100.
PUBLIC ($)	72300.	108000.	137600.
ON-FARM ($)	6000.	7200.	8500.
ANNUAL MAINTENANCE ($)	3097.	4204.	5208.
LAND USE			
CEREAL CROPS (AC.)	900.	900.	900.
TAME HAY (AC.)	0.	0.	0.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 60. C.F.S.

SUBWATERSHED AREA = 900. ACRES

PRESENT LAND USE (ACRES): A = 232.; P = 12.; K = 416.; T = 240.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 01.04.00

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	135.	244.	354.
B/C RATIO	1.88	1.52	1.34
INCREMENTAL B/C RATIO	1.88	0.57	0.05
PRESENT VALUE OF BENEFITS ($)	301622.	335556.	337108.
PRESENT VALUE OF COSTS ($)	160695.	220642.	252739.
ANNUAL BENEFITS ($)	37458.	41656.	41838.
COSTS:			
CAPITAL: TOTAL ($)	103206.	140107.	162568.
PUBLIC ($)	83900.	105200.	126500.
ON-FARM ($)	19306.	34907.	36068.
ANNUAL MAINTENANCE ($)	6716.	9409.	10535.
LAND USE			
CEREAL CROPS (AC.)	2320.	2204.	2204.
TAME HAY (AC.)	788.	904.	904.
NATIVE HAY (AC.)	120.	120.	120.
UNIMPROVED (AC.)	40.	40.	40.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 25. C.F.S.

SUBWATERSHED AREA = 3268. ACRES

PRESENT LAND USE (ACRES): A = 988.; P = 528.; K = 1396.; T = 356.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 01.05.00

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	124.	223.	322.
B/C RATIO	1.43	1.28	1.10
INCREMENTAL B/C RATIO	1.43	0.46	0.10
PRESENT VALUE OF BENEFITS ($)	209259.	222780.	225029.
PRESENT VALUE OF COSTS ($)	146254.	174415.	205334.
ANNUAL BENEFITS ($)	27485.	28948.	29328.
COSTS:			
CAPITAL: TOTAL ($)	94002.	114646.	136085.
PUBLIC ($)	76300.	95800.	116000.
ON-FARM ($)	17702.	18846.	20085.
ANNUAL MAINTENANCE ($)	6105.	6983.	8090.
LAND USE			
CEREAL CROPS (AC.)	1528.	1528.	1528.
TAME HAY (AC.)	956.	956.	956.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 25. C.F.S.

SUBWATERSHED AREA = 2484. ACRES

PRESENT LAND USE (ACRES): A = 1028.; P = 608.; K = 368.; T = 480.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 01.06.00

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	106.	177.	253.
B/C RATIO	1.78	1.91	1.75
INCREMENTAL B/C RATIO	1.78	2.73	0.87
PRESENT VALUE OF BENEFITS ($)	320623.	399049.	431898.
PRESENT VALUE OF COSTS ($)	180421.	209564.	246286.
ANNUAL BENEFITS ($)	45403.	58421.	64361.
COSTS:			
CAPITAL: TOTAL ($)	108900.	128800.	153600.
PUBLIC ($)	91800.	108600.	131900.
ON-FARM ($)	17100.	20200.	21700.
ANNUAL MAINTENANCE ($)	8356.	9436.	10828.
LAND USE			
CEREAL CROPS (AC.)	2684.	2684.	2684.
TAME HAY (AC.)	672.	672.	672.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 30. C.F.S.

SUBWATERSHED AREA = 3356. ACRES

PRESENT LAND USE (ACRES): A = 776.; P = 456.; K = 1036.; T = 1088.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 02.01.01

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	216.	424.	633.
B/C RATIO	.675	.544	.444
INCREMENTAL B/C RATIO	.675	.160	.043
PRESENT VALUE OF BENEFITS ($)	227617.	245912.	250733.
PRESENT VALUE OF COSTS ($)	337332.	451803.	564406.
ANNUAL BENEFITS ($)	26592.	28730.	29293.
COSTS:			
CAPITAL: TOTAL ($)	277706.	363816.	468079.
PUBLIC ($)	273500.	350100.	452900.
ON-FARM ($)	4206.	13716.	15179.
ANNUAL MAINTENANCE ($)	6966.	10279.	11254.
LAND USE			
CEREAL CROPS (AC.)	2316.	2316.	2316.
TAME HAY (AC.)	192.	192.	192.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	4.	4.	4.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 7. C.F.S.

SUBWATERSHED AREA = 2616. ACRES

PRESENT LAND USE (ACRES): A = 1808.; P = 116.; K = 88.; T = 500.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 02.01.02

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	125.	296.	465.
B/C RATIO	1.562	.468	.372
INCREMENTAL B/C RATIO	1.562	.102	.050
PRESENT VALUE OF BENEFITS ($)	68742.	82116.	84763.
PRESENT VALUE OF COSTS ($)	44014.	175464.	227955.
ANNUAL BENEFITS ($)	8031.	9594.	9903.
COSTS:			
CAPITAL: TOTAL ($)	26645.	134512.	176302.
PUBLIC ($)	22600.	128200.	168800.
ON-FARM ($)	4045.	6312.	7502.
ANNUAL MAINTENANCE ($)	2029.	4784.	6035.
LAND USE			
CEREAL CROPS (AC.)	1712.	1712.	1712.
TAME HAY (AC.)	176.	176.	176.
NATIVE HAY (AC.)	80.	80.	80.
UNIMPROVED (AC.)	8.	8.	8.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 53. C.F.S.

