ANALYSIS OF SUBSURFACE DRAINAGE FOR LAND USE PLANNING

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ANALYSIS OF SUBSURFACE DRAINAGE FOR LAND USE PLANNING

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Aan mijn ouders

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STATEMENTS

1. Many of the most intractable environmental problems arise because either the causes or the consequences of development activities extend far beyond the local or even national areas responsible for managing these activities.
Clark, W.C. and R.E. Munn. 1986. Sustainable development of biosphere. IIASA.

2. The remarkable increase in agricultural production during recent years has been due to a myopic view on growth and development that involved an unabated exploitation of land and water resources with an intensive use of chemicals and equipment.
This thesis.

3. From a global perspective we are entering an era of profound transition in technologies, climate and scale of effects. In response to these changes focus in most sciences including agriculture and rural land use planning is on ecologically sustainable development.
This thesis.

4. Recent trends in the growing competition and conflicts over the use of limited land resources and the common recognition of environmental stress are some of the new parameters that are rapidly changing previous thinking about land use patterns.
This thesis.

5. Any expansion in the use of land resources for increasing agricultural productivity would require a considerable adjustment in current modes of withdrawal, delivery, removal, and total management of water.
This thesis.

6. One of the most important aspects of the required adjustment in the use of water is the need to develop a comprehensive integrated soil-water management system.
This thesis, and Bogardi, J.J. 1990. Op weg naar integraal waterbeheer. Inaugurele rede. Wageningen Agricultural University.

7. A comprehensive integrated soil-water management system is a reference to a complex system that can take into account the biophysical cause-effect structure of the dynamic system of land and water utilization in a manner that causes minimum damage to the environment.
This thesis.

8. With regard to agricultural drainage there is need for an integrated approach that not only considers agricultural perspectives of drainage in the area but also recognizes the environmental consequences of the lowering of ground water in the immediate area and its surroundings.
This thesis.

9. Considering the economic predicament of most non-industrialized and limited resource countries there is a need for mobilization of global resources to assist these countries to achieve a sustainable agricultural and economic growth.

10. It would be justified to apportion a larger part of the "peace dividend" to integrated land use planning and conservation efforts, particularly in non-industrialized and limited resource countries.

11. Non-industrialized countries that due to their strategic location unwittingly became victims of the "cold war" should receive a greater portion of the "peace dividend" for reconstruction and environmental rehabilitation.

Statements accompanying the thesis of Hamid Jorjani
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PREFACE

This research has been part of a cross-cultural and cross-discipline experience that was setup under a joint academic program between Wageningen Agricultural University, Wageningen, the Netherlands and University of Guelph, Guelph, Ontario, Canada.

The thesis presented here is part of an ambitious academic idea of the researcher to develop a comprehensive framework as a tool for rural land use planning. But as always ambitious academic ideas are hard to realize and require passing through several hurdles such as lack of recognition, data, funding and likes. Nevertheless, a researcher cannot abandon a dream and a purpose in his academic career because of these hurdles. By believing in himself and his dexterity and a desire to succeed, a researcher will try to make the best out of every opportunity given to him until eventually he realizes his dream.

From the outset this research was faced with a number of difficulties. Funding of the project was one of the main obstacles which was eventually removed with the help of Wageningen Agricultural University and later on with some assistance from Ontario Ministry of Agriculture and Food (OMAF). Because of limited financial resources the research had to be based on secondary data. Consequently, the investigator had to rely on some of the available sources of data in IJsselmeerpolders and Ontario. The biggest setback was when it became impossible to gather additional primary information to compliment the set of data that was obtained from Ontario. As a result the format of the research had to be restricted to a more modest quantitative analysis than it was initially planned. For example, in quantitative terms the study focuses only on two case studies that represent agricultural perspectives of subsurface drainage from farmers point of view. The analysis of environmental perspectives was left out primarily due to the prohibitive cost of collecting adequate biological input data. Societal aspects of the investigation were also excluded on account of similar reasons.

Despite the fact that the research was modest in available resources some of the theoretical analyses and the framework presented in the earlier chapters of this thesis provide a foundation for research of the future less constrained by resources. Furthermore, most findings of the thesis are consistent with theory and comply with a priori knowledge.
Some of the findings of the thesis can be used as a bench mark for further studies and decisions on land use that involve agricultural drainage. Land use planners in non-industrialized countries may also find some of the chapters very useful.

The study is an improvement over earlier similar investigations as it provides a fairly new theoretical approach for examining biophysical cause-effect structure of agricultural drainage and its impacts. Moreover, it also presents a better understanding of the interaction between factors such as: a) yearly effects, b) nitrogen fertilizer application, and c) subsurface drainage (i.e. ground water regimes) and annual production of two apple cultivars. In addition, it provides a better perception of economics of subsurface drainage with respect to different soil texture and natural drainage classes in Eastern Ontario.

Being a joint Ph.D. program between Wageningen Agricultural University and university of Guelph, this project also assisted authorities of the two universities to identify some of the logistic problems as well as potential benefits that are associated with such joint academic programs.

Finally, it is hoped that this thesis will serve not only as a bench mark for further studies but also as an informative reference, particularly for those who are interested in the biophysical cause-effect structure of agricultural drainage and its impacts.

SUMMARY

The trend of increasing agricultural output in recent decades has been noted. To some extent this increase has been due to a myopic view on growth and development that involved an unabated exploitation of land and water resources with intensive use of complex technology. In this process, for the past few decades, man has influenced the natural state of the environment in order to create an ideal environmental condition for producing biomass and energy at a rate that surpassed all previous limits. This remarkable achievement was, however, at the expense of a greater social cost. Today the harmful effect of these modifications can be seen in terms of a decline in natural habitats and an increase in various forms of pollution. Nevertheless, it would be a gross hypocrisy if one does not appreciate positive impacts of this increased agricultural productivity. Agriculture and its supporting industries are the backbone of our economies. Besides providing a continuous and cheap supply of food and raw material the agro-food industry has contributed significantly to the well being of our societies through an economic chain-effect.

Despite all these negative and positive aspects, a surplus agricultural sector and an over-exploited environment are the realities of our time and have become a challenge to scientists. While the surplus agricultural sector has depressed commodity prices and as a result is threatening the survival of our farm communities, the over-burdened environment is becoming increasingly unsafe for various forms of life that depend on it.

In order to avoid such problems we need to redefine various components of our planning procedures so that all possible cause-effect structures are incorporated in alternative plans. What we need are well defined processes of decision making whereby resources are allocated over space and time according to the needs, aspirations, and desires of our societies within the framework of our technological inventiveness and giving due regards to the environment. It is to this end that the present investigation was embarked upon

with the aim of examining one of the land use conflicts involving agricultural drainage and conservation of natural habitats. This detail examination comprised a review of the existing material delineating the conflict and a theoretical framework for evaluating trade-offs between the two land uses.

The theoretical framework developed in this thesis is based on a systematic approach to economics of subsurface drainage (Figure 4.2 of this thesis). This systemic approach focuses on the biophysical cause-effect structure of drainage and its impacts from agricultural and environmental perspectives. The biophysical cause-effect structure of drainage involves a complex process that includes hydrological, biological, ecological, and finally economic linkages. These linkages have several components that are interrelated and their individual or collective impacts are observed when the hydrological linkage (i.e. lowering of the ground water) is set in motion. In order to examine the economic consequences of these linkages a system of performance indicators (SPI) was developed. The SPI system is rather a simplistic technique whereby all agricultural and environmental impacts of drainage are expressed in monetary equivalent. This system will allow a relatively less complicated comparison of all costs and benefits of drainage from agricultural and environmental perspectives. Hence, the framework presented in this thesis can be used as a decision-making tool to evaluate trade-offs between agricultural drainage and wetland conservation from farmer's (micro) and societal (macro) perspectives.

Since the empirical testing of the entire framework was beyond the scope of this thesis, instead two sets of data (i.e. two case studies) were used to quantify the farmer's perspective on agricultural drainage. In order to test the approach under different conditions two separate sites and two entirely different crops were chosen.

The first case study was based on some experimental data from IJsselmeerpolders, in the Netherlands. Although this set of data was obtained from an experimental field, some of its conditions, such as soil type (marine clay soil), represented a wide geographic area in the region and other parts (e.g., areas with river clay soils) of the country. Thus the investigation was not considered as an isolated experiment that could not be related to the actual farm situation. The study was designed to analyze the effect of drainage (subsurface) conditions and nitrogen fertilizer application on production of two apple cultivars, Cox's Orange Pippin and Golden Delicious. The analysis was carried out in two parts: a statistical analysis to determine the effects of drainage conditions (i.e. different ground water regimes), yearly fluctuations, and nitrogen fertilizer application on apple production; and an economic analysis to determine economic viability of drainage investment for apple production. The general findings of these analyses were:

1. There was a significant relationship between apple production and drainage classes (i.e. different ground water regimes) , annual climatic changes, and application of nitrogen fertilizer.

2. Yield of Cox's apples responded more positively to drainage improvements and a moderate application of nitrogen fertilizer.

3. Drainage improvement resulted in 45 and 26 percent increase in the average yield of Cox's and Golden apples respectively.

4. The highest yield levels for both cultivars were reached on the very well drained soils with a moderate application of nitrogen fertilizer. Excess nitrogen doses had a negative impact on the quality of apples.

5. Drainage investment was highly profitable for apple production, provided moderate levels of nitrogen fertilizer were applied.

The second case study was based on actual farm records (corn yields) representing eastern Ontario, Canada. This investigation was designed to determine the economic viability of subsurface drainage under different

agroclimatic and soil conditions. The study was carried out in two parts. The first part was focussed on determining the change in physical yield resulting from subsurface drainage. The second component was an economic analysis examining the economic viability of subsurface drainage due to changes in physical yield and a shift in cropping pattern. Results of these analyses revealed that:

1. As expected, the increase in physical yield due to subsurface drainage was much higher on naturally poorly than on naturally imperfectly drained soils.

2. The largest increase in physical yield due to subsurface drainage was found on light (mostly with impervious subsoils) as well as on heavy soils rather than on the medium textured soils.

3. Despite relatively large increase in physical yields on heavier soils, the economic returns of drainage investment on these soils were actually low, mainly because of higher installation costs.

4. It was also found that there was a substantial payoff in subsurface drainage investments if such investments are followed by a change in cropping pattern.

The highlights of the study are elaborated in the summarizing chapter (i.e. chapter 10) of the thesis.

SAMENVATTING

In de laatste decennia is sprake van een toenemende agrarische produktie. Deze toename is tot op zekere hoogte toe te schrijven aan een kortzichtige visie op groei en ontwikkeling.

Volgens deze visie kunnen de hulpbronnen bodem en water met een intensief gebruik van complexe technologie onverminderd worden geëxploiteerd. Daartoe is tijdens de laatste decennia ingegrepen in de natuurlijke omstandigheden, teneinde ideale groeiomstandigheden te creëren voor de produktie van biomassa en energie. Dit is op zodanige wijze gebeurd dat een hoger produktieniveau dan ooit werd bereikt. Dit opmerkelijke resultaat is echter bereikt ten koste van hogere maatschappelijke kosten. De schadelijke effecten van de aanpassingen worden nu zichtbaar in de vorm van een afname van gebieden met een natuurlijke leefomgeving (habitat) en een toename van verschillende vormen van verontreiniging. Het zou niettemin erg hypocriet zijn de positieve effecten van de verhoogde agrarische produktiviteit niet op prijs te stellen. Landbouw en de bijbehorende toeleverende en verwerkende industrieën vormen de ruggegraat van onze economieën. Door een economische kettingreactie heeft de levensmiddelenindustrie -naast een voortdurende en goedkope levering van voedsel en ruwe grondstoffen- zeer duidelijk bijgedragen aan het welzijn van onze gemeenschappen.

Ondanks al deze negatieve en positieve aspecten is vandaag de dag sprake van overschotten in de agrarische sector, van een uitputting van de natuur en van een aantasting van het milieu. Dit is een uitdaging voor wetenschappers geworden. Door de overschotten in de agrarische sector zijn de prijzen van de produkten gedaald, waardoor het voortbestaan van onze landbouwbedrijven en van agrarische gebieden wordt bedreigd. Tegelijkertijd wordt het overbelaste milieu in toenemende mate onveilig voor verschillende levensvormen die er van afhankelijk zijn.

Om zulke problemen te vermijden, is het nodig de verschillende onderdelen van de planningsprocedures opnieuw te definiëren, zodat alle mogelijke oorzaak-gevolg relaties in alternatieve plannen worden opgenomen. Daartoe zijn goed gedefinieerde besluitvormingsprocessen nodig, waarbij de hulpbronnen worden toegedeeld in ruimte en tijd, in overeenstemming met de wensen en behoeften van onze samenleving, binnen het kader van onze technologische vindingrijkheid en met de vereiste aandacht voor het milieu. Tegen deze achtergrond is de hier beschreven studie opgezet, met als doel het onderzoeken van de tegenstrijdigheden tussen twee inrichtingsvormen, namelijk landbouwkundige drainage en behoud van natuurlijke leefomstandigheden. Deze detail-studie omvat een overzicht van literatuur waarin het conflict wordt geschetst en een theoretisch kader voor de evaluatie van wisselwerkingen tussen beide inrichtingsvormen.

Het in deze studie ontwikkelde theoretisch kader is gebaseerd op een systeem-analytische benadering van doelmatigheid van drainage. Het is schematisch weergegeven in figuur 4.2 van dit proefschrift. Deze systeem-analytische benadering richt zich op de bio-fysische oorzaak-gevolg relaties van drainage en op de gevolgen daarvan vanuit landbouwkundig oogpunt en vanuit oogpunt van milieubeheer. De bio-fysische oorzaak-gevolg relaties van drainage vormen een complex geheel, onder meer op het vakgebied van de hydrologie, de biologie, de ecologie en tot slot de economie. Verschillende onderdelen van deze relaties hangen op hun beurt weer onderling samen. Wanneer het onderdeel van de hydrologie wordt veranderd (dat wil zeggen: de grondwaterstand wordt verlaagd), worden de gevolgen voor de afzonderlijke relaties en voor het geheel bestudeerd. Teneinde de economische gevolgen van deze relaties te onderzoeken is een systeem van reactie-indicatoren (System of Performance Indicators, SPI) ontwikkeld. Het SPI-systeem is een relatief eenvoudige techniek, waarbij alle effecten van drainage, zowel de landbouwkundige als die op het vlak van het natuurlijk milieu, in geld worden uitgedrukt. Dit systeem maakt op relatief weinig gecompliceerde wijze een vergelijking mogelijk van alle kosten en baten van drainage, vanuit het gezichtspunt zowel van de landbouw als van het natuurlijk milieu. Het in dit proefschrift gepresenteerde kader is daarom geschikt als beslissingsinstrument voor de keuze tussen aanleg van drainage voor de landbouw of behoud van natte natuurgebieden ('wetlands'), vanuit het gezichtspunt van zowel de boer (micro-economisch) als de samenleving (macro-economisch).

