AGRICULTURAL DRAINAGE DEVELOPMENT: A SIMULATION APPROACH FOR PUBLIC EXPENDITURE DECISIONS

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by

Ranjit H. Singh

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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.

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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.

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[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.