SUBWATERSHED AREA = 1976. ACRES

PRESENT LAND USE (ACRES): A = 1144.; P = 132.; K = 352.; T = 348.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 02.01.03

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	85.	237.	382.
B/C RATIO	4.522	.999	.851
INCREMENTAL B/C RATIO	4.522	.148	.096
PRESENT VALUE OF BENEFITS ($)	203487.	230965.	235329.
PRESENT VALUE OF COSTS ($)	45001.	231131.	276496.
ANNUAL BENEFITS ($)	23773.	26984.	27493.
COSTS:			
CAPITAL: TOTAL ($)	27300.	181276.	216628.
PUBLIC ($)	23600.	174800.	208800.
ON-FARM ($)	3700.	6476.	7828.
ANNUAL MAINTENANCE ($)	2068.	5825.	6994.
LAND USE			
CEREAL CROPS (AC.)	996.	996.	996.
TAME HAY (AC.)	1080.	1080.	1080.
NATIVE HAY (AC.)	4.	4.	4.
UNIMPROVED (AC.)	56.	56.	56.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 7. C.F.S.

SUBWATERSHED AREA = 2136. ACRES

PRESENT LAND USE (ACRES): A = 1092.; P = 680.; K = 108.; T = 256.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 02.03.00

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	115.	142.	172.
B/C RATIO	1.053	.929	.771
INCREMENTAL B/C RATIO	1.053	.112	0.000
PRESENT VALUE OF BENEFITS ($)	58656.	59601.	59601.
PRESENT VALUE OF COSTS ($)	55726.	64152.	77339.
ANNUAL BENEFITS ($)	6853.	6963.	6963.
COSTS:			
CAPITAL: TOTAL ($)	37493.	44493.	55093.
PUBLIC ($)	31600.	38600.	49200.
ON-FARM ($)	5893.	5893.	5893.
ANNUAL MAINTENANCE ($)	2130.	2297.	2599.
LAND USE			
CEREAL CROPS (AC.)	1100.	1100.	1100.
TAME HAY (AC.)	0.	0.	0.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 25. C.F.S.

SUBWATERSHED AREA = 1120. ACRES

PRESENT LAND USE (ACRES): A = 492.; P = 48.; K = 244.; T = 316.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 02.04.01

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	429.	757.	1098.
B/C RATIO	.266	.289	.274
INCREMENTAL B/C RATIO	.266	.352	.196
PRESENT VALUE OF BENEFITS ($)	94223.	138248.	155906.
PRESENT VALUE OF COSTS ($)	353565.	478706.	568917.
ANNUAL BENEFITS ($)	11008.	16151.	18214.
COSTS:			
CAPITAL: TOTAL ($)	277293.	385980.	469277.
PUBLIC ($)	266000.	370200.	452300.
ON-FARM ($)	11293.	15780.	16977.
ANNUAL MAINTENANCE ($)	8911.	10833.	11641.
LAND USE			
CEREAL CROPS (AC.)	2536.	2536.	2536.
TAME HAY (AC.)	56.	56.	56.
NATIVE HAY (AC.)	416.	416.	416.
UNIMPROVED (AC.)	60.	60.	60.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 251. C.F.S.

SUBWATERSHED AREA = 3300. ACRES

PRESENT LAND USE (ACRES): A = 1680.; P = 40.; K = 856.; T = 492.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 02.04.02

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	398.	678.	951.
B/C RATIO	1.336	1.226	1.052
INCREMENTAL B/C RATIO	1.336	.824	.293
PRESENT VALUE OF BENEFITS ($)	439886.	514292.	542478.
PRESENT VALUE OF COSTS ($)	329282.	419585.	515680.
ANNUAL BENEFITS ($)	51392.	60084.	63377.
COSTS:			
CAPITAL: TOTAL ($)	241314.	319481.	394947.
PUBLIC ($)	223400.	298000.	369900.
ON-FARM ($)	17914.	21481.	25047.
ANNUAL MAINTENANCE ($)	10277.	11695.	14105.
LAND USE			
CEREAL CROPS (AC.)	3312.	3312.	3312.
TAME HAY (AC.)	732.	732.	732.
NATIVE HAY (AC.)	416.	416.	416.
UNIMPROVED (AC.)	4.	4.	4.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 89. C.F.S.

SUBWATERSHED AREA = 4712. ACRES

PRESENT LAND USE (ACRES): A = 1324.; P = 412.; K = 1556.; T = 1172.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 03.04.03

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	93.	133.	173.
B/C RATIO	1.198	1.087	.986
INCREMENTAL B/C RATIO	1.198	.590	.349
PRESENT VALUE OF BENEFITS ($)	151469.	168222.	176793.
PRESENT VALUE OF COSTS ($)	126392.	154787.	179340.
ANNUAL BENEFITS ($)	17696.	19653.	20655.
COSTS:			
CAPITAL: TOTAL ($)	82978.	101873.	121209.
PUBLIC ($)	71600.	87200.	105500.
ON-FARM ($)	11378.	14673.	15709.
ANNUAL MAINTENANCE ($)	5072.	6182.	6791.
LAND USE			
CEREAL CROPS (AC.)	2792.	2792.	2792.
TAME HAY (AC.)	184.	184.	184.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 17. C.F.S.