Een empirische toetsing van het volledige theoretische kader viel buiten het bestek van dit proefschrift. In plaats daarvan zijn twee waarnemingsbestanden (dat wil zeggen twee case studies) gebruikt voor het kwantificeren van de effecten van landbouwkundige drainage vanuit het gezichtspunt van de boer. Teneinde deze wijze van aanpak onder verschillende omstandigheden te kunnen toetsen, is gekozen voor twee verschillende gebieden (IJsselmeerpolders en Ontario) en twee volstrekt verschillende gewassen (appel en tarwe).

De eerste case studie is gebaseerd op proeven in de IJsselmeerpolders. Ofschoon het waarnemingsbestand gebaseerd is op proefveldwaarnemingen, zijn sommige omstandigheden, zoals grondsoort (zeekleigrond), representatief voor grote gebieden, zowel in de regio als in andere delen van het land (bijvoorbeeld gebieden met rivierkleigrond). Er is daardoor geen sprake van een geisoleerd experiment, waarvan de resultaten niet gerelateerd kunnen worden aan de feitelijke omstandigheden op een boerderij. Dit onderzoek is opgezet voor het analyseren van de effecten van verschillende drainageomstandigheden en de toepassing van verschillende stikstof giften op de produktie van twee appelrassen, Cox's Orange Pippin en Golden Delicious. De analyse valt uiteen in twee stappen. In de eerste plaats is een statistische analyse uitgevoerd voor het bepalen van het effect van de verschillende drainage omstandigheden (grondwaterstanden), jaarlijkse verschillen en de effecten van stikstofgiften op de produktie van appels. In de tweede plaats is een economische analyse uitgevoerd, teneinde de economische haalbaarheid na te gaan van investeringen in drainage voor de teelt van appels. De algemene conclusies van deze analyse luiden als volgl.

1. Er bestaat een significant verband tussen de kilo-opbrengst van appels en de grondwaterstand, jaarlijkse klimatologische schommelingen en de stikstofgift.

2. De opbrengst van het ras Cox's Orange Pippin reageert positiever op verbetering van de ontwatering en een matige stikstofgift dan Golden Delicious.

3. Verbetering van de drainage leidt tot een verhoging van de gemiddelde opbrengst van 45% voor Cox's Orange Pippin en van 26% voor Golden Delicious.

4. Voor beide rassen worden de hoogste opbrengsten bereikt op de zeer goed ontwaterde gronden met een matige stikstofgift. Een extreme toediening van stikstof leidt tot kwaliteitsverlies van de appels.

5. De investering in ontwatering voor de teelt van appels is zeer rendabel, mits matige stikstofgiften worden toegepast.

De tweede case studie is gebaseerd op praktijkgegevens: tarweopbrengsten volgens de registratie per bedrijf uit het oosten van Ontario (Canada). Deze case studie wordt gebruikt voor het bepalen van de economische haalbaarheid van drainage onder verschillende omstandigheden van bodem en microklimaat. De studie is in twee delen uitgevoerd. Het eerste deel is gericht op het bepalen van de verandering van de kilo-opbrengsten ten gevolge van drainage. Het tweede deel omvat een economische analyse. Daarin is de economische haalbaarheid van drainage onderzocht, die is toe te schrijven aan veranderingen van de kilo-opbrengsten en aan een gewijzigd teeltplan. Uit deze analyse kunnen de volgende conclusies worden getrokken.

1. Overeenkomstig de verwachting is de verhoging van kilo-opbrengsten door drainage veel hoger op gronden met een van nature slechte ontwatering dan op gronden met tekortkomingen in de natuurlijke ontwatering.

2. De grootste toename van de kilo-opbrengst door drainage is gevonden op lichte (meestal met een slecht doorlatende ondergrond) en op zware gronden, meer dan bij zavelgronden.

3. Ondanks een relatief sterke stijging van de kilo-opbrengsten op zwaardere gronden, blijken de economische baten van de investering in drainage slechts laag te zijn. Dit is in hoofdzaak toe te schrijven aan de hogere aanlegkosten.

4. Er is sprake van aanzienlijke baten van de investeringen in ondergrondse drainage wanneer deze investeringen worden gevolgd door een verandering in het teeltplan.

De hoofdlijnen van het onderzoek zijn uitvoeriger uitgewerkt in het Engelstalige samenvattende hoofdstuk 10.

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ABOUT THE AUTHOR

Hamid Jorjani was born in July 1950 in Qazvin, Iran. He grew up in the Northern part of the country where he completed his elementary and secondary education. In 1965 he joined the Mazandarn Agricultural Training Center, Sari, Iran, to study agriculture. In 1968 his agricultural training was completed and he received a Diploma in Crop Science. After two years of language training he was sent to India in order to continue his studies at Jawaherlal Nehru Agricultural university in Jabalpur. In 1974 he received a B.Sc. in Agriculture with a major in agricultural economics and extension education. Subsequently, he joined the graduate program at the same university and in 1976 he completed his M.Sc. degree in Agricultural Economics with a major in farm management. Later that year he returned to Iran and as part of his National Conscript Program joined the Free University of Iran as a junior lecturer in the Department of Economics. In 1977 he gathered a team of agricultural and natural resources experts and formed a consulting firm (Agrec. Inc.) in Tehran. In December 1979 he left Tehran in order to continue his studies in Canada. In 1980 he joined University of Guelph where he completed a Master's thesis (in 1982) in Agricultural Economics with a major in resource economics. Subsequently, he was contracted as a Research Associate in the Department of Agricultural Economics to continue his research. In September 1985 he received a scholarship from University of Guelph and a fellowship from Wageningen Agricultural university to start a joint Ph.D. program in Wageningen. In September 1986 he officially joined the Department of Land and Water Use to carry out his joint Ph.D. project. His contract with Wageningen Agricultural university ends in September 1990.

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CHAPTER 1

INTRODUCTION TO THE TOPIC

1.1 Global perspectives

From a global perspective we are entering an era of profound transition in technologies, climate and scale of effects. In response to these changes the focus in most sciences including agriculture and rural land use planning is on ecologically sustainable development. Ecologically sustainable development implies sacrificing short-term gains in return for long-term benefits of future generations.

This is of course a very unfamiliar concept to many individuals who for a long time were used to make relatively short-term decisions that only involved their own lives and sometimes those who immediately depended on them. But as we are entering the 21st century we are becoming more concerned about issues that involve the interlinks between human activities and the environment. We frequently encounter questions such as how the planet earth respond to some of the current pressures. Pressures such as an unabated increase in human population. Will we be able to feed ourselves without destroying the fragile ecosystem?

Recent estimates reveal that the world's population is likely to grow from 5 to 8.2 billion within 35 years (Stigliani et al. 1989). In order to meet the food requirements of such a large global population food production must increase by 3-4 percent annually (Stigliani et al. 1989). Given these estimates, it is no surprise why the focus of research in most sciences is on ecologically sustainable development.

With regard to agricultural development, ecologically sustainable means there will be a gradual transition from an agriculture that is heavily dependent on chemicals to one which is more based on the application of biotechnologies. For example a genetically engineered corn variety with a nitrogen-fixing characteristic will minimize the need for nitrogen fertilizer application in corn fields (Crosson and Rosenberg, 1989). Moreover, sustainable agricultural development may require more land base so as to maintain productivity in the absence of high-yield inducing chemicals.

Hence, higher yields on relatively smaller scale arable land base with the extensive use of chemicals is no more acceptable as it is not sustainable. Consequently, in order to maintain productivity good quality agricultural lands are imperative to an environmentally friendly agricultural operation.

Furthermore, wise use of soil and water resources becomes paramount because of recent climatic changes and the likelihood of a long-term increase in annual global temperature.

In non-industrialized and limited resource countries where natural resources account for most of their economic production, employment, and export, various forms of environmental catastrophe are inevitable. Currently, most of these countries are burdened with debt loads that are beyond their repayment capacity. According to some estimates (IIED and WRI, 1987) during the last ten years the external debt of most non-industrialized and limited resource countries has grown by massive proportions. Because of these economic problems on one hand, and the rapidly expanding population on the other, there are already environmental crises in most of these countries. Too many people, too little arable land base, and too often perverse land use patterns (e.g. deforestation of fragile rain forests) in order to increase the area under cultivation of export earning crops, is creating havoc. For example, expansion of coffee farming in Latin America has led to expulsion of many small farmers from communal lands (Wirick, 1989). These marginal lands include hillsides and pristine forests of rapidly receding frontiers. While hillside farms are eroded within a few years, the soil of pristine forests are quickly exhausted by intensive farming. Moreover, on the issue of debt and export crops, it is becoming increasingly apparent that most non-industrialized and limited resource countries with huge debt obligations often attempt to increase their agricultural export at the expense of food crops. This by itself aggravates food shortages and as a result creates more pressure on land and environmental resources in those regions. The current pressure on rain forests in some of those countries in Latin America and Asia is a witness to this problem.

Hence, long-term decisions on land use options are becoming more complex both at micro and macro levels. In order to achieve long-term (sustainable) agricultural development it is becoming increasingly apparent that we need to understand the linkages involved in soil-water management activities. We should also be willing to depart from some of the traditional ways of thinking in terms of environmental values. The market failure to assign values to environmental functions is not because these functions have no commercial utility but because the earlier economic wisdom did not recognize those functions as scarce commodities. According to Crosson and Rosenberg (1989), essentially the reason for that failure is the lack of adequate mechanisms for conveying the social scarcity of environmental resources. The fact that no property rights are attached to these commodities is by itself another important reason why market cannot assign values to such commodities.

If market related pricing mechanisms cannot be established to facilitate valuation of wetland resources, then certain policies must be introduced. However, most governments are reluctant to introduce such policies because of their heavy social costs. Moreover, these policies may never become popular because they may fringe upon people's private right of ownership. For example, some governments may find it costly and legally difficult to ask a farmer not to reclaim a pothole in the middle of his farm mainly because some waterfowl use that wetland as their nesting area. Therefore, such policies may foster political conflicts, unless governments (with the help of experts, including land use planners) devise a compensatory policy that integrates societal and individual interests rather than imposing one over another. For example, provision of a better rural environment at the cost of extra public taxes in order to compensate farmers for refraining from reclaiming environmentally sensitive areas. Under such mechanisms it will be possible to use the profit motive in order to get farmers and other individuals to manage environmentally sensitive lands for sustainable uses. However, the essential pre-conditions to that are (a) peoples' (particularly farmers') knowledge of the services that environmentally sensitive lands can provide within the framework of a sustainable development, (b) proper identification of these services in scientific ways in order to facilitate their measurement and weighing their positive and negative values in empirical land use decision-making analysis, (c) peoples' willingness to pay for these services, and (d) designing mechanisms to translate people's willingness to pay into actual compensation payments. Currently, a number of EEC member countries including the Netherlands have adopted a land use program known as "Management Agreement" through which farmers are compensated for preserving environmentally sensitive areas (van Lier, 1989).

Although a critical examination of environmental stress in industrialized and non-industrialized countries is an important issue, it warrants a separate investigation. While reading this thesis the important thing to consider is the fact that there is an important linkage between economic development and natural resources. An example of this linkage involves the topic of this thesis, that is the economics of agricultural drainage. Hence, the thesis attempts to provide a new theoretical approach to economics of agricultural drainage that includes some of the environmental aspects that can be used globally within the framework of sustainable agricultural development.

1.2 Local perspectives

Southwestern Ontario, with its highest population density and best agricultural land in Canada, provides difficult challenges in terms of agricultural drainage versus nature conservation. Because of its rich land resources and unique geographic characteristics, the region is currently under intensive land use pressure. Continuous urbanization and industrialization on farm lands, especially around major cities such as Toronto, Ottawa, Hamilton, London, Niagara on the Lake, Kitchner-Waterloo, and Guelph, among others, and their satellites have put a tremendous pressure on Ontario's limited prime agricultural land.

The reason for land use conflicts is primarily due to the fact that there are different interest groups who most often compete for the use of same land resources. However, these conflicts are usually less complicated in countries or regions where there are efficient systems of land use planning in place. For example, there are relatively limited land use conflicts in the Netherlands. One of the main reasons is the geographic characteristics of the country which has compelled Dutch authorities to develop an efficient land use planning system which reduces land use conflicts. This is particularly true in the case of multijurisdictional conflicts where several ministries are involved. In the Netherlands ministry of agriculture and fisheries is also responsible for the environment. Therefore, most potential conflicts involving agricultural and environmental interests of individuals and society at large are resolved by one minister who's mandate includes protecting both interests at local, regional, and national levels.

In most other countries where a comprehensive (national) system of land use planning is not common there are more likelihood of land use conflicts. For example, in Ontario there are different interest groups and several ministries with different mandates over the use of land resources in the province. Under these conditions agriculturalists who are losing their prime land to urban and industrial development strongly lobby for use of farm drainage to maintain and improve farm productivity. Because of the agroclimatic conditions in Ontario, most agricultural lands in the region require improved drainage for efficient agricultural production. At the same time, naturalists and environmentalists who are concerned with the long-term deleterious impacts of agricultural drainage on environmentally sensitive areas are lobbying for nature conservation (mostly involving wetlands of provincial or national importance). However, some resource economists in that province tend to downplay these types of arguments that involve land use conflicts on two grounds:

1. Looking at the current surplus order in the agricultural sector they conduce to disagree with agriculturalists who complain about the loss of prime farm land. This is mainly due to the fact that these economists do not foresee any short-term threats to the agricultural productivity if in fact some farm lands are withdrawn from agricultural production. Essentially, they believe that increases in yield will compensate for any reduction in production due to the loss of arable land base.

But what these economists do not realize are: (a) increasing yield is only possible through intensive farming which is no more environmentally acceptable; (b) a sustainable agricultural development (i.e. a chemical free agricultural development) may require larger land base in order to maintain adequate production levels; and finally (c) in the long-term some of the losses due to land conversion (i.e. the non-agricultural uses of prime farm lands) may be irreversible. This irreversibility can be caused due to the extent of physical changes that take place on these lands.

2. With regard to the current pricing mechanism (e.g. agricultural subsidies) that mostly favors agricultural development, these economists believe that farmers will always opt for agricultural drainage because environmental functions are not properly valued in the market system. In other words, because wetland benefits are not accurately quantified most land use decisions involving agricultural drainage and wetland conservation will automatically favor decisions on drainage improvements.

Unfortunately, the prevailing conditions in Ontario are such that a number of other economists and opinion leaders may agree with some or all of these notions about benefits of wetlands. Because, first of all, not only Ontario is a land rich province but it is also part of a vast country where land is not as limiting as in other parts of the globe. Second, the idea of a long-term sustainable economic development has not been fully appreciated in Ontario mainly because the issue is not as tangible as it is for example in Western Europe. Moreover, the old pioneer attitude is still very much in place in the mind of some of its residents. Consequently, unlike their European colleagues, some of the resource economists in Ontario are not very familiar with the idea of sustainable growth and a holistic approach towards various aspects of growth and development. This holistic approach is currently viewed as the most appropriate tool for solving land use conflicts, owing to the reason that it considers the entire cause-effect structure of different activities in the ecosystem.

Besides these philosophical views it became also evident through earlier stages of this research that not all the conflicts in land use in Ontario arise from rhetorical arguments between resource economists on one hand, and agriculturalists and environmentalists on the other. It was also evident that these conflicts were not entirely due to the unwillingness of planners to recognize the intricate relationship between agricultural activities and nature conservation. On the contrary, it is often due to lack of a reliable information base and comprehensive decision guidelines whereby a sufficiently broad array of alternatives is evaluated across a consistent set of systems indicators.

Recognizing these deficiencies, this study focused on a strategy through which some of these problems are addressed in the best possible way, given the available resources. In this process it was soon realized that; (a) although the project could not generate a complete and reliable information base for land use decision-making (involving agricultural and environmental perspectives of drainage), it was possible to develop a holistic theoretical decision guideline that would highlight some of the areas where the needed micro and macro input data are currently missing, (b) it was possible to test at least two components of this holistic decision guideline (that is as part of the economic linkage of the system) by utilizing some of the available information in the Ijsselmeerpolders in the Netherlands, and in eastern Ontario, Canada.

1.3 Statement of the Problem

Demands for various forms of land resources are rapidly increasing. This is evident in some of the recent upward trends in land prices, greater competition among users, and renewed emphasis on land use planning. These are particularly more relevant in most land-limited industrialized and non-industrialized countries where fertile agricultural land is relatively more scarce. In some land-rich industrialized countries such as Canada the sheer size of the country inhibits private and public decision makers to realize that how much of the productive land is being lost and misused annually. The reason for this short-sighted view is rooted in the current surplus state of the agricultural sector. What some of these decision makers fail to grasp is that a productive land base is imperative to the success of a sustainable agricultural development in the 1990s and beyond.

Much of the farm land losses in Canada are said to be due to urban expansion into surrounding rural areas (e.g. Rodd, 1976; FitzSimons, 1983; OECD, 1979; Phipps, 1981). Witness the case of rapid urban expansion in the surrounding rural areas of Southwestern Ontario, Canada, where the urban resettlers can outbid farmers with their ability to pay a higher economic rent for the use of rural land (e.g. Rodd, 1976; McRae, 1980).

The perplex, central issue is that as population and economic growth increase, the demands made upon land resources also become greater, thus putting a tremendous pressure on these limited resources. Today, much of the demand for land resources particularly in industrialized societies, is for urban.and industrial development, roads and other transport services, agricultural and forestry, and finally recreation and conservation purposes.

Because land resources are becoming increasingly scarce, we are confronted with the problem of how to allocate them among different usually, competing uses. For this reason too often decision problems on land use involve several conflicting interests. An example of the latter is the topic of this research, the conflict between agricultural drainage programs and preservation of wetlands.

When the population is small and the arable land base is abundant, single individual decision-making processes are relatively straight-forward. That is farmers will occupy the best agricultural lands characterized by no or few limitations with regard to agricultural production. As population and non-agricultural uses of land increase, the availability of the existing or additional agricultural land varies (e.g. may decline) proportionately. Because farmers and other users of land will have to compete for the rapidly shrinking land resources, particularly in certain areas where climatic and physical characteristics of land are suitable for agricultural and non-agricultural uses. For example, Southwestern Ontario with its relatively mild climate, fertile soil, and a prime location for economic (i.e. proximity to Toronto, Montreal, and a few major cities in the U.S.) and political (i.e. proximity to Ottawa and Quebec) activities is currently facing a rapid economic growth that has put a tremendous pressure on land resources in the region. As the price of property is continuously growing in major cities of Southwestern Ontario, industries, service sectors, and urban developers are moving to surrounding rural areas. Therefore, at present a number of parties (i.e. groups of individuals) are involved in a competitive biding over the use of scarce land resources in the region. This process involves a number of decision makers both at micro and macro levels. The issue is that due to all these rapid expansions in the region various interest groups are trying to protect their own interest. For example, environmentalists and naturalists try to curb economic activities in environmentally sensitive areas and surroundings for conservation reasons. Commercial developers lobby for more favorable legislation that would allow them to sever farm lands for non-agricultural uses. Agriculturalists who need to maintain a functional (some of the old systems need to be replaced) soil-water management systems in their fields lobby for more investment in drainage projects.

Unfortunately, to the dismay of many farmers and environmentalists, sometime simple management decisions, especially when they involve overlapping jurisdictions on land use (e.g. drainage and conservation of natural habitats) have often been constrained by the inability of decision makers to resolve the conflict due to virtual absence of an appropriate information base and decision-making guidelines. These are needed in order to provide some empirical bases (e.g. costs and benefits) for resolving land use conflicts. In order to develop an appropriate decision-making guideline, a comprehensive knowledge of various forms of land use are absolutely essential.

For example, despite the importance of agricultural drainage in its role as an important soil-water management technique both in the past and at present, its biophysical cause-effect structure and economic linkages are not fully and correctly recognized. The biophysical cause-effect structure of artificial drainage refers to a number of cause and effect relationships that include hydrological, biological, ecological, and economic linkages that are involved in agricultural drainage. The knowledge of these linkages would enable decision makers to properly identify all the positive and negative aspects of agricultural drainage (subsurface drainage) from different points of view.

Hence, this investigation is not just an economic case study. By examining some aspects of land use planning the study attempts to firstly, understand the nature of land use conflicts involving subsurface drainage and secondly, to present a holistic view of how (theoretically) some of the positive and negative aspects of a drainage project may be calculated at different levels and from different points of view. The main reason for this part of the exercise is not only to demonstrate environmental costs and benefits of drainage but also to show how income generating potential of wetlands may be used to enhance the preservation and management of these environmentally sensitive areas. Later on the study uses two sets of data to demonstrate how economic benefits of subsurface drainage can be quantified from farmer's perspective, with respect to economic linkages of this holistic framework.

1.4 Research Objectives

The general objective of this investigation is to examine the economic viability (e.g. farmer's and societal perspectives) of subsurface drainage within the context of land use planning. The study aims to achieve this general goal by converging on some specific objectives that can be listed as follows:

1. To review some of the general concepts pertaining to land resources as a habitat and as a factor of economic development, land use patterns, the critical nexus between development (primarily rural development) and land use planning.

2. To examine agricultural and environmental perspectives on subsurface drainage.

3. To provide a theoretical framework for evaluating the trade-offs between agricultural drainage and wetland conservation.

4. To focus on the economics of subsurface drainage from the farmer's perspective by taking two separate examples representing the Ijsselmeerpolders in Holland, and Eastern Ontario in Canada.

1.5 Outline Of The Thesis

This thesis presents an analysis of subsurface drainage for land use planning. In this process the study will first examine some general concepts that deal with land resources, some aspects of development as it relates to land use, and land use planning. Later, the study will examine subsurface drainage from agricultural and environmental perspectives and present a theoretical paradigm for resolving land use conflicts related to those two perspectives. However, since dealing with both perspectives quantitatively goes beyond the scope of this academic exercise, instead the thesis will be limited to agricultural perspectives on subsurface drainage at the farm level. In this approach two separate examples that represent two land use alternatives namely field crop and fruit production are used to demonstrate the economic viability of subsurface drainage under different conditions.

The material delineating all these discussions and findings are presented as several independent sections, the content of which have either partly or entirely been presented in international academic gatherings or published either as refereed working paper and proceedings or as scientific manuscripts in international journals. The following is a brief description of each chapter.

In chapter 2. while reviewing some general aspects of land resources the study will discuss some land uses and their resulting conflicts. It also discusses the need for developing effective means of land use decision-making for assessing, allocating and managing scarce land resources.

Due to the extreme agroclimatic conditions in most non-industrialized and limited resource countries, poor soil-water management has been recognized as one of the most important obstacles in their quest for increased agricultural productivity. Since most soil-water management projects in non-industrialized countries are implemented within rural development programs, chapter 3. is designed to analyze the critical link between land use planning and rural development.
The main theme of this section is that, in order to allow a sustainable agricultural development in non-industrialized countries, an integrated approach

towards rural development is needed. This integrated approach recognizes the cause-effect structure and impacts of soil-water management projects (e.g. agricultural drainage) within rural development programs.

Chapter 4. examines agricultural drainage as a soil-water management technique. In examining agricultural drainage the study provides a holistic view of its impacts which is referred to as biophysical cause-effect structure of drainage. Then, the chapter describes various components of this complex cause-effect structure and discusses why it is important to adopt this approach in valuating costs and benefits of agricultural drainage.

Chapter 5. is focused on a framework that provides a system of performance indicators. This system is designed a) to provide a broad array of indicators that might be considered in drainage vs. wetland conservation decisions, (b) to broaden the array of alternatives that might be considered, and (c) to ensure that analyses of merits and demerits of draining land for agricultural development provides system-response projection for all identified performance indicators.

Chapter 6. describes two case studies that were used for testing two components of the framework discussed in the earlier chapter. The first case study is based on some experimental data from the IJsselmeerpolders in the Netherlands, and the second case study is based on farm records from eastern Ontario, canada.

The results of a statistical analysis of the effect of drainage conditions and application of nitrogen fertilizer on apple production are provided in chapter 7. It is shown that significant changes in apple yields can be attributed to climatic fluctuations, subsurface drainage and nitrogen fertilization.

Chapter 8. focuses on the economic assessment of subsurface drainage improvements and nitrogen fertilizer treatments in apple orchards. By examining different marketing strategies it is shown that the incremental net returns of subsurface drainage in apple orchards increase (as a result of subsurface drainage installation) using farm gate prices. It is also shown that the increased application of nitrogen fertilizer has an adverse effect on the quality of apples produced. This has a direct bearing on the economic returns of apple production and subsurface drainage investment.

Chapter 9. provides the results of an investigation in Eastern Ontario, Canada. The study examines the economic returns of subsurface drainage with respect to different soil types and natural drainage classes. It is shown that due to inherent characteristics of different soil types the economic returns of subsurface drainage vary among light, medium and heavy soils. It is also shown that returns of subsurface drainage on account of a change in cropping pattern are more substantial than the resulting changes in the yield of the existing cash crop in Eastern Ontario.

Chapter 10. comprises an overview of the thesis which is a synthesis of all the previous chapters. The summary provided here describes how various components of the study are linked together and what it attempts to achieve.

CHAPTER 2

LAND RESOURCES

2.1 Introduction

Land is a limited resource. There is no doubt about the significance of this scarce natural resource in our lives. We all require land to live on, to produce food, and to provide means and opportunities for our recreational needs. In a more technical sense land resources can be viewed from three perspectives (a) as a habitat for growing vegetation either natural or cultivated by man, (b) as an essential factor for living and working space, and finally (c) as a natural ecosystem, a source of vitality, inspiration, recreation, and even identity. Consequently, today, much concern is directed towards preserving and enhancing the quality of existing land resources. These concerns arise from a global awareness of the extent of recent trends in land degradation.

Land degradation is a process through which the existing or long-term productive capacity of the land is hampered or lost due to unsuitable uses of land or a combination of over-exploitation and detrimental climatic impacts. Thus land degradation can be caused by several processes such as soil erosion, desertification, pollution and land conversion from productive agricultural or forestry land to other uses.

Land as a factor for living and working space (for different economic activities) and also as a natural ecosystem is therefore a key resource that not only has to be appropriately allocated among alternative activities, but should also be conserved for future uses.

However, the use of any given unit of land affects not only those who possess that land (for whatever purpose it may be) but also those who live on or have use of adjacent and surrounding areas. Hence, there are both interactions and conflicts between uses and among users over time and space (Figure 2.1).

As shown in Figure 2.1, there is an interaction between the existing land use options such as agriculture, forestry, residential and commercial, industry, and services. For example, agricultural activities can have far-reaching effect on other actual and potential uses of land both over space and time. Witness the extent of non-point pollution particularly in industrialized countries. The intensive use of chemicals and livestock slurry on agricultural land as fertilizer have seriously affected the quality of ground water in Western Europe. Industrial production too can restrict other land use activities. Nitrogen and sulphur emission from industrial units using fossil fuel can cause acidification of soil and water over

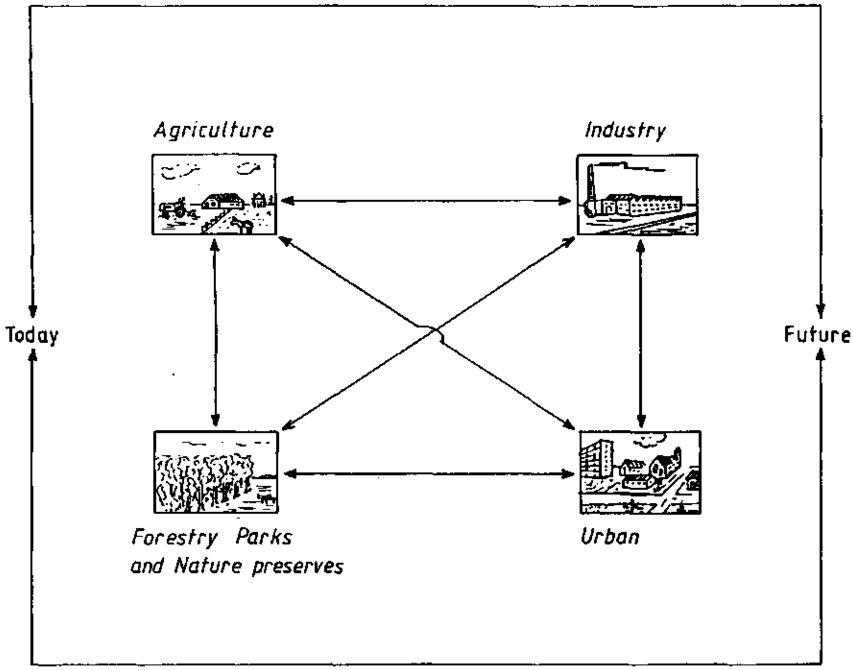


Figure 2.1 Schematic representation of interactions between different landuse alternatives.

a long distance. This is a serious concern in Nordic countries of Europe and in North America (OECD, 1985). Another important aspect of this interaction between various land use activities is their temporal impact. In other words what we do with our land resources today has a direct bearing on the potential uses of land in the future. For example, the logging activity in a tropical rain forest today, will have not only an impact on the productive capacity of that land in the future, but it will also cause numerous ecological, and socio-economic problems the effects of which can last over a long time in the future. Furthermore, the logging activity can cause intense conflicts between loggers and native communities who depend on the rain forest for their livelihood on one hand, and between different lobby groups within a local government or between different independent states on the other.

Because of all these complexities today, more government and non-government investigations are carried out on patterns and extent of land use, and the conversion and preservation of areas that are subject to various forms of land use stress.