SUBWATERSHED AREA = 3008. ACRES

PRESENT LAND USE (ACRES): A = 932.; P = 132.; K = 1236.; T = 676.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 03.04.04

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	111.	203.	294.
B/C RATIO	1.158	.355	.310
INCREMENTAL B/C RATIO	1.158	.009	0.000
PRESENT VALUE OF BENEFITS ($)	85052.	86544.	86544.
PRESENT VALUE OF COSTS ($)	73449.	243806.	279274.
ANNUAL BENEFITS ($)	9937.	10111.	10111.
COSTS:			
CAPITAL: TOTAL ($)	44700.	179867.	204167.
PUBLIC ($)	37600.	171800.	196100.
ON-FARM ($)	7100.	8067.	8067.
ANNUAL MAINTENANCE ($)	3359.	7470.	8775.
LAND USE			
CEREAL CROPS (AC.)	2008.	2008.	2008.
TAME HAY (AC.)	640.	640.	640.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 20. C.F.S.

SUBWATERSHED AREA = 2648. ACRES

PRESENT LAND USE (ACRES): A = 1296.; P = 436.; K = 692.; T = 224.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 03.04.05

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	75.	130.	185.
B/C RATIO	1.151	.694	.624
INCREMENTAL B/C RATIO	1.151	.096	.125
PRESENT VALUE OF BENEFITS ($)	65435.	69617.	71378.
PRESENT VALUE OF COSTS ($)	56874.	100384.	114477.
ANNUAL BENEFITS ($)	7645.	8133.	8339.
COSTS:			
CAPITAL: TOTAL ($)	36972.	64642.	76242.
PUBLIC ($)	28800.	54500.	66100.
ON-FARM ($)	8172.	10142.	10142.
ANNUAL MAINTENANCE ($)	2325.	4176.	4467.
LAND USE			
CEREAL CROPS (AC.)	1224.	1224.	1224.
TAME HAY (AC.)	68.	68.	68.
NATIVE HAY (AC.)	4.	4.	4.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 20. C.F.S.

SUBWATERSHED AREA = 1296. ACRES

PRESENT LAND USE (ACRES): A = 540.; P = 44.; K = 404.; T = 308.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 04.01.00

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	83.	142.	200.
B/C RATIO	1.240	.753	.629
INCREMENTAL B/C RATIO	1.240	.118	.075
PRESENT VALUE OF BENEFITS ($)	70841.	75992.	77674.
PRESENT VALUE OF COSTS ($)	57134.	100906.	123423.
ANNUAL BENEFITS ($)	8276.	8878.	9075.
COSTS:			
CAPITAL: TOTAL ($)	37100.	64900.	81500.
PUBLIC ($)	28800.	54500.	71100.
ON-FARM ($)	8300.	10400.	10400.
ANNUAL MAINTENANCE ($)	2341.	4207.	4898.
LAND USE			
CEREAL CROPS (AC.)	1464.	1464.	1464.
TAME HAY (AC.)	0.	0.	0.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 25. C.F.S.

SUBWATERSHED AREA = 1464. ACRES

PRESENT LAND USE (ACRES): A = 1112.; P = 28.; K = 208.; T = 116.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 04.02.00

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	49.	109.	186.
B/C RATIO	1.238	.589	.445
INCREMENTAL B/C RATIO	1.238	.077	.031
PRESENT VALUE OF BENEFITS ($)	46246.	49895.	50796.
PRESENT VALUE OF COSTS ($)	37341.	84728.	114262.
ANNUAL BENEFITS ($)	5403.	5829.	5934.
COSTS:			
CAPITAL: TOTAL ($)	21773.	57022.	80410.
PUBLIC ($)	15400.	48100.	70900.
ON-FARM ($)	6373.	8922.	9510.
ANNUAL MAINTENANCE ($)	1819.	3237.	3955.
LAND USE			
CEREAL CROPS (AC.)	1120.	1120.	1120.
TAME HAY (AC.)	80.	80.	80.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 20. C.F.S.

SUBWATERSHED AREA = 1224. ACRES

PRESENT LAND USE (ACRES): A = 616.; P = 60.; K = 28.; T = 496.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 04.04.06

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	96.	178.	260.
B/C RATIO	.746	.586	.510
INCREMENTAL B/C RATIO	.746	.149	.073
PRESENT VALUE OF BENEFITS ($)	118305.	126977.	129728.
PRESENT VALUE OF COSTS ($)	158484.	216833.	254315.
ANNUAL BENEFITS ($)	13822.	14835.	15156.
COSTS:			
CAPITAL: TOTAL ($)	103900.	148017.	174226.
PUBLIC ($)	97700.	141000.	166800.
ON-FARM ($)	6200.	7017.	7426.
ANNUAL MAINTENANCE ($)	6377.	8040.	9357.
LAND USE			
CEREAL CROPS (AC.)	1032.	1032.	1032.
TAME HAY (AC.)	408.	408.	408.
NATIVE HAY (AC.)	828.	828.	828.
UNIMPROVED (AC.)	532.	532.	532.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 14. C.F.S.