This chapter is designed to provide an overview on land and its uses and how conflicts arise from different uses. In this process the section presented here will focus on the important role of land as the main resource base for food production. The justification for this approach is rooted in our past insights on land use. It is known that land degradation (mainly in the form of soil-water degradation) has the capacity to cause a detrimental impact on the productive capacity of land resources. Some economist in North America argue that soil-water degradation does not have a negative impact on the productive capacity of farm land resources in North America. This is of course very true in the short-term owing to current agricultural prices (which are usually subsidised) allow farmers to compensate the gradual loss of productivity by an increase in the use of chemicals. However, in the long-term this loss of the productive capacity of farm lands will eventually reach to a level which becomes economically too costly to compensate.

Land degradation results from non-suitable land use and its management. In order to avoid non-suitable land uses and to enhance effective soil-water management practices, it is imperative to provide information bases and develop reliable decision-making guidelines (frameworks and methods) that would enable private and public decision makers to utilize land resources more optimally (i.e. from private and public points of view). However, a pre-condition to collecting appropriate data base and to designing such comprehensive methods is a better understanding of the issues that involve land use patterns.

2.2 Land use patterns and their conflicts

Land plays an important role in agricultural, forestry, urban, and industrial development. While agricultural activities remain as an important aspect of land use in most countries at the present time, the increased importance of urbanization, outdoor recreation, and nature conservation have received increasing attention from public planners, academics, opinion leaders, and land developers. Each of these alternatives tend to maximize human welfare in a different way (by using different criteria) which could sometimes have a deleterious impact on other land use options. For example, agriculturalists emphasize improvement of drainage conditions in existing or newly developed farm lands in order to increase agricultural output. Environmentalists urge governments to preserve natural habitats in order to provide more opportunities and facilities for outdoor recreation concomitant with nature conservation and the preservation of unique habitats for their aesthetic, scientific, and heritage values. Foresters call for afforestation and new approaches to agricultural land by converting these lands into productive and aesthetically pleasing timberlands. These type of arguments are currently very common in Western Europe where agro-forestry is being viewed as a mean for cutting back excess agricultural production and also as a substitute for timber imports. Then we have industrialists and commercial land developers who with their attractive development ideas try to attract farmers into selling their prime agricultural land for conversion into new urban developments, industrial parks, highways and airports. Some or all of these interest groups are of course supported by some political groups who represent different ministries with different mandates or even party platforms depending on the political shape of the government (e.g. whether the government is in favor of environmental protection or of agricultural expansion). There is often a conflict between these groups of people not only because they deal with multijurisdictional issues of land use patterns (due to different mandates), but also because they have to consider the special demand and interest of their constituencies. Witness the interest of a strong agricultural lobby that favored agricultural expansion into an environmentally sensitive area in England. Nearly 10 years ago, in the Wash on the east coast of England 340 hectare of land were reclaimed from the sea by construction of an earth floodbank. Ironically, that area was designated by the Nature Conservancy Council as a site of special scientific interest on account of its exceptional biological importance as one of the U.K.'s most important winter feeding areas for waders and wildfowl. The economic rationale for undertaking this project was based on calculations which indicated that the total cost of the land to be reclaimed would be less than the purchase price of similar agricultural land. The market value of such land after reclamation was estimated to be 4500-6000 pounds (Cook, 1982). Witness the interest of a constituency in Holland that opposed agricultural expansion in the Dollard region, or lately the reclamation of the Markerwaard in the IJsselmeer. All of these examples indicate a complex multifaceted nature of land use decisions. However, the pursuit of these many faceted, and usually conflicting uses should be based on scientific analysis. These analyses include several studies that are aimed at determining the inherent capacity of the land (soil and water resource base) to perform various functions, and the economic viability of those functions from the private and public's point of view. Findings of all these analyses will constitute the required information base that are needed for weighing positive and negative aspects of each land use option with respect to its spatial and temporal characteristics.

For example, in the case of agricultural development particularly, in non-industrialized countries more accurate soil analysis should be conducted, topographic surveys made, and field crops (including fruits and vegetables) production must be tested in the laboratories (e.g. bio-engineering) and in the field. Results of these tests not only would enable land use planners to determine which crops are best suited for cultivation under different agroclimatic and soil-water management conditions, but would also allow them to investigate possibilities of adopting a particular tillage (e.g. conventional or conservation tillage) in different areas. Findings from these scientific observations will also provide a valuable information base (input data) that can be used for further land use analyses.

Based on the results of earlier studies, we know that on a relatively aggregate level humid regions in the tropics and the temperate zones are characterized by soil-water management problems that are largely associated with excess soil moisture, among other things. Consequently, any expansion in the intensity of agricultural or forestry production or conserving and enhancing the quality of the existing land resource base in those regions would require an integrated soil-water management system. An integrated soil-water management system would be imperative as a decision-making guideline for resolving multijurisdictional land use conflicts (e.g. conflicts on outlet drains in Ontario that involve different ministries and conservation authorities) and to develop guidelines for maintaining long-term growth in those areas.

It is also common knowledge that a great proportion of the Earth's land resources are either arid or semiarid regions. Most of these areas are either deserts or sensitive areas that are subject to varying degrees of desertification hazards and unsuitable uses of land (e.g. over-grazing). Most of these fragile lands occur in non-industrialized and limited resource countries of Africa and Asia, where because of unpredictable (either too much or too little) precipitation patterns rainfed and irrigated farming is a common practice. Thus, to enhance agricultural productivity and food production in these regions an integrated method of soil-water management would be required too.

Essentially, whether it is a humid or arid region, intensification of agriculture and forestry or even conservation implies a considerable adjustment in the current methods of soil tillage and the withdrawal, delivery, and management of water. One of the most important adjustments required would be the development of a sophisticated and clever soil-water management system that takes into account the biophysical cause-effect structure (biophysical interactions) of the withdrawal, delivery, and removal of water in a manner that results in a dynamic equilibrium in the hydrological cycle of a region with minimum adverse physical, biological and socio-economic effects.

This integrated soil-water management system can be seen as a comprehensive method of determining physical, biological, and socio-economic issues of various aspects of soil-water use. Of course such a holistic approach (details in chapter 4) may be very cumbersome for one or a few scholars to develop. But by adopting a multidisciplinary approach of scientific enquiry, scientists from different disciplines may be able to develop various components of such integrated soil-water management. Currently, a number of scientists from various disciplines are working towards this direction at different scales. The most important example is the experiment known as "biosphere II" which is being carried out in the U.S.

The urgency and the need for an integrated soil-water management system can be seen in the context of an ancient struggle against waterlogging, salinization, and other forms of land degradation. In some cases these problems have been responsible for serious soil and water degradation that has caused the downfall of a number of ancient civilizations.

2.3 Preserving and enhancing the land resource base

"According to the World Commission on Environment and Development (WCED), a fivefold to tenfold increase in world economic activity during the next 50 years will be required to meet the basic needs and aspirations of the future population." (Clark, 1989)

In view of the current environmental degradation, climatic changes, increasing desertification particularly in arid regions of Africa and Asia, the implications of the projected need for an increase in the world economic activity causes a great deal of concern among scholars and researchers who are facing yet another challenge. Despite some of these concerns there are a group of scientists who believe that a continuous but managed (i.e. somewhat restricted) growth is attainable.

According to this new school of thought, in order to achieve growth, certain social and economic changes will have to be made to persuade individual farmers to adopt methods that will increase food production without further degradating the environment (Crosson and Rosenberg, 1989). But, this approach may prove to be more useful in industrialized countries where because of the existing socio-economic and physical infrastructure farmers can adopt the new structural change in their agricultural activities. These structural changes involve the use of a number of institutional and technological inputs that are often costly. In most non-industrialized countries where farmers and governments are desperate in their quest for food security, different and more comprehensive structural changes (a host of socio-economic changes including a new pricing mechanism that would induce farmers to adopt new sustainable technologies and farming practices) are needed in order to avoid environmental degradation.

Although our knowledge of the interface between human activities and the Earth system is incrementing, we still do not know accurately how much adjustments we need to make in our new approach towards uses of land resources. To provide a better understanding of the cause and effect structure of some human activities the following section will focus on two major components of land degradation, soil erosion and the twin menace of waterlogging and salinization.

2.3.1 Soil Erosion

Soil erosion is caused or induced by the action of wind, overland flow and freezing-thawing conditions in the lower section of the soil profile during or after winter thawing on the soil surface. This is of course more characteristic of a natural process of erosion. However, this natural process can be accelerated due to mismanagement of agricultural fields (e.g., continuous row cropping). According to some estimates the annual rate of erosion on crop lands in U.S.A., Soviet Union, India, and China is said to be 9.0, 9.2, 33.6, and 33.3 tones per hectare (van Lier, 1989). Most of this erosion may have been averted if wiser soil-water management practices were adopted.

Since this thesis is ultimately limited to subsurface drainage as a soil-water management practice, the present discussion will be limited to soil erosion due to overland flow which is considered as water-caused erosion.

Overland flow and surface runoff have been recognized as major causes of erosion of farm lands in several regions. This type of erosion occurs more frequently on exposed and compacted arable soils with low infiltration capacities. Water-caused erosion entails serious environmental degradation as well as economic problems. With regard to the Netherlands water-caused erosion is relatively limited due to the efficiency of the existing soil-water management systems. However, in some parts of the country particularly in southern Linburg where topographic and soil characteristics are quite different from the rest of the country water-caused erosion occurs (on arable lands) usually after a heavy rainfall (Eppink, 1986). THe problem is said to be more serious in areas where row cropping and an intensive soil tillage practices are carried out. These areas are mainly used for cultivation of sugar beets and potatoes both of which require lifting of soil at the time of harvest. Hence, after harvest loess soils (material transported and deposited by wind and consisting predominantly of silt-sized particles) on these hilly areas are subjected to water-caused erosion in the event of a heavy rainfall (Eppink, 1986). The economic aspects of water-caused erosion in this region have already been investigated with respect to erosion related preventive, repair, and maintenance costs in seven municipalities of the region (Schouten et al., 1985).

In the case of Canada it is known that as a result of water-caused erosion the water quality in Lake Erie and Lake Ontario has drastically deteriorated due to loading of phosphorus and toxic substances (PLUARG, 1978). While phosphorus is known to be responsible for eutrophication of the Great Lakes, toxic and hazardous substances can endanger aquatic life and any other form of life that depend on the affected habitat. Soil eroded from agricultural fields have been recognized as one of the major components in the siltation and eutrophication of the lake systems in Southwestern Ontario (Rast, 1981). This harmful effect of soil erosion on water quality of the Great Lakes is said to be higher especially in areas where the eroding soil contains more clay particles. This is mainly due to the small size of clay particles that allows them to stay in suspension once detached. Very fine clay particles can remain almost indefinitely in suspension, assuming no flocculation. Moreover, because agricultural chemicals are soil-fixed, the suspended clay particles can easily transport these chemicals downstream and consequently cause severe pollution problems. Rast (1981) notes that more than 50 percent of the Canadian Lake Erie basin is characterized with finely-textured clays. The process involved in water-caused erosion can be summarized in a schematic representation (Figure 2.2).

Figure 2.2 demonstrates that the amount of erosion by water depends on a number of factors such as: climate, soil erodibility and topography, types of vegetation cover, and conservation or cropping practices. The knowledge of these factors and their interrelationship is very important for understanding risks of water erosion. Given the schematic representation discussed earlier it can be noted that, precipitation amounts, infiltration and permeability of the soil are the most important factors in this general system of water-caused erosion. This system is set in motion by precipitation and accumulation of excess moisture on the soil surface.

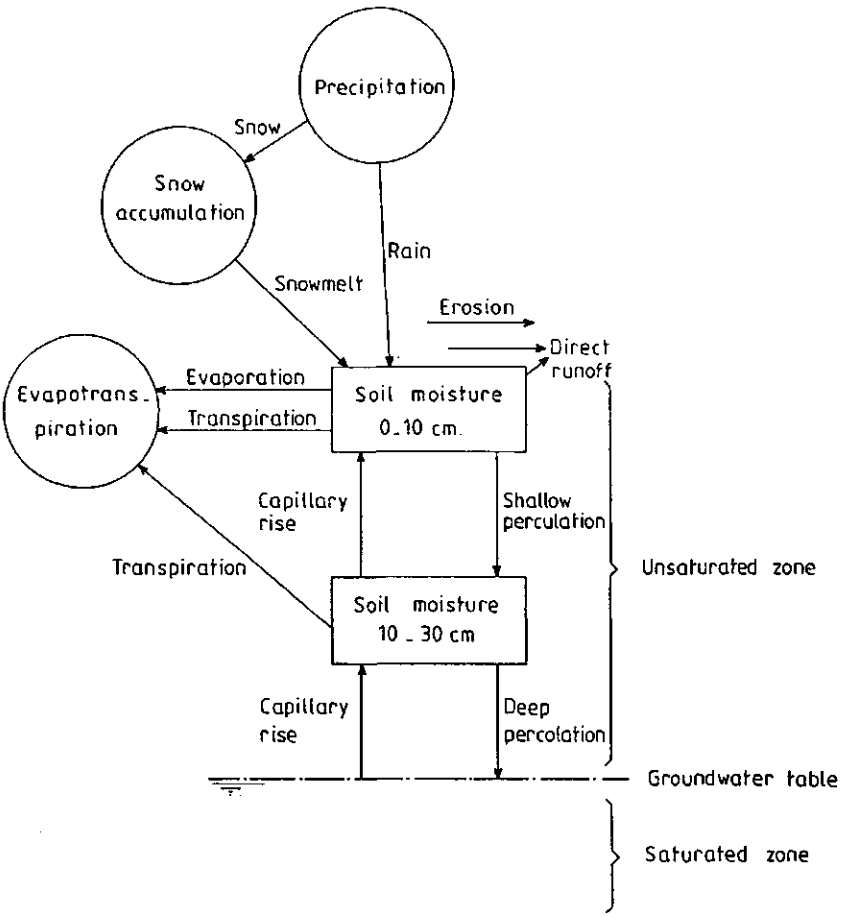


Figure 2.2 A schematic representation of the process involved in water - caused erosion. Modified from : Haith et al. 1984.

Overland flow and surface runoff are caused in situations where rainfall intensities are greater than the infiltration capacities of the soil. This causes excess moisture to accumulate on the soil surface by forming little ponds in small depressions and in time initiating a continuous flow downstream. Overland flow and surface runoff are very common on exposed or compacted arable soils with low infiltration capacities or on soils that are inherently susceptible to crusting (de Ploey, 1981; Shainberg and Singer, 1986). Overland flow and surface runoff are highly erosive and their impact can be accelerated on lands with steep slopes. Most erosion due to overland flow occurs when the preparation of the seedbed is followed by rainfall. The loose soil particles are then easily disposed, hindering the infiltration and leading to runoff. Sometimes erosion can take place during growing season even though at that time crops are sufficiently grown to protect the soil. This is mainly due to frequent thunder-showers and sometimes prolonged rainfall.

The central issue here is why should water-caused erosion be a serious problem in Southwestern Ontario where soil-water management practices have been in place for the last few decades.

Essentially, most farms in the level clay plains of Southwestern Ontario already possess a relatively modern artificial system of subsurface drainage (tile drainage) which might have been installed during the last few decades. Assuming that the prevailing soil type in those parts of Southwestern Ontario is Brookston Clay Loam, which is considered as a naturally poorly drained lacustrine soil (orthic humic gleysol), the recommended drainage design for this soil may be as follows:

Tile drain diameter = 100 mm.
Tile drain spacing = 12-15 meters apart
Tile drain depth = 70 cm.

Although, this configuration may seem to be an intensive system, yet it would only allow a limited amount of discharge particularly when:

(1) rainfall intensity is greater than infiltration rate, and

(2) discharge is hampered due to structural damages such as collapsing of the tubing, blow-outs on account of silt build up in the tubing, outlets obstructed by ice formation, and when outlet ditches are full in parts of the field.

Considering that most drainage systems in the region were installed as early as the 1950s and 1960s, it is likely that during the past 30 years some of the systems have been damaged. Most frequent damages to subsurface drains have been attributed to either: (a) collapsing of drain pipes due to traffic of heavy farm machinery and equipment on the field and a few other related factors (e.g. Broughton and Mayo, 1987), or (b) blow-outs on account of silt build-up in tiles (typically not a problem on the clay soils).

Under these situations soil moisture can only move at a limited rate. Hence, if during certain periods of the year the amount of rainfall exceeds the soil's moisture holding capacity, excess moisture over and above the soils' storage capacity results (Figure 2.2). This excess moisture can not be quickly removed from the soil with the existing drainage system especially when it is damaged, and as a result runoff takes place. This runoff produces erosion. In the absence of an efficient subsurface drainage system, those affected areas would primarily have to depend on a network of outlet drains (ditches) that provide surface drainage.

Skaggs (1987) has reported that surface drainage systems tend to have higher rates of runoff with more sediment, phosphorus, and pesticides than systems with efficient subsurface drainage systems. In an attempt to demonstrate the effect of subsurface drainage on peak outflow rates Skaggs (1987) compared two watersheds during a storm event in eastern North Carolina. The first watershed had a good surface drainage system (parallel ditches 100m apart) but relatively poor subsurface drainage. The second watershed had a good surface drainage system as well as a good subsurface drainage system because of drain tubes that were installed at 33m intervals between the ditches. By examining the runoff hydrographs of the storm event (with 3.25 cm rain), he found that the peak runoff rate for the first watershed (with poor subsurface drainage) was more than twice that from the adjacent watershed which had good subsurface drainage. This indicates that good subsurface drainage removes excess moisture from the soil profile more efficiently.

The ability of a good subsurface drainage system to remove excess moisture more efficiently is based on an a priori assumption that runoff (**R**) is a function of several factors. It increases with slope, flow rate and rainfall amount and intensity, and decreases with an increase in infiltration rate, length of run, and bed and vegetative drag. Therefore, changes in the amount of surface runoff over time or among areas are related to changes in soil moisture storage capacity in the soil profile (S_t), the amount of precipitation (P_t), and evapotranspiration (ET_t) between two storm events. The relationship between evapotranspiration and surface runoff may, however, be viewed as a secondary phenomenon. This is mainly due to the fact that the low evapotranspiration after a heavy downpour allows excess moisture to remain on the soil surface. Then, if the next downpour occurs while some of this excess moisture is still present on the soil surface it will accelerate the initiation of the next overland flow. In order to illustrate this relationship mathematically, these terms can be expressed as follows:

Since

$$R_t = f(P_t, S_t, ET_t) \qquad 2.1$$

Expressing this model as a balanced equation we will have:

$$P_t = S_t + ET_t + R_t + V_t \qquad 2.2$$

Now if

$$P_t > S_t + V_t \qquad 2.3$$

Then

R > 0 and erosion is initiated

AS Increasing **S**=Decreasing **R**

Therefore

Increase **S** by improving the existing drainage system to reduce **R** and erosion

Where:

R=Surface runoff in mm. over time,
P=Precipitation in mm. over time,
S=Available soil moisture storage capacity in the soil profile either as a percentage or volume of available moisture over time,
ET=Evapotranspiration over time,
V=Deep drainage, that is the amount of moisture that disappears in the lower profile in mm. over time,
$_t$=Subscript denoting time,

Hence, in areas where flooding, surface runoff and related problems are frequent, effective soil-water management systems such as improved on-farm subsurface drainage systems are needed to reduce the peak surface runoff. On the basis of these facts it can be argued that by installing one or more laterals, particulary in affected areas, the drainage efficiency (i.e the ability to remove the accumulated excess moisture as rapidly as possible) of the region is improved and risks associated with that undesirable seasonal excess moisture are averted.

Because of the interrelationship between phosphorus loading, soil erosion, and hydrologic characteristics of drainage, the significance of such an effective soil-water management system in Southwestern Ontario can be seen in terms of savings that would result from controlling runoff and erosion. These savings can be measured in terms of three sets of benefits:

a) in terms of minimizing costs that runoff and erosion can otherwise impose on a farm enterprise or society in general. These water-caused erosion imposed expenses are usually associated with costs for dredging and removing sediments, costs of water-quality improvements, and the forgone utility of the natural functions of waterways, reservoirs, and lakes due to pollution. Clark et al. (1985) noted that the cost of changes (e.g. sediment transport and turbidity of drinking water) directly related to cropland erosion in the U.S. are estimated to be between $1.1 to $1.3 billion annually. Estimates of some of these expenses in Southwestern Ontario can be obtained from Municipalities, regional authorities and perhaps individual land owners.

b) in terms of greater physical yields. Poor natural drainage is often considered as one of the major risks involved in crop production. Row cropping, soil compaction and erosion are components of these plant-soil-water associated risks (more details in chapter 4). Battiston and Miller (1984) examined crop yield related impacts of soil erosion in parts of Southwestern Ontario and found that eroded plots possessed lower fertility and lower available water holding capacity than plots with no erosion. Due to inherent characteristics of clay soils these risks are known to be much more severe in level clay plains. This is primarily because of the high delivery ratio of existing clay soils in these areas due to the proximity to the Great Lakes. These characteristics can therefore, influence the economic viability of farming operations in these regions. However, an improved on-farm subsurface drainage system because of its hydrologic characteristics will create a favorable groundwater regime that can prevent erosion of soil and production losses associated with the above mentioned risks.

c) Savings on the replacement cost of fertilizers, chemicals, and seeds that are otherwise lost if surface runoff and erosion are not controlled.

There is no doubt that knowledge of these economic aspects plays an important role in farmers decision-making.

2.3.2 Waterlogging and salinization

Waterlogging and salinization are the twin menace of ill-designed and poorly implemented irrigation systems. Apparently, every year some 10 million hectares of land are abandoned because of salinization, alkalization and waterlogging (WCED, 1987).

The causes for salinity include a complex cause-effect structure that begins either with (a) poor quality soil that often creates salt loading which in turn has a deleterious effect on the quality of irrigation water, (b) application of irrigation water that contains large quantities of dissolved salts, and finally a high evapotranspiration rate. Waterlogging is due to excess moisture in the soil profile which is directly related to the soil type and its permeability at the lower levels of the soil profile, and to entry of water from atmosphere, irrigation, runoff, or seepage into the soil profile.

It is documented that continuous irrigation and inefficient drainage in the once fertile Tigris-Euphrates-Karoon river basins of ancient Persia and

Babylon (referred to as the Fertile Crescent in the Bible) caused salt to accumulate in the soil surface and subsequently, the appearance of soil salinity problems (Luthin, 1957; Adams, 1962).

Today millions of hectares of fertile land in arid regions of the Middle East, Indian subcontinent, North Africa, and South America are affected by salinity (El-Gabaly, 1977; Abrol, 1987; Aceves-Navarro, 1987; Rangeley, 1987). Much of this problem is attributed to deficient irrigation water management and poor drainage in irrigation districts of these regions.

According to estimates provided by the U.S. Council on Environmental Quality and the Department of State (1980) the twin effect of waterlogging and salinity in nearly 11 million hectares of irrigated land in Pakistan is responsible for pronounced reductions in crop yields. Similar problems are reported in irrigated lands of other regions in North Africa, the Near East and in the irrigation districts of the San Joaquin Valley in California. Witness the case of Egypt where the Nile river is the life line of its agricultural industry. The river's natural rise and fall nourish farm lands with rich alluvial silt that fertilizes soil in the surrounding areas. For many years Egyptian farmers have cut narrow channels along the Nile river to irrigate their farm lands during dry periods. Today Egyptian farmers have more access to irrigation water because of modern technology and massive irrigation systems (Aswan Dam). However, intensive farming and continuous irrigation and seepage from irrigation channels has elevated the ground water table level to an alarmingly high level. Consequently, crop yields are depressed and arable lands are turned into saline marsh or salt poisoned lands. Since there are no natural outlets for the irrigation water, excess salt is not flushed from the soil and vast tracts of farm lands have become uncultivable. Because agriculture is one of the important sectors of the Egyptian economy, one can fully appreciate the staggering cost of this loss of productivity due to the twin effect of waterlogging and salinity.

Poor soil-water management in conjunction with irrigation has undoubtedly reduced the productive capacity of millions of hectares of fertile land in most arid and semiarid regions of our planet. Besides losses in crop yields, considerable amounts of funds are needed to reclaim these lands if their productive capacity is to be maintained and enhanced for present and future uses. The extent of this problem is illustrated in Table 2.1.

Table 2.1, indicates that more than 78 million hectares of land need to be reclaimed in order to alleviate the harmful effect of the twin menace of waterlogging and salinization. Out of this total figure, over 52 million hectares are on irrigated lands and the remaining 26 million hectares are on non-irrigated land. In economic terms, assuming an average cost of 1000 Canadian Dollars (approximately 2000 Dutch Guilder) as the cost of drainage installation per hectare, this would involve billions of dollars or Guilders to reclaim these

TABLE 2.1 Drainage Targets for 1990

CONTINENTS OR REGIONS	IMPROVEMENT TARGETS FOR 1990 in 1000 hectares
Africa	5900
Latin America	19245
Near East	9643
Asia	43396
TOTAL	**78184**

Modified from the U.S. Council on Environmental Quality and the Department of State (1980)

affected areas. Although from an economic point of view each case must be analyzed as a separate case.

Since most of these areas are located in non-industrialized and limited resource countries one can appreciate the gravity of the problem. Undoubtedly, the economic rational and the need for a long-term management of these areas justifies the need for further research in physical, biological, and socio-economic aspects of soil-water management at regional and global levels.

2.4. Summary

Recent trends in the growing competition and conflicts over the use of limited land resources, and the common recognition of environmental stress are some of the new parameters that are rapidly changing previous thinking about land use patterns.

The vicissitudes of climate and the menace of land degradation particularly in arid and semiarid regions in the face of increasing population and the inability of some countries (mostly non-industrialized and limited resource countries) to cope with these crises calls for a new approach in land use problems. Some argue that the inability of non-industrialized countries to cope with these crises is mainly due to economics. But by looking at the present complications pertaining to soil-water management crises in the Nile delta one realizes that it is not just economics. There were sufficient funds for constructing the Aswan Dam. But it was the lack of a clear understanding of the biophysical cause-effect structure of a massive irrigation project that unabled planners to recognize the need for adequate drainage facilities that would prevent the rise of the ground water table due to intensive irrigation. This lack of a clear understanding of the intricate cause-effect relationship has now created a serious problem for Egyptian farmers and its government which can only be solved by a sizeable investment in subsurface and surface drainage systems.

The most important components of this new approach are more research on various aspects of land use primarily on physical, biological, and socio-economic issues of soil-water management. Soil and water degradation are the most serious threats that can have a detrimental impact on existing as well as future land resource potentials particularly in non-industrialized and limited resource countries.

Any expansion in the use of land resources for increasing agricultural productivity would require a considerable adjustment in current modes of withdrawal, delivery, removal, and total management of water. One of the important components of this adjustment is to develop a comprehensive integrated soil-water management system.

A comprehensive integrated soil-water management system is a reference to a complex system that can take into account the biophysical cause-effect (including socio-economic aspects) structure of the dynamic system of land and water utilization in a manner that causes minimum damage to the environment. An investigation of such a magnitude is cumbersome and requires a lot of resources. However, individual investigations on each of these aspects would eventually lead to the development of such an integrated system.

CHAPTER 3

THE CRITICAL NEXUS BETWEEN INTEGRATED RURAL DEVELOPMENT AND LAND USE PLANNING

3.1 Introduction

Agriculture is a vital sector within the economic structure of almost every society. In the last several decades, agriculture particularly in North America and Western Europe has been most productive. The increased agricultural productivity in Western Europe has been most impressive in view of its limited land base. This unprecedented agricultural development in western Europe began after introduction of the generous post WW II reconstruction program known as the Marshall Plan. Later on, the momentum in Western Europe's agricultural development was accelerated by the Common Agricultural Policy (CAP) of the EEC and the subsequent public support that not only emphasized on attaining self sufficiency in food production but also encouraged an export-oriented agricultural development. Similar public policies such as various forms of farm subsidies and farm policies like sod busters and swamp busters were also responsible for a significant surge in agricultural productivity in North America. Other countries such as Australia, New Zealand, and currently several Asian and Latin American countries have also contributed to the increasing agricultural production particularly in the past few years. The extent of this increased productivity can be partly noted in the export figures of selected countries in Table 3.1.

As shown in Table 3.1, several countries such as the U.S.A., France, the Netherlands, and West Germany have annually earned billions of dollars from the export of agricultural products. Some of the agricultural export earnings of these countries are comparable with the national budgets of some non-industrialized and limited resource countries. Hence, one can not deny the

Table 3.1 Export of total agricultural products in selected countries in $100,000

COUNTRY	1981	1982	1983	1984	1985	1986
Algeria	1323	717	377	479	558	630
Argentina	63775	48636	58902	60604	56578	45632
Brazil	96878	80786	90389	104626	96739	77957
Canada	78425	80470	82269	85115	69956	66568
Denmark	50622	49193	46621	45301	47279	58287
Egypt	7405	6729	7264	7520	6656	6436
France	179012	158332	160376	160111	165207	197725
German DR	6086	4890	4027	3868	4254	4978
German FR	106152	101166	95830	98298	100391	130720
India	26980	23095	24035	23791	23449	24619
Iran	1590	1337	1556	1770	1501	1385
Iraq	433	565	504	260	322	295
Israel	9427	9024	8261	9042	8613	8662
Kenya	6150	5914	6324	7467	6760	8908
Netherlands	156375	151377	147361	150558	152102	192538
Pakistan	12607	8464	7958	7832	6955	10276
Syria	2361	2906	2789	4109	2063	1961
Turkey	25488	25901	24091	23947	22064	23396
UK	79353	73837	67471	67474	69870	86118
U.S.A.	450529	382426	375426	393505	305836	280713
USSR	29733	28087	23668	22024	22119	24639

Modified from Table 6. Agricultural products, total, exports. FAO trade yearbook. Vol. 40. Pp. 42-44.

significance of agricultural export earnings in a country's economy. Furthermore, it is also noted in Table 3.1, that by excluding the U.S. from the list of countries provided in the table, it becomes evident that most West European countries have dominated the export market of agricultural products in most of the 1980s. The increased agricultural export capacity of West European countries is also notable within the EEC. Table 3.2, illustrates the agricultural trade figures representing the volume of agricultural trade between the EEC-9 member states. This is also indicative of a substantial export earnings by some of the EEC member states that amount to billions of Guilders annually.