SUBWATERSHED AREA = 2800. ACRES

PRESENT LAND USE (ACRES): A = 276.; P = 208.; K = 1336.; T = 980.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 04.06.00

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	170.	299.	429.
B/C RATIO	.720	.579	.462
INCREMENTAL B/C RATIO	.720	.139	.046
PRESENT VALUE OF BENEFITS ($)	238066.	252723.	258408.
PRESENT VALUE OF COSTS ($)	330784.	436491.	559481.
ANNUAL BENEFITS ($)	27813.	29526.	30190.
COSTS:			
CAPITAL: TOTAL ($)	243900.	325543.	422571.
PUBLIC ($)	219700.	295300.	388300.
ON-FARM ($)	24200.	30243.	34271.
ANNUAL MAINTENANCE ($)	10151.	12962.	15995.
LAND USE			
CEREAL CROPS (AC.)	4204.	4204.	4204.
TAME HAY (AC.)	300.	300.	300.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 40. C.F.S.

SUBWATERSHED AREA = 4504. ACRES

PRESENT LAND USE (ACRES): A = 1728.; P = 208.; K = 64.; T = 2504.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 04.07.02

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	50.	142.	235.
B/C RATIO	1.033	.644	.526
INCREMENTAL B/C RATIO	1.033	.141	.044
PRESENT VALUE OF BENEFITS ($)	63544.	70257.	71425.
PRESENT VALUE OF COSTS ($)	61521.	109108.	135669.
ANNUAL BENEFITS ($)	7424.	8208.	8345.
COSTS:			
CAPITAL: TOTAL ($)	36457.	70495.	89925.
PUBLIC ($)	30100.	63400.	82500.
ON-FARM ($)	6357.	7095.	7425.
ANNUAL MAINTENANCE ($)	2928.	4511.	5344.
LAND USE			
CEREAL CROPS (AC.)	2684.	2844.	2844.
TAME HAY (AC.)	160.	160.	160.
NATIVE HAY (AC.)	80.	0.	0.
UNIMPROVED (AC.)	132.	52.	52.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 34. C.F.S.

SUBWATERSHED AREA = 3056. ACRES

PRESENT LAND USE (ACRES): A = 1452.; P = 112.; K = 140.; T = 1352.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 05.01.01

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	230.	413.	580.
B/C RATIO	.313	.236	.190
INCREMENTAL B/C RATIO	.313	.061	.018
PRESENT VALUE OF BENEFITS ($)	83297.	90434.	92293.
PRESENT VALUE OF COSTS ($)	265829.	383756.	484832.
ANNUAL BENEFITS ($)	9732.	10565.	10783.
COSTS:			
CAPITAL: TOTAL ($)	203800.	298061.	387807.
PUBLIC ($)	193400.	284200.	373200.
ON-FARM ($)	10400.	13861.	14607.
ANNUAL MAINTENANCE ($)	7247.	10012.	11335.
LAND USE			
CEREAL CROPS (AC.)	2240.	2240.	2240.
TAME HAY (AC.)	0.	0.	0.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 46. C.F.S.

SUBWATERSHED AREA = 2240. ACRES

PRESENT LAND USE (ACRES): A = 2156.; P = 12.; K = 56.; T = 16.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 05.01.02

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	162.	282.	400.
B/C RATIO	1.052	.847	.708
INCREMENTAL B/C RATIO	1.052	.175	.070
PRESENT VALUE OF BENEFITS ($)	292250.	307070.	312616.
PRESENT VALUE OF COSTS ($)	277704.	362404.	441723.
ANNUAL BENEFITS ($)	34143.	35875.	36523.
COSTS:			
CAPITAL: TOTAL ($)	182193.	237335.	289745.
PUBLIC ($)	163600.	213900.	265100.
ON-FARM ($)	18593.	23435.	24645.
ANNUAL MAINTENANCE ($)	11159.	14612.	17756.
LAND USE			
CEREAL CROPS (AC.)	3972.	3972.	3972.
TAME HAY (AC.)	864.	864.	864.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 30. C.F.S.

SUBWATERSHED AREA = 4860. ACRES

PRESENT LAND USE (ACRES): A = 2338.; P = 586.; K = 640.; T = 1272.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 05.04.00

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	107.	212.	322.
B/C RATIO	1.065	.529	.399
INCREMENTAL B/C RATIO	1.065	.054	.019
PRESENT VALUE OF BENEFITS ($)	116853.	123490.	125010.
PRESENT VALUE OF COSTS ($)	109673.	233529.	312964.
ANNUAL BENEFITS ($)	13652.	14427.	14605.
COSTS:			
CAPITAL: TOTAL ($)	67175.	161697.	218209.
PUBLIC ($)	55300.	146700.	202400.
ON-FARM ($)	11875.	14997.	15809.
ANNUAL MAINTENANCE ($)	4965.	8392.	11070.
LAND USE			
CEREAL CROPS (AC.)	2156.	2156.	2156.
TAME HAY (AC.)	588.	588.	588.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	36.	36.	36.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 19. C.F.S.

SUBWATERSHED AREA = 2780. ACRES

PRESENT LAND USE (ACRES): A = 1692.; P = 352.; K = 196.; T = 540.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 05.05.00

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	75.	197.	275.
B/C RATIO	1.686	.497	.433
INCREMENTAL B/C RATIO	1.686	.062	0.000
PRESENT VALUE OF BENEFITS ($)	107706.	118500.	118500.
PRESENT VALUE OF COSTS ($)	63900.	238224.	273693.
ANNUAL BENEFITS ($)	12583.	13844.	13844.
COSTS:			
CAPITAL: TOTAL ($)	37055.	173979.	198279.
PUBLIC ($)	30200.	164400.	188700.
ON-FARM ($)	6855.	9579.	9579.
ANNUAL MAINTENANCE ($)	3136.	7506.	8811.
LAND USE			
CEREAL CROPS (AC.)	1964.	1964.	1964.
TAME HAY (AC.)	356.	356.	356.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 19. C.F.S.