Demands for an increase in agricultural production are expected to continue in response to an increasing trend in global population and the recent

Table 3.2 EEC AGRICULTURAL TRADE FIGURES REPRESENTING THE VOLUME OF TRADE BETWEEN THE EEC-9 MEMBER STATES

	VOLUME OF TRADE IN % OF THE TOTAL TRADE IN AGRICULTURAL PRODUCTS						TOTAL VOLUME OF TRADE IN BILLION GUILDERS		
	IMPORTS			EXPORTS					
	1980	1984	1988	1980	1984	1988	1980	1984	1987
TOTAL AGRICULTURAL PRODUCTS	46.3	48.7	55.4	64.7	63.2	67.2	101.3	141.3	147.8
Crop production	52.5	56.7	64.6	51.0	52.8	58.2	26.1	38.4	38.8
Horticulture products	68.8	71.1	70.6	81.0	79.8	80.6	11.0	15.7	17.6
Animal products	82.0	82.4	84.5	72.6	68.2	72.5	36.2	43.3	46.6
Other products	25.6	29.7	35.4	66.7	65.2	66.5	27.8	43.9	44.8

Source: Landbouw-Economisch Instituut (1989) Landbouw-Economisch Bericht. Periodiek Rapportage 1-89. Den Haag Pp. 105-106.

quest for food security and economic growth in non-industrialized countries. There are, however, growing concerns among the scientific and policy groups related to the wise use of land, water, and energy to accommodate such growth in agricultural production. The reasons for such concerns are rooted in the environmental consequences of nearly four decades of intensive agriculture in North America and Western Europe. During the past few decades there has been a significant increase in agricultural productivity in those regions. Although this increased productivity brought about a considerable economic growth and prosperity, it also triggered serious environmental degradation. Whatever the detailed reasons for this long-term environmental degradation, there appears wide spread agreement that in some of the industrialized countries appropriate actions are urgently needed to stop environmental degradation caused by intensive farming. There also appears equal agreement that due to the current global circumstances non-industrialized countries should be encouraged to increase their agricultural productivity to meet their own demands for food and other agricultural products and also to stimulate an overall growth in their rural areas through exports of their excess supply of their agricultural products.

With regard to appropriate actions, the Structure Directive (797/85) is a European response to such calls (Harvey and Whitby, 1988). According to this directive member states of EEC are supported financially in encouraging farm practices that are environmentally friendly. For example, article 19 of this directive allows EEC member states to pay farmers who abstain from intensifying production in "Environmentally Sensitive Areas". For example, in the Netherlands sandy areas in the south, and wet meadows in the western part of the country are being preserved through a "Management Agreement Program" which is sponsored by the Dutch government (van Lier, 1989).

As far as agricultural development in non-industrialized countries is concerned, the crucial question here is how these countries can achieve increased agricultural productivity.

It is a fact that increasing agricultural production can be achieved in various ways such as by genetic means, increasing the area under cultivation, and improving crop yields through better management techniques. Undoubtedly, these are not easy means to increase agricultural production in those countries. In order to employ these methods a number of essential pre-conditions must be met. Some of these can be listed as follows:

Education and research

In order to be able to develop high yielding varieties a country must have appropriate know how and research facilities. For example, India could not have developed those high yielding dwarf varieties of wheat in the absence of agricultural universities and a large contingent of agricultural scientist during 1960s and early 1970s.

Arable land base

To allow increased agricultural production a country's arable land base must be adequate in quantitative and qualitative terms. Whether it is an intensive agricultural system (with extensive use of chemicals) or a biological method of farming (a sustainable system with almost no chemicals) adequate and suitable land base is imperative. A balanced agricultural development can not take place without the necessary land base. Multi-tier greenhouse farming or reclaiming the sea to augment the land base is an extremely expansive alternative in the absence of an adequate land base. Most limited-resource countries are not economically in a position to use these alternatives.

People's role

Agricultural productivity cannot be achieved in the absence of people's participation, motivation, and a desire to succeed. This is particulary true in the case of agricultural development projects in every rural community. According to

Bamberger (1988) there is accumulating evidence that beneficiaries' participation in project design and management has caused efficiency in implementation, cost recovery and project longevity. There are both economic and moral reasons why people (i.e. project beneficiaries) must be involved in project design, implementation and management.

In view of the fact that most non-industrialized countries lack the required infrastructure to increase agricultural productivity, the need for Rural Development (RD) in such countries (including some of the newly emerging democratic countries of Eastern Europe) becomes paramount. From insights gained in recent years it is now almost certain that a sustainable agricultural development in non-industrialized countries cannot be achieved without a new approach in RD. This new approach in RD can be viewed as a multidimensional process for achieving long-term sustainability in agricultural production, meaning that intended RD projects must focus on the wise use of land, water, and other inputs within the framework of a sustainable agricultural growth. Furthermore, since most soil-water management projects in non-industrialized countries are implemented within rural development projects, it is essential that various linkages between land use planning and IRD are recognized. The understanding of these linkages will enable planners and farmers to plan and implement agricultural development projects that are economically and environmentally sound.

This chapter's focus is on the important link between soil-water management as a component of land use planning and Integrated Rural Development (IRD) in the context of a long-term sustainable agricultural development. By describing this critical nexus this chapter strives to highlight the important role of artificial drainage for agricultural development in non-industrialized countries as a component of IRD projects. While examining these issues the section will dwell upon the need for better quantitative means for land use decision-making particularly in the area of soil-water management.

3.2 A new approach in rural development

3.2.1 Rural areas

Rural areas in limited-resource and non-industrialized countries are distinct locations that possess several unique characteristics that act like a common thread that binds these varying forms of societies in different geographic dimensions. Most of these societies experience common problems that are directly or indirectly a reflection of past events such as feudalism (instituted by the local elites) or colonization (imposed by a foreign sovereign) in those societies.

Because of the deep scars of these socio-economic and political processes these rural societies have developed a distant feeling towards urban people particularly those who represent authority. The members of these societies have usually a simple life style, most often a very self sustained one, and too often with a fatalistic attitude towards life in general. The fatalistic attitude is often more prevailing in rural areas where rainfed agriculture is practiced. Because farmers have little or no control over climatic events most often they have to rely on supernatural sources or simply fate with regard to the success or failure of their crops. They are usually content with nature and follow a unique pattern of life which is based on respect for the environment. The fact that some of these societies have survived (some with very little change) over these years is a witness to this reality. One of the main features of rural areas in non-industrialized countries is that they are dominated by an extensive and an intensive system of land use. In most populous countries of South-East Asia rural lands are very intensively used. According to Cloke (1985) most rural lands in non-industrialized countries are either used for agricultural activities or in some cases for forestry.

3.2.2 Development

Traditionally, development implies a process of positive change in the economic, social, and physical structure of a society from status-quo-ante. Because of the multitude of actions that are involved in the process of development, it is influenced by a number of factors such as: the prevailing socio-economic and political situation of a society; attitudes, skills and perceptions of society members (both as private and public decision makers); and finally, the geographic characteristic and physical conditions of a society.

Development is a relative term. What is perceived as desirable change in one rural society may not be acceptable in an other society. This is indicative of the two characteristics of rural areas and their people. First, despite many physical and economic similarities each society is a unique entity. Hence, there is no universal development package that fits all rural societies. Second, most rural people by virtue of their beliefs and traditions sometimes deliberately oppose what we call "development" particulary when it is designed by outsiders. This is mainly due to a general belief that no outsider can be interested in their welfare. Moreover, they believe that their interests are almost always defined from the perspective of development agencies rather than theirs (e.g., Head, 1989). Consequently, they feel that all the sudden changes that have been induced by outsiders are unfamiliar and may eventually destroy the serenity of their environment. This fear for outsiders and their imposed ideas clearly indicate that top-down oriented development may not be a desirable approach in certain rural areas.

3.2.3 Integrated rural development (IRD)

In the past it was widely accepted that individuals by optimising their own position under given circumstances would create a dynamic system which would bring about economic growth and prosperity. This was a value system that had its roots in some cultural and intellectual background and training that started with Adam Smith's The Wealth of Nations (1776) that emphasized the creative capacity of man and the practically limitless producibility of commodities (Quadrio-Curzio and Antonelli, 1988). Although since Adam Smith the theory of economic growth has been argued by different individuals, this simple principle remained as a dominant theory that influenced activities in market economies particularly after World War II. Apparently this principle had some influence in our approach towards rural development as well. According to Poostchi (1986) the earlier view of rural development in the post war era was primarily focused on plans and policies which would simply bring about an overall increase in a country's economic development as measured by economic indicators such as gross national product (GNP). This approach not only excluded socio-political and socio-cultural changes, but too often it also created a conflict between agricultural growth and environmental quality. There was another drawback with the previous approach towards rural development which was a direct consequence of the manner in which some rural development projects were implemented. This was particularly true in the case of rural development projects that were implemented in non-industrialized countries by different international agencies. In most cases such plans were haphazardly implemented. In a classic example cited by Little and Horowitz (1987) it is demonstrated how different land use surveys sponsored by 3 development agencies in the same region of Peru in 1981 generated 3 radically different land use alternatives. While the first land use survey that was sponsored by the World Bank indicated that only 5% of the region should be allocated to forestry and 42% for clear-cut agriculture in annual crops, the other surveys sponsored by the Peruvian government and USAID each proposed different alternative ratios of 50% forestry vs. 17% agriculture, and 65% forestry vs. 8% agriculture respectively. Obviously, none of these options could be considered as optimum unless the biophysical cause-effect structure and impacts of each option were fully understood. Without a proper pre-project implementation analysis with a holistic approach (that includes all the exogenous and endogenous factors) it becomes extremely difficult to discern how each land use alternative would impact upon that society for which land use alternatives are prescribed, and the global society at large in terms of a sustainable growth. Hence in the absence of a holistic approach towards changes in rural areas, sometimes inadvertently, the projects may be poorly planned and become a failure shortly after its is implemented (as in the Aswam irrigation project). This is obviously self defeating and is a less effective way of utilizing development funds. The present agricultural crisis and their associated rural problems in non-industrialized and the less favored areas (LFA's) of industrialized countries are a witness to some of these shortcomings.

Due to these problems it was soon realized that rural problems must be addressed in an integrated fashion. With this insight IRD emerged as a dominant concept in contemporary rural development (Abdul Hye, 1984). According to this new thinking IRD became widely accepted as an approach which involves a holistic process that is designed to bring about changes in impoverished rural areas. In other words IRD is a combination of well defined and co-ordinated actions that are community based (involves the local people) and are in agreement with the interest of society . This new integrated approach in rural development is also considered as a harmonized collaborative method by which several development agencies pool their inputs to produce an optimum combination of resources with which positive changes can be brought about in a society. Currently, IRD is also being used in industrialized countries. According to van der Plas and Ulbricht (1986) IRD is strongly supported for solving the newly emerging rural problems of western Europe that are associated with the new socio-economic order (i.e. a surplus agricultural sector and an overburdened environment) and the plight of less favored ares (LFA's) within the EEC.

There are several important areas to be considered when dealing with IRD. These are societal goals, technological change, market signals and individuals' response to these signals, and institutional aspects.

Societal goals

IRD cannot succeed without a thorough assessment of societal goals set by inhabitants of the project area. But this assessment requires an understanding of what constitutes societal goals. Societal goal can be viewed as a collective entity that comprises different layers that are interlinked and interact with changes in time and place. These layers or components include the entrenched values, norms, and traditions in a society; the level of people's education and awareness; the prevailing socio-economic, political, and environmental conditions; and the general attitude of the population towards life in general, that is whether or not they have a desire to succeed or accept responsibilities and leadership.

Technological changes

There is a direct link between IRD and technological inputs. For example, the newly emerging biotechnology in combination with information technology and the mechanical and chemical technologies will have a significant impact on IRD. That means method and result demonstrations can be done more effectively. In other words rural people can immediately see the effect of say a new variety of corn (biologically engineered) that can give high yields with no nitrogen fertilizer applied. Or the impact of laser equipped machinery for leveling soil for rain harvest in arid regions. However, the true impact of these resources is determined by several factors such as the educational level of farm individuals in the project area. Furthermore, it will also depend on their willingness to adopt the new technology, and their financial ability to apply these inputs.

Market changes and the individual's response to these signals

Essentially prices and costs are said to be market signals. Although in market economies these signals are primarily controlled by the interaction of supply and demand, there are certain legislation and guidelines that govern this entire process. These signals are sometimes influenced by government intervention or by a collective action of a producer's lobby. For example, government farm subsidies in Western Europe, North America, and Japan or a collective action of a producer's group such as a milk marketing board. It is also widely accepted that societal goals can sometimes influence these signals. For example, with the recent public concern over the excessive use of chemicals in agriculture the demand for organic (chemical free) agricultural products has increased. This increase in demand for these products has increased the price of such commodities. Hence in formulating IRD projects one has to recognize the important role of these signals and also make sure that individuals benefiting from a specific IRD project would be able to respond to these changes with adequate flexibility.

Institutional aspects

Institutional aspects are perhaps one of the most important factors in an IRD project as they involve a number of complicated esoteric and logistics issues such as land ownership, taxation, and jurisdictional aspects. It also involves other non-government institutions such as religious organizations. Sometimes an IRD project must take into account various concerns that these institutions may have.

3.3 The nexus between IRD and land use planning

It was said earlier that IRD deals with problems of rural areas as a complex system. This complex system may include several issues that are inter-linked. For example consider the vicious circle of low agricultural productivity in limited resource and non-industrialized countries which is related to a number of socio-economic and political cause-effect structures and their impacts.

It has also been said that in order to achieve increased agricultural productivity most non-industrialized countries particularly those with limited resources have to meet certain pre-conditions. One of the major pre-conditions was the question of land base which encompasses several issues such as availability of arable land, quality of arable land base and sustainability of land use activities.

As deficient soil-water management is one of the major impediments to agricultural development in most non-industrialized countries, rural development projects in such countries will require efficient land use planning schemes. Consequently, land use constitutes an important part of IRD that like its other components must be carefully examined. In view of this requirement the following section will examine land use in the context of long-term sustainable growth within the framework of IRD. However, before defining land use planning its position within an IRD project can be presented schematically as shown in Figure 3.1. This illustration indicates that IRD can be viewed as a large system which may include several components one of which may be land use planning. However, within the sphere of land use planning (in this chapter) the focus is on soil-water management.