SUBWATERSHED AREA = 2320. ACRES

PRESENT LAND USE (ACRES): A = 1124.; P = 228.; K = 40.; T = 928.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G1 (cont'd)

BENEFIT-COST ANALYSIS RESULTS FOR SUBWATERSHED 05.06.00

	LEVELS OF DRAINAGE IMPROVEMENT		
	LEVEL-2	LEVEL-3	LEVEL-4
OUTLET CAPACITY (C.F.S.)	102.	186.	269.
B/C RATIO	1.392	.433	.379
INCREMENTAL B/C RATIO	1.392	.031	0.000
PRESENT VALUE OF BENEFITS ($)	102215.	107601.	107601.
PRESENT VALUE OF COSTS ($)	73449.	248780.	284248.
ANNUAL BENEFITS ($)	11942.	12571.	12571.
COSTS:			
CAPITAL: TOTAL ($)	44700.	182320.	206620.
PUBLIC ($)	37600.	171800.	196100.
ON-FARM ($)	7100.	10520.	10520.
ANNUAL MAINTENANCE ($)	3359.	7764.	9069.
LAND USE			
CEREAL CROPS (AC.)	2092.	2092.	2092.
TAME HAY (AC.)	116.	116.	116.
NATIVE HAY (AC.)	0.	0.	0.
UNIMPROVED (AC.)	0.	0.	0.

NOTE:

DISCOUNTED RATE = .08

PROJECT LIFE =15. YEARS

OUTLET CAPACITY OF THE EXISTING CHANNEL = 19. C.F.S.

SUBWATERSHED AREA = 2208. ACRES

PRESENT LAND USE (ACRES): A = 1360.; P = 84.; K = 48.; T = 716.

INCREMENTAL RATIOS ARE CALCULATED FROM THE CHANGE IN BENEFITS AND COSTS FROM THE PRECEDING LEVEL TO THE LEVEL INDICATED.

TABLE G2

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE B	DELTA B	MB	C	DELTA C	MC	RATIOS B/C	RATIOS INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
01.01.01	102										
	496	394	299	273	273	692	406	406	1030		.67
	896	400	696	322	49	122	564	158	395	.67	.31
	1257	361	1076	338	16	44	694	130	360	.57	.12
										.49	
01.01.02	58										
	440	382	249	340	340	890	325	325	850		1.05
	822	382	631	391	51	133	442	117	306	1.05	.43
	1208	386	1015	408	17	44	541	99	256	.89	.17
										.75	
01.02.00	20										
	94	74	57	37	37	499	59	59	797		.62
	168	74	131	39	2	27	103	44	594	.62	.06
	242	74	205	40	1	13	130	27	364	.38	.04
										.31	
01.03.01	130										
	334	204	232	82	82	401	80	80	392		1.02
	541	207	437	103	21	101	95	15	72	1.02	1.42
	752	211	646	111	8	37	106	11	52	1.09	.75
										1.05	

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE B	DELTA B	MB	C	DELTA C	MC	RATIOS B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
01.03.02	60										
		147	133	52	52	353	104	104	707		.51
	207									.51	
		147	280	73	21	142	151	47	319		.45
	354									.49	
		121	414	82	9	74	190	39	322		.20
	475									.43	
01.03.03	20										
		156	98	239	239	1532	307	307	1967		.78
	176									.78	
		156	254	271	32	205	411	104	666		.31
	332									.66	
		156	410	280	9	57	487	76	487		.11
	488									.58	
01.03.04	20										
		74	57	148	148	1999	278	278	3756		.53
	94									.53	
		68	128	162	14	205	364	86	1264		.16
	162									.45	
		63	193	166	4	63	432	68	1079		.06
	225									.39	
01.04.00	25										
		110	80	301	301	2736	160	160	1454		1.88
	135									1.88	
		109	189	335	34	312	220	60	550		0.57
	244									1.52	
		110	299	337	2	18	252	32	290		.05
	354									1.34	

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE B	DELTA B	MB ($)	PRESENT VALUE C	DELTA C	MC	RATIOS B/C	RATIOS INCRE. B/C
				..($ "000)..			..($ "000)..				
01.05.00	25										
		99	74	209	209	2111	146	146	1474	1.43	1.43
	124	99	173	222	13	131	174	28	282	1.28	0.46
	223	99	272	225	3	30	205	31	313	1.10	0.10
	322										
01.06.00	30										
		76	68	320	320	4210	180	180	2368	1.78	1.78
	106	71	141	399	79	1113	209	29	408	1.91	2.73
	177	76	215	431	32	421	246	37	486	1.75	0.87
	253										
02.01.01	7										
		209	111	227	227	1086	337	337	1612	.67	.67
	216	208	320	245	18	86	451	114	548	.54	.16
	424	209	528	250	5	23	564	113	540	.44	.04
	633										
02.01.02	53										
		72	89	68	68	944	44	44	611	1.56	1.56
	125	171	210	82	14	81	175	131	766	.47	.10
	296	169	380	84	2	11	227	52	307	.37	.05
	465										