3.3.1 Land use planning

Background

Since the dawn of history, man has been involved in the use of land and its management. By experience members of the earliest hunting and gathering societies learned what alternative uses land could offer and how these various uses could be managed. Later on with the advancement of those societies man became more aware of land use alternatives. Yet, because of the unique characteristic of those early civilizations such as limited population, the alternative use of land and their management were less complex. As population increased and with it human aspirations, desires and wants became incremented the alternative land uses and their planning and management became more complex. In the wake of these changes each society developed certain techniques and designed a set of rules and guidelines that governed alternative land uses.

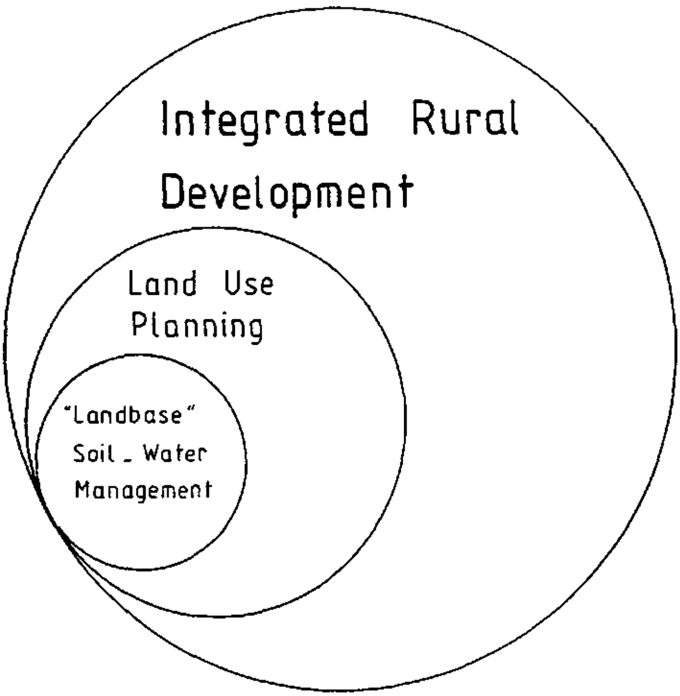


Figure 3.1 The critical link between IRD and Land Use Planning.

These diversities and complexities were so unique that they became the distinctive features of different civilizations. For example, witness the land use pattern in each of the known ancient civilizations such as the mesopotamian, Persian, Assyrian, Egyptian, Greek, Roman, Inca, and Mya. Each of these civilizations had a unique feature that was a reflection of their aspirations, inventiveness, custom, and most important, the geographic characteristic of their lands. Each of these ancient societies developed a set of land use techniques (means and methods) and designed a set of guidelines that were akin to their specific conditions. In fact it is the legend and the reminiscence of those techniques such as the hanging gardens, the Persian wheel, the Archimedean screw, and agricultural terracing on the high ridges of the Andes that structured the very foundation of today's land use technology.

3.3.2 Land use planning as an interdisciplinary process

Land use planning is a multidisciplinary concept that deals with: (a) habitats including natural, man made (e.g. polders), urban, and agricultural; (b) habitat users; (c) habitat users behavior, aspirations, and willingness to pay for land use services; and (d) socio-economic and political aspects that govern land use services. Hence land use planning involves several disciplines such as applied physical sciences, social sciences, and esoteric concepts such as the state's law and its extension to land use legislation. A land use planner, is an individual with a specific training in one or more of the related areas. However, in order to avoid confusion the topic of land use is divided into two major areas namely **rural** and **urban** use. Although these topics are perceived as two independent areas of research, it is very common to see scientists from these disciplines work on similar issues. This is primarily due to the dynamic nature of our societies (population movement from urban to rural areas and vis-versa) that has created an interaction between these topics.

Land use planning can be defined as a process of optimum allocation, development and management of land with respect to specific objectives that are set in response to societal goals, the state of natural endowments, socio-economic beliefs, and political rules of an area (Figure 3.2).

Figure 3.2, represents a complex multi-level and multi-faceted system. Multi-level, because it involves the collective actions of several users (e.g. farmers and society at large) and planning instruments (e.g. local, regional, national, and international) who determine land use options and actions. Multi-faceted, because it includes different functions of land resources. In order to better understand this system lets focus on farm land reallocation processes in Holland. According to van Lier (1986) farm land reallocation is an old system of rural land use planning that has been practiced in several countries

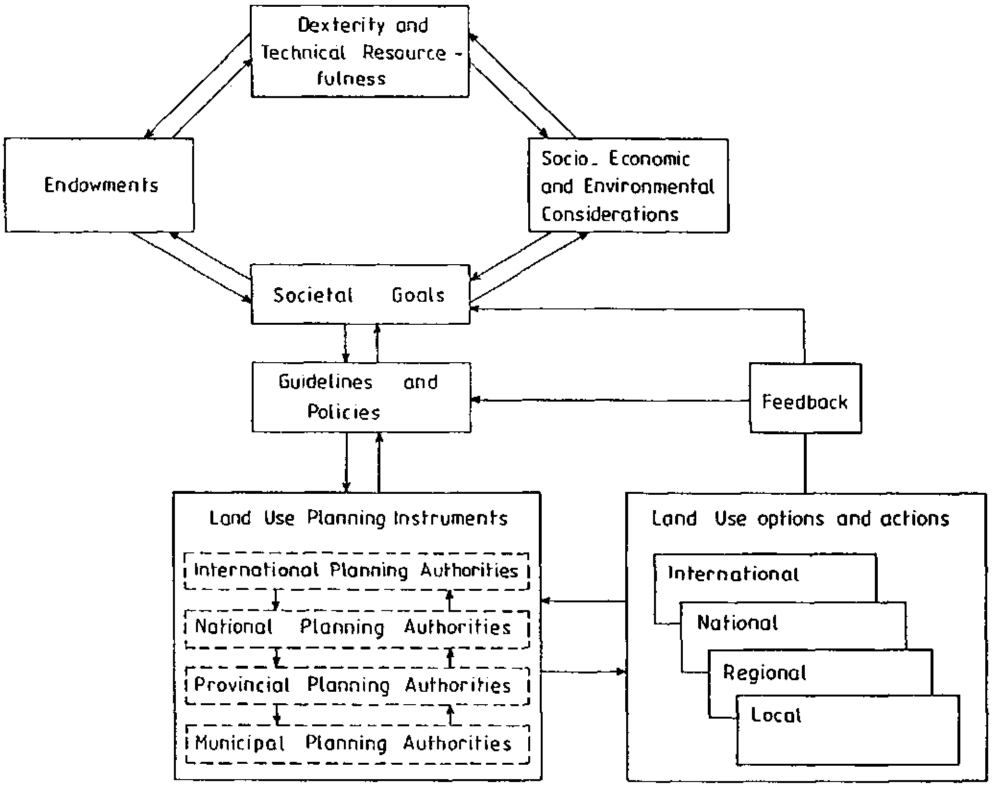


Figure 3.2 Schematic of a complex multi_level and multi_faceted system ivolved in land use planning

in the European continent (e.g. Austria, Belgium, Germany, the Netherlands, and Switzerland). It is a systematic process by which fragmented holdings, owned by individual farmers are reallocated so that each individual's holding is situated within the boundaries of a single aggregated unit of holding. For example, if a farmer owns several small holdings that are spread over an area around his dwelling, through a reallocation process the farmer can bring together those fragmented holdings in one aggregated unit near farm headquarters. From an economic point of view land reallocation is a process by which a group of farmers seek to: (a) increase their agricultural production capacity, and (b) reduce costs (mostly variable costs) associated with their farming activities. Both of these societal goals depend on a multitude of factors that are inter-linked. The production level of arable crops depends largely on genetic characteristics of the crop, soil fertility, soil moisture level, timeliness of farm operations, efficiency of farm machinery and farm buildings, and finally farmers' managerial skills. Costs, on the other hand, are influenced by two main sets of factors; first, those that are influenced by individual farmers and second, those that are associated with exogenous factors such as the public soil-water management system (i.e. the system that monitors the water table in outlet drains and the network of connecting channels), rural roads and other farm related public facilities.

In view of the fact that land reallocation programs involve many farmers as well as socio-economic and political aspects of rural areas certain organizational measures must be taken. Due to this reason the Dutch government had to devise certain guidelines and policies that marshalled its land reallocation processes. Hence, appropriate land use planning instruments were established at the government, regional, and local levels. The first law governing the process of land reallocation was enacted in 1924. As years went by, societal goals and aspirations and dexterity and the knowhow of its members changed too. Hence, in response to these changes the 1924 Law was revised several times (in 1938, 1942, 1953, 1975, and 1985). A comprehensive account of reallocation of agricultural land under the land development Law in the Netherlands is given by Grossman and Brussaard (1989).

In order to facilitate the smooth process of reallocation, in 1935 a section within the government was created which was primarily responsible for land consolidation. However, with the increased farm activities and consequently more demand for land consolidation during the post-war reconstruction period, in 1958 a more specialized public authority within the ministry of agriculture (Centrale Cultuurtechnische Commissie) was established. Increased agricultural activity and the resulting demand for land consolidation gave rise to some land use conflicts. Thus, to facilitate a better decision making process a specialized team of experts was brought together to devise a systematic approach for land use decisions pertaining to land consolidation. This team prepared a comprehensive decision making package that incorporated several aspects of land use planning such as: consequences of the reallocation project for the economic situation including work opportunities, living and working conditions, nature, and landscape, and quality of water, land, and air (Grossman and Brussaard, 1989). This comprehensive evaluation package is commonly referred to as the HELP (Herziening Evaluatie Landinrichtings Plannen). In the early 80s in response to the new societal goals at the local, regional and national level, the land reallocation program evolved into a sophisticated rural development program (the 1985 Act) that focused on various aspects of land use, including agricultural, agro-forestry, conservation of unique natural habitats, outdoor recreation and other uses. Thus, from this example it can be appreciated why land use planning is a complex system with many inter-linked components that often cross the boundaries of several scientific disciplines and professions.

Land use planning is said to have two major characteristics, dynamic and static. These are also referred to as the active and passive aspects of land use. The dynamic characteristic deals with actions that bring about material development and growth such as allocating land for agricultural, industrial, transportation, housing, nature conservation, and many other commercial and non-commercial activities. The static characteristic involves situations in which land resources are either abandoned (as seen in parts of southern Europe and particularly in some non-industrialized countries) or preserved (with some management activities) for amelioration or its natural and heritage values (e.g. The black forest in Western Germany). Hence, land use planning is the science of analyzing different alternative uses, weighing each option in the context of natural endowments of the region and its societal goals, customs and traditions, and laws, as well as selecting the most viable option based on the given circumstances. In some instances land use planners may consider some external factors in their analysis and the subsequent decision. For example, a decision concerning polderizing and reclaiming a large wetland may be taken in response to the lucrative agricultural export market at the time. Or as another example is a decision concerning reclamation of a rain forest for increasing agricultural productivity which may be influenced by an offer for debt settlement made by several countries in the global community.

Land use planning is heavily influenced by the political system of a society. In some countries all the land is owned by the state and there is no private ownership. In such cases there is no significant grassroots participation in land use decisions which are mostly designed as components of a centrally planned development strategy. In contrast to this system, in market economies most land is owned by members of society. As a result, there is a general participation of people in a majority of major land use decisions. For example, land reallocation in the Netherlands is a major land use decision process that involves several farm groups as decision makers (e.g. van Lier, 1988). The third category includes certain countries where some of the land is owned by the state. These type of lands are said to be "crown lands". But in most cases these crown lands are controlled by a democratic government that represents the people of that particular country. The last category includes countries in which some lands (particularly agricultural lands) are commonly owned. These type of lands are usually part of a collective or cooperative farming system and are more common in Israel, part of Africa where tribal owning of land is practiced, and perhaps in some countries with a social democrat system of government. There is no doubt that each of these various land use patterns have certain advantages or disadvantages. However, because of the esoteric nature of this subject further discussion warrants a separate report. Nonetheless, it is important to demonstrate some of the factors that influence land use planning and some of the likely conflicts that may be involved. These aspects are very important when land use planning is implemented within the context of IRD.

3.3.3 Land use planning and development

During the last forty years the focus of land use planning was primarily on agricultural, industrial, and urban expansion. These, at the time, well intended decisions to provide flood protection, increased agricultural production and water supplies, and many other private and public benefits have caused the alteration of the natural state of the environment. Although most of this environmental degradation occurred in industrialized countries particularly in Western Europe where the post war reconstruction plans (e.g. Marshall Plan) in conjunction with agricultural subsidies and other government policies encouraged an unabated use of natural resources, some setbacks have been noted in Eastern European and non-industrialized countries as well. Today, as a result of this new phenomenon (i.e. the new socio-economic order mentioned earlier), society has realized the drawbacks of the post World War II myopic view on an exponential growth. At present, increased attention is being directed towards a sustainable development. The World Commission on Environment has described sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

This means, every human action must be seen from the outset with respect to its cause-effect structure and impacts on the environment. In response to this new global attitude towards growth and development, today, more than ever, land use planners are concerned about sustainable development based on flexibility of land and water uses. This approach is not very simple mainly because it requires an interdisciplinary technical approach, an effective participation of private landowners as well as private and public sector organizations, and finally a broader outreach to the general public for the planning and implementation of sustainable land use plans and adjustments on the part of consumers or society as a whole.

EXHIBIT 3.1 An arbitrary land use transfer pattern

State of land use	
ORIGINAL	PRESENT
Forest	Enclosed Family Farm (EFF)
EFF	Huge hedgeless agri-business complex (Ag. Comp.)
Ag. Comp.	Golf Course (GC)
GC	Urban Sprawl (USP)
USP	Decaying innercity ghetto (DIG)
DIG	Modern Commercial Development (MCD)
MCD	?

Because such a planning procedure involves different individuals and public agencies, the task of land use planners is becoming more difficult. Hence, land use planners are concerned with the question of how, when, why, what if, and how much land to allocate to various uses. For example, the task of land use planners is to find out how a particular parcel of land has its present use (Exhibit 3.1). This would be necessary to marshal and utilize land resources in the most effective and efficient way possible. In order to understand why land use pattern changes take place, and what the implications of these changes are, land use planners need a variety of facts and figures that cover a wide spectrum of disciplines from social to physical sciences. That is the reason why land use planners often work along side of a number of scientists who are familiar with the specific aspects of soil and water. It is the combination of this knowledge along with other socio-economic information that land use planners apply for deciding alternative uses of land. However, sometimes because land use planners' work is influenced by societal goals that are reflected in the political manifestation of a democratically elected representatives, their plans may be short-sighted. This is not entirely due to their inability to foresee some of the adverse implications of their decisions, but rather due to several other factors such as:

a) Lack of a clear understanding of the long-term cause- effect structure and impacts of certain land use decisions by the scientific community (e.g. reclamation of wetlands),

b) Absence of adequate biological and physical input data to facilitate an in depth cause-effect investigation,

c) A general lack of awareness and flexibility on the part of the public who demands changes in the name of short-term economic growth, and finally,

d) Too often the short-term nature of a democratically elected government that represents a specific party platform (e.g. different party platforms on the issue of environmental protection or sustainable growth and so on). A term of government in a democratic system is usually 4-5 years.