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE B	DELTA B	MH	C	DELTA C	MC	RATIOS B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
02.01.03	7										
	85	78	46	203	203	2602	45	45	576	4.52	4.52
	237	152	161	230	27	177	231	186	1223	1.00	.15
	382	145	309	235	5	34	276	45	310	.85	.10
02.02.01	176										
	391	215	283	77	77	358	441	441	2051	.18	.18
	606	215	498	91	14	65	375	-66	-306	.24	-.20
	820	214	713	95	4	18	456	81	378	.21	.05
02.02.02	51										
	260	209	155	157	157	751	214	214	1023	.74	.74
	469	209	364	201	44	210	258	44	210	.78	.98
	679	210	574	208	7	33	299	41	195	.70	.18
02.02.03	75										
	254	179	164	136	136	759	246	246	1374	.55	.55
	433	179	343	154	18	100	286	40	223	.54	.44
	612	179	522	160	6	33	328	42	234	.49	.15

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE						RATIOS	
				B	DELTA B	MB	C	DELTA C	MC	B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
02.03.00	25										
		90	70		58	644		55	611	1.05	1.05
	115			58			55				
		27	128		1	37		9	333	.93	.11
	142			59			64				
		30	157		0	0		13	433	.77	0.00
	172			59			77				
02.04.01	251										
		178	340		94	528		353	1983	.27	.27
	429			94			353				
		328	593		44	134		125	381	.29	.35
	757			138			478				
		341	927		17	49		90	263	.27	.20
	1098			155			568				
02.04.02	89										
		309	243		439	1420		329	1064	1.34	1.34
	398			439			329				
		280	538		75	267		90	321	1.23	.82
	678			514			419				
		273	814		28	102		96	351	1.05	.29
	951			542			515				
02.04.03	288										
		205	390		133	648		396	1931	.34	.34
	493			133			396				
		231	608		25	108		75	324	.34	.34
	724			158			471				
		203	825		9	44		84	413	.30	.11
	927			167			555				

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE B	DELTA B	MB	C	DELTA C	MC	RATIOS B/C	RATIOS INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
02.05.00	11										
		44	33	14	14	318	38	38	863		.38
	55	25	67	15	1	40	70	32	1280	.38	.02
	80	22	91	15	0	0	64	-6	-272	.22	0.00
	102									.24	
02.06.01	38										
		175	125	133	133	759	296	296	1691		.45
	213	187	306	156	23	122	399	103	550	.45	.22
	400	177	488	162	6	33	468	69	389	.39	.09
	577									.35	
02.06.02	61										
		143	132	196	196	1370	206	206	1440		.95
	204	141	274	224	28	198	277	71	503	.95	.39
	345	136	413	235	11	80	378	101	742	.81	.11
	481									.62	
02.06.03	40										
		84	82	94	94	1119	206	206	2452		.46
	124	84	166	106	12	142	253	47	559	.46	.26
	208	79	247	111	5	63	311	58	734	.42	.08
	287									.36	

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE B	DELTA B	MB	C	DELTA C	MC	RATIOS B/C	RATIOS INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
02.07.00	29										
	77	48	53	35	35	729	53	53	1104		
	146	69	111	35	0	0	93	40	579	.66	.66
	215	69	180	35	0	0	115	22	318	.38	.00
										.30	.00
02.08.00	65										
	110	45	87	22	22	488	81	81	1799		
	166	56	138	22	0	0	98	17	303	.28	.28
	222	56	194	22	0	0	118	20	357	.23	.01
										.19	0.00
02.09.00	564										
	1254	690	909	27	27	39	863	863	1250		
	1900	646	1577	32	5	7	1191	328	507	.03	.03
	2546	646	2223	34	2	3	1604	413	639	.03	.02
										.02	.01
02.10.00	19										
	142	123	80	105	105	853	176	176	1430		
	264	122	203	105	0	0	207	31	254	.60	.60
	387	123	325	105	0	0	240	33	268	.51	0.00
										.44	.01

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE						RATIOS	
				B	DELTA B	MB	C	DELTA C	MC	B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
02.11.00	270										
		443	491		71	160		224	505		.32
	713			71			224			.32	
		465	945		26	55		66	141		.41
	1178			97			290			.34	
		463	1409		12	25		79	170		.15
	1641			109			369			.30	
03.01.00	25										
		22	36		3	136		27	1227		.11
	47			3			27			.11	
		35	64		0	0		11	314		.00
	82			3			38			.08	
		30	97		0	0		6	199		0.00
	112			3			44			.07	
03.02.00	11										
		18	20		11	611		31	1722		.39
	29			11			31			.39	
		18	38		0	0		9	499		0.00
	47			11			40			.29	
		16	55		0	0		9	562		0.00
	63			11			49			.24	
03.03.00	20										
		26	33		25	961		55	2115		.46
	46			25			55			.46	
		32	62		1	31		17	531		.04
	78			26			72			.36	
		20	88		0	0		17	850		0.00
	98			26			89			.29	

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE						RATIOS	
				B	DELTA B	MB	C	DELTA C	MC	B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
03.04.01	93										
		276	231		178	644		354	1282		.50
	369			178			354			.50	
		283	510		30	106		74	261		.41
	652			208			428			.49	
		276	790		2	7		78	282		.03
	928			210			506			.42	
03.04.02	92										
		206	195		210	1019		276	1339		.76
	298			210			276			.76	
		235	415		17	72		65	276		.26
	533			227			341			.67	
		238	652		5	21		62	260		.09
	771			232			403			.58	
03.04.03	17										
		76	55		151	1986		126	1657		1.20
	93			151			126			1.20	
		40	113		17	425		28	700		.59
	133			168			154			1.09	
		40	153		8	200		25	625		.35
	173			176			179			.99	
03.04.04	20										
		91	65		85	934		73	802		1.16
	111			85			73			1.16	
		92	157		1	10		170	1847		.01
	203			86			243			.35	
		91	248		0	0		36	395		0.00
	294			86			279			.31	

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE B	DELTA B	MB	C	DELTA C	MC	RATIOS B/C	RATIOS INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
03.04.05	20										
		55	47		65	1181		56	1018		1.15
	75			65			56			1.15	
		55	102		4	72		44	799		.10
	130			69			100			.69	
		55	157		2	36		14	254		.12
	185			71			114			.62	
03.04.06	20										
		23	31		25	1086		26	1130		.96
	43			25			26			.96	
		23	54		1	43		7	304		.08
	66			26			33			.79	
		24	78		0	0		6	249		.03
	90			26			39			.67	
03.05.00	288										
		921	748		13	14		27	29		.50
	1209			13			27			.50	
		1022	1720		4	3		3	2		1.08
	2231			17			30			.56	
		869	2665		1	1		4	4		.37
	3100			18			34			.54	
03.06.01	240										
		841	660		362	430		595	707		.61
	1081			362			595			.61	
		842	1502		88	104		236	280		.37
	1923			450			831			.54	
		841	2343		34	40		242	287		.14
	2764			484			1073			.45	

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE						RATIOS	
				B	DELTA B	MB	C	DELTA C	MC	B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
03.06.02	290										
		757	668		325	429		517	682		.63
	1047			325			517			.63	
		757	1425		57	75		174	229		.33
	1804			382			691			.55	
		757	2182		23	30		182	240		.13
	2561			405			873			.46	
03.06.03	178										
		468	412		360	769		690	1474		.52
	646			360			690			.52	
		497	894		50	100		277	557		.18
	1143			410			967			.42	
		471	1378		13	27		251	532		.05
	1614			423			1218			.35	
03.06.12	12										
		324	174		79	243		191	589		.42
	336			79			191			.42	
		306	489		10	32		55	179		.17
	642			89			246			.36	
		307	795		2	6		63	205		.04
	949			91			309			.30	
03.07.01	28										
		52	54		109	2096		116	2230		.94
	80			109			116			.94	
		156	158		22	141		107	685		.21
	236			131			223			.59	
		156	314		2	12		69	442		.02
	392			133			292			.45	

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE B	DELTA B	MB	C	DELTA C	MC	RATIOS B/C	RATIOS INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
04.04.01	20										
		257	148	192	192	747	296	296	1151	.65	.65
	277										
		256	405	192	38	148	296	63	246	.65	.61
	533										
		257	661	230	13	50	359	72	280	.64	.17
	790			243			431			.56	
04.04.02	12										
		214	119	86	86	401	109	109	509	.79	.79
	226										
		214	333	104	18	84	150	41	191	.70	.44
	440										
		214	547	110	6	28	184	34	158	.60	.15
	654										
04.04.03	45										
		21	55	24	24	1142	190	190	9047	.13	.13
	66										
		21	76	28	4	190	242	52	2476	.12	.09
	87										
		22	98	31	3	136	293	51	2318	.11	.06
	109										
04.04.04	21										
		196	119	101	101	515	208	208	1061	.49	.49
	217										
		196	315	115	14	71	269	61	311	.43	.22
	413										
		197	511	119	4	20	308	39	197	.39	.10
	610										

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE B	DELTA B	MB ($)	C	DELTA C	MC	RATIOS B/C	INCRE. B/C
				..($ "000)..			..($ "000)..				
03.07.02	48										
		74	85		84	1135		122	1648		
	122			84			122			.69	.69
		74	159		2	27		71	959		.03
	196			86			193			.45	
		73	232		0	0		28	383		0.00
	269			86			221			.39	
04.01.00	25										
		58	54		70	1206		57	982		1.24
	83			70			57			1.24	
		59	112		5	84		43	728		.12
	142			75			100			.75	
		58	171		2	34		23	396		.07
	200			77			123			.63	
04.02.00	20										
		29	34		46	1586		37	1275		1.24
	49			46			37			1.24	
		60	79		3	49		47	783		.08
	109			49			84			.59	
		77	147		1	12		30	389		.03
	186			50			114			.44	
04.03.00	222										
		512	478		63	123		275	537		.23
	734			63			275			.23	
		507	987		9	17		118	232		.07
	1241			72			393			.18	
		506	1494		3	5		124	245		.03
	1747			75			517			.15	

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE						RATIOS	
				B	DELTA B	MB	C	DELTA C	MC	B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
04.04.05	11										
		150	86	540	540	3599	224	224	1493	2.41	2.41
	161	150	236	588	48	319	299	75	499	1.97	.65
	311	149	385	602	14	93	377	78	523	1.60	.17
	460										
04.04.06	14										
		82	55	118	118	1439	158	158	1926	.75	.75
	96	82	137	126	8	97	216	58	707	.59	.15
	178	82	219	129	3	36	254	38	463	.51	.07
	260										
04.05.00	29										
		26	42	6	6	230	19	19	730	.36	.36
	55	27	68	7	1	37	42	23	851	.18	.03
	82	36	100	10	3	83	57	15	416	.18	.18
	118										
04.06.00	40										
		130	105	238	238	1830	330	330	2538	.72	.72
	170	129	234	252	14	108	436	106	821	.58	.14
	299	130	364	258	6	46	559	123	946	.46	.05
	429										

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE						RATIOS	
				B	DELTA B	MB	C	DELTA C	MC	B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
04.10.00	1105										
		1424	1817	122	122	85	95	95	66	1.29	1.29
	2529										
		1424	3241	143	21	14	139	44	30	1.03	.46
	3953										
		1424	4665	149	6	4	195	56	39	.77	.12
	5377										
05.01.01	46										
		184	138	83	83	451	265	265	1440	.31	.31
	230										
		183	321	90	7	38	383	118	644	.24	.06
	413										
		167	496	92	2	11	484	101	604	.19	.02
	580										
05.01.02	30										
		132	96	292	292	2212	277	277	2098	1.05	1.05
	162										
		120	222	307	15	124	362	85	708	.85	.17
	282										
		118	341	312	5	42	441	79	669	.71	.07
	400										
05.02.01	34										
		112	90	63	63	562	163	163	1455	.39	.39
	146										
		112	202	67	4	35	229	66	589	.30	.06
	258										
		112	314	69	2	17	300	71	633	.23	.02
	370										

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE						RATIOS	
				B	DELTA B	MB	C	DELTA C	MC	B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
05.06.00	19										
	102	83	60	102	102	1228	73	73	879	1.39	1.39
	186	84	144	107	5	59	248	175	2083	.43	.03
	269	83	227	107	0	0	284	36	433	.38	0.00
05.07.00	1308										
	2922	1614	2115	30	30	18	57	57	35	.54	.54
	4536	1614	3729	36	6	3	88	31	19	.41	.17
	6150	1614	5343	37	1	0	114	26	16	.33	.07
05.08.00	1231										
	2908	1677	2069	15	15	8	32	32	19	.48	.48
	4584	1676	3746	18	3	1	48	16	9	.38	.19
	6261	1677	5422	19	1	0	60	12	7	.33	.10
06.01.00	300										
	2407	2107	1353	233	233	110	213	213	101	1.09	1.09
	4514	2107	3460	271	38	18	432	219	103	.63	.17
	6621	2107	5567	287	16	7	731	299	141	.39	.05

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE B	DELTA B	MB	PRESENT VALUE C	DELTA C	MC	RATIOS B/C	RATIOS INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
04.07.01	30										
		131	95	208	208	1587	428	428	3267	.49	.49
	161										
		131	226	224	16	122	524	96	732	.43	.17
	292										
		131	357	230	6	45	642	118	900	.36	.05
	423										
04.07.02	34										
		16	42	63	63	3937	61	61	3812	1.03	1.03
	50										
		92	96	70	7	76	109	48	521	.64	.14
	142										
		93	188	71	1	10	135	26	279	.53	.04
	235										
04.08.00	48										
		74	85	45	45	608	217	217	2932	.21	.21
	122										
		73	158	47	2	27	242	25	342	.20	.10
	195										
		74	232	49	2	27	269	27	364	.18	.04
	269										
04.09.00	30										
		37	48	10	10	270	90	90	2432	.11	.11
	67										
		51	92	10	0	0	115	25	490	.09	.02
	118										
		51	143	10	0	0	136	21	411	.08	0.00
	169										

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE						RATIOS	
				B	DELTA B	MB	C	DELTA C	MC	B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
06.02.00	1470										
	3163	1693	2316	133	133	78	158	158	93	.85	.85
	4857	1694	4010	153	20	11	258	100	59	.59	.20
	6550	1693	5703	160	7	4	350	92	54	.46	.08

NOTE:

MB = DELTA B / DELTA C.F.S.
MC = DELTA C / DELTA C.F.S.
INCRE. B/C = DELTA B / DELTA C OR MB / MC

TABLE G2 (cont'd)

SUMMARY OF BENEFIT-COST RESULTS

SWS NO.	OUTLET C.F.S.	DELTA C.F.S.	MID-PT C.F.S.	PRESENT VALUE						RATIOS	
				B	DELTA B	MB	C	DELTA C	MC	B/C	INCRE. B/C
				..($ "000)..		($)	..($ "000)..				
05.02.02	20										
		67	53		45	671		105	1567		.43
	87			45			105			.43	
		67	120		2	29		23	343		.07
	154			47			128			.37	
		68	188		0	0		28	411		.01
	222			47			156			.30	
05.03.00	31										
		135	98		189	1399		405	2999		.47
	166			189			405			.47	
		127	229		4	31		91	716		.04
	293			193			496			.39	
		125	355		0	0		68	544		0.00
	418			193			564			.34	
05.04.00	19										
		88	63		116	1318		109	1238		1.07
	107			116			109			1.07	
		105	159		7	66		124	1180		.05
	212			123			233			.53	
		110	267		2	18		79	718		.02
	322			125			312			.40	
05.05.00	19										
		56	47		107	1910		63	1124		1.69
	75			107			63			1.69	
		122	136		11	90		175	1434		.06
	197			118			238			.50	
		78	236		0	0		35	448		0.00
	275			118			273			.43	