Consequently, todays' land use planners are concerned with problems and complexities involving various uses of land and their interaction with the environment. In this process they attempt to resolve conflicting objectives that are associated with multijurisdictional aspects of land. For example, in implementing the Management Agreement Program, land use planners should be able to create a balance between farmers' and environmentalists' interest with regard to the use of environmentally sensitive areas. Furthermore, land use planners also attempt to reconcile the contrasting needs that must be met by a world-wide growth and development particularly in the area of agriculture. This indeed could be a serious problem in some of the non-industrialised countries where local tribes and public agencies may support different alternative land uses. For this reason a sustainable IRD project for increasing agricultural productivity in non-industrialized countries would require highly skilled land use planners who, in cooperation with other experts, are capable of resolving such conflicts.

In order to be able to design a long-term sustainable plan for different land use options, planners require quantitative means by which limited land resources can be allocated to alternative uses in response to societal goals. One of the areas where such quantitative means can be useful is in the field of soil-water management particularly in non-industrialized countries. This is primarily due to the fact that on account of the extreme nature of agroclimatic conditions (that is either very humid or arid) in most non-industrialized countries, soil-water management is indispensible to their agricultural growth and productivity. Table 3.3, provides a few examples of water resource development projects in some of the limited resource and non-industrialized countries involving the World Bank. In the absence of an adequate irrigation or artificial drainage scheme, no significant increase in their agricultural output can be expected (Jorjani, 1990). According to Rangeley (1987) poor drainage and flooding constitute some of the main obstacles to agricultural productivity in most limited resource and non-industrialized countries such as India, Pakistan, Bangladesh, and Cambodia, to name a few.

Table 3.3 Representative examples of major water resource developments involving the World Bank

NAME OF DEVELOPMENT	LOCATION	NATURE OF DEVELOPMENT
Tropical lowland development	Mexico	Drainage and rain-fed agriculture
Indus river basin	Pakistan	Irrigation, drainage, flood control, and hydroelectric power
Land and water	Bangladesh	Medium-range and long-range plans for irrigation, drainage, and flood control
Lower Magdalena river	Colombia	Flood control, drainage, and rain-fed agriculture
Lower Guayas river development	Ecuador	Flood control, drainage, and rain-fed agriculture
Santiago region development	Chile	Water supply, flood control, irrigation, drainage, and hydroelectric power

Modified from Kirpich (1984).

Thus soil-water management techniques such as artificial drainage are considered as an important part of IRD for curbing the twin menace of waterlogging and salinity in arable lands of such countries. But because of the biophysical cause-effect structure and impacts of artificial drainage on the surrounding areas, it may create conflicts with other land uses. For this reason the availability of accurate means of decision making becomes imperative to effective land use planning. Such quantitative means would be useful in the weighing of costs and benefits of agricultural drainage which is often an important issue when agricultural development in an environmentally sensitive area is weighed against alternative uses of land such as wetland conservation. For example, environmentally sensitive areas that are dominated by hydric soils because of their high organic matter content are most favored for agricultural development. Albeit in some areas such as the peat districts of the Netherlands this may not be done at present because of the twin effect of sinking of these peat lands and the rise in ground water table. However, in areas where such limitations do not exists, lands with fertile hydric soils are almost the first areas that would be subjected to reclamation and drainage in order to create a desirable soil-moisture regime that would allow maximum agricultural productivity. However, hydric soils, because of their high moisture content provide an excellent habitat for a number of hydrophytic and water tolerant plants. These habitats not only contribute to the hydrological balance of the region but also provide a crucial genetic pool for numerous species of flora and fauna, some of which are rare. Furthermore, most of these natural habitats provide selected outdoor recreational and tourist related services that can become a significant source of income for rural people of non-industrialized countries where most of our global natural heritage lies.

Hence we need evaluation methods that not only consider agricultural perspectives of drainage and its contribution to the region's agricultural development, but also recognizes the ecological, recreational, and heritage value of those habitats in the planning process. In fact these values if appropriately monetized can be considered as conservation "crops" with an income generating potential that can be compared with agricultural crops in terms of economic returns. Treating conservation as a "crop" with a price rates fixed and agreed (by farmers and project planners) was a successful concept introduced in an IRD project in UK, with the aim of combining food production and environmental management (Parker, 1986).

Furthermore, because artificial drainage requires a substantial commitment to capital financing, decisions on the installation of a complex artificial drainage systems as a soil-water management technique in a limited resource non-industrialized country would require a careful knowledge of costs and benefits of the project (Jorjani, 1990). This knowledge would be particularly of importance when development funds are being allocated within an IRD project.

From IRD 's point of view poor socio-economic and environmental judgments for such capital intensive projects can easily cause overinvestment or underinvestment with serious environmental and economic ramifications. Inappropriate and badly conceived soil-water management projects that fail to recover their costs of investment, operations, and maintenance can cause serious setbacks in a limited resource country for several years. What is at issue is the economic efficiency of soil-water management techniques in these countries. Whether these projects are financed internally or externally, the point is that these investment projects must be self-sustaining and affordable to their beneficiaries. Lest agricultural development may not occur.

Due to these complexities, a better understanding of agricultural perspectives of drainage is therefore, a key element in addressing some of these concerns. The following section will provide the agricultural perspectives of drainage as a soil-water management technique.

3.4 Summary

Today allocating natural resources to their best use is the most crucial component in the complex process of land use planing, particularly in the context of rural development projects that are designed to bring about sustainable agricultural development. The global trends in the environmental effects of recent transformations, and the difficulties of predicting land use decision outcomes is a witness to this complexity.

With the new socio-economic order, that is the surplus agricultural sector and an over-burdened environment in industrialized countries on one hand, and the twin perils of pervasive hunger and persistent poverty in non-industrialized countries on the other, an increased effort for agricultural development in non-industrialized countries is anticipated. However, it is common knowledge that agricultural development in most of these countries requires certain pre-conditions such as a physical and economic infrastructure. Considering the economic predicament of most non-industrialized countries there is a need for mobilization of global resources to assist these countries to pave the road for achieving increased agricultural productivity and economic growth. From past experiences it is certain that a sustainable agricultural development in those countries cannot be achieved without a new approach in rural development. This new approach which is known as Integrated Rural Development (IRD) can be viewed as a multidisciplinary process for achieving long-term sustainable agricultural growth. That means in order to be effective and sustainable IRD projects must also focus on the wise use of soil, water, and other inputs. Because of this new focus in IRD projects, land use planning is becoming an important component of IRD. Hence, it is due to importance of land resources and their wise use within an IRD project that an understanding of the critical link between land use planning and IRD has become urgent. The lack of this knowledge in the past has wrought great costs to donor agencies and the aid recipients alike. The Aswan project is of course a classic example. A massive irrigation project was implemented without any consideration for the gradual rise in ground water table that caused a decline in crop yields and farmer's income in the region. In addition to these problems, Egyptian authorities had to seek further assistance from outside in order to implement agricultural drainage projects that would alleviate the twin menace of waterlogging and salinization in those irrigated fields.

Thus, in a thesis that deals with a theoretical holistic framework for agricultural drainage the need to provide farmers, development agencies, and public planners with an understanding of this critical link becomes paramount.

CHAPTER 4

AGRICULTURAL DRAINAGE AS A SOIL-WATER MANAGEMENT TECHNIQUE

4.1 Introduction

4.1.1 What is soil?

From agricultural point of view soil may be defined as the naturally occurring, unconsolidated, mineral or organic material on the landscape that is capable of supporting plant growth. Hence, materials that constitute soil consist of various proportions of weathered rocks (e.g. gravel, sand, silt, clay, and others), organic matter (e.g. Humus), soil organisms (e.g. insects, worms, bacteria, fungi etc.), gases (e.g. oxygen, nitrogen, as well as carbon dioxide), and most important, water that regulates the activity of other soil constituents. The soil forming process is an interaction between these constituents, vegetation, topography and climate through time (Foth and Turk, 1972). Due to this complex process of soil formation sometimes on a particular farm there may be different soil series. For instance, two soils may have similar surface layers but one may have a compact subsoil that restricts water movement and root penetration while the other may have an open porous subsoil that permits rapid water movement and better root development (Foth and Turk, 1972; Dijkerman, 1981).

Some agricultural soils may consist of a layer of fine sandy loam on a sand and gravel subsoil. For people not familiar with soil science their first reaction is that these type of soils must be well drained. On the contrary these soils have a great water-holding capacity and at times can be as wet as any poorly drained soil (Foth and Turk, 1972). The reason being when a downward moving water (accumulated due to rainfall or irrigation) encounters a coarse-textured layer, water movement will stop, at least temporarily. Water will not be pulled down into the sand layer until the overlying fine-textured soil is nearly saturated. This is the reason why these soils (Known as stratified soils) are sometimes waterlogged. Another form of these stratified soils is the one which is consist of coarse-textured soil (e.g. sands) on the top of a fine-textured layer (e.g. clays). Under these conditions the low transport capacity of the heavier soil may cause a build up of water in the upper Coarse-textured soil. During wet seasons this causes accumulation of water on the soil surface. Consequently, the entire soil profile must be taken into consideration when estimating the productivity of a soil. Soil profile is defined as a vertical cross-section of the soil through all of its horizons and extending into the parent material (Agriculture Canada, 1978).

4.1.2 Soil properties

The physical properties of a soil are a combination of several indicators that determine the suitability of that soil for different uses. These properties are usually associated with certain characteristics such as permeability, moisture storage capacity, rootability, aeration of the soil as well as its ability to retain nutrients, among others. Most of these properties are expressed by the term soil texture. The soil texture is determined by the relative proportions of sand, silt, and clay (Foth and Turk, 1972). Hence, the rate and extent of most important physical and chemical reactions in soils are influenced by soil's texture. For example, clay particles because of their small size expose more surface as compared with that exposed by an equal amount of sand which is a coarse material. Therefore, by holding more water on their surface, the amount of clay in the soil plays an important role on the water holding capacity of the soil and the movement of water in its profile. Soil classes are usually described on the basis of the proportions of sand, clay, and silt present in a soil. These proportions have been calibrated (in percentages) in a "textural triangle" that is provided in most soil science text books (e.g. Foth and turk, 1972). The sum of the percentages of sand, silt, and clay at any time in that triangle is 100.

4.1.3 Hydrological condition of the soil

Basically, under natural conditions, the growth of plants depends on the soil for water, nutrients, root development and anchorage. Under artificial conditions such as hydroponics or greenhouse, plants are supported with the help of a wire network. Therefore, under natural conditions, soil must: a) have enough pore spaces to facilitate root development and its extension in the soil, b) possess adequate amount of oxygen for root respiration, and c) be capable of supplying essential nutrients for plant growth.

Water is the most important factor that can influence the availability of pore spaces, oxygen, and nutrients in the soil. Deficit or excess moisture in the soil can cause a number of deficiencies that will inhibit plant growth. For example, excess water caused the famine in Bangladesh in 1974 (Bradly and Carter, 1989). Excess moisture in the soil suffocates most plant roots. Some plants such as paddy rice have stems through which oxygen can diffuse from atmosphere to the roots. Excess moisture in soils is also responsible for slow rates of nitrification (Dijkerman, 1981). Hence, hydrological condition of the soil can play an important role in the success or failure of a crop. Ever since man domesticated plants for agricultural production nearly 10,000 BC in the "fertile crescent" he has been devising methods to manipulate hydrological conditions of the soil in order to avoid crop losses (e.g. Foth and Turk, 1972; Heathcote, 1983). Archeological evidence in western Iran (dated to 5,500 BC) are a witness to this ancient tradition of water manipulation and the extent of communal activities required to establish and maintain water control systems for agricultural uses (e.g. Heathcote, 1983).

With regard to the importance of hydrological condition of the soil and its management (manipulation) for increasing agricultural productivity, this chapter will analyze agricultural drainage as a soil-water management practice. This analysis will focus on a systemic approach that includes an examination of various linkages that are involved in agricultural drainage. The knowledge of these linkages is needed for understanding the biophysical cause-effect structure of drainage and its impacts when allocating land for agricultural or non-agricultural uses in rural areas.

4.2 Agricultural Drainage

Agricultural drainage consists of removal and disposal of excess moisture from farmlands. Excess moisture in soil can be attributed to (a) precipitation, (b) irrigation water, (c) overland flow or underground seepage from adjacent fields, artesian flow from deep aquifers, flood water from rivers/canals, or (d) water applied for special purposes other than irrigation, such as for leaching salt or pollutant material from soil or for temperature control.

In nature the drainage process involves ground water flow to natural outlets, vertical seepage to lower aquifers, and lateral seepage to adjacent areas. Under certain agroclimatic and soil conditions this natural process is adequate to allow a normal plant growth and agricultural production. However, if soil is naturally poorly drained, crop production will not be possible unless artificial drainage systems are installed.

Artificial drainage systems comprise different man made structures varying from surface drainage to subsurface drainage systems. Surface drainage systems are a network of open drain ditches in the field that are constructed with respect to some predetermined specifications such as the required drain spacing, and depth. Most of these specifications are influenced by soil properties, cropping patterns, and topography of the field. One of the main disadvantages of surface drainage systems is that drainage ditches divide the field into small parcels (depending on the drainage requirements of the field) which are often inconvenient for the use of farm implements and machinery. Subsurface drainage systems are usually a network of underground perforated plastic pipes (tile drains) that are installed under the top soil. When the soil surrounding the plastic pipe is saturated with water, water seeps into the tile (installed on a grade) and then it eventually reaches an outlet where it is disposed. The intensity of a subsurface drainage system depends upon drain spacing and depth which in turn are determined on the basis of agroclimatic and soil conditions of the field.

In addition to soil and agroclimatic conditions, the depth of outlet has a direct bearing on the depth at which subsurface drains may be placed. The basic agrohydrology principle involved in drainage systems requires that water table in drainage outlets be sufficiently lower than the depth at which tile drains are placed. Otherwise excess water must be lifted mechanically (e.g. pumped) in order to facilitate an effective function of subsurface drains (Figure 4.1).

In this investigation the focus is on subsurface drainage. Consequently, terms such as artificial or agricultural drainage used in this thesis are a reference to subsurface drainage systems.

4.3 A holistic view on agricultural drainage

> "Having been a government research officer, farmer, rancher, consultant, and politician, I have viewed resource management from many angles and can imagine no better way to ensure sound overall national resource management than the use of the Holistic Resource Management model .... The absence of such a broad and consistent approach has wrought great damages to the health and wealth of the world and continues to do so."
> (Savory, 1988 p. 475)

For the last forty years the focus of land use was primarily on agricultural expansion through mainly various ways of land reclamation that most often included intensive drainage. These well intended decisions to provide flood protection, increased agricultural production, and many other private and public benefits were further accelerated with an artificial pricing mechanism that encouraged intensive farming in order to increase agricultural exports (e.g., farm subsidies in EEC, North America, and Japan). It is said that in the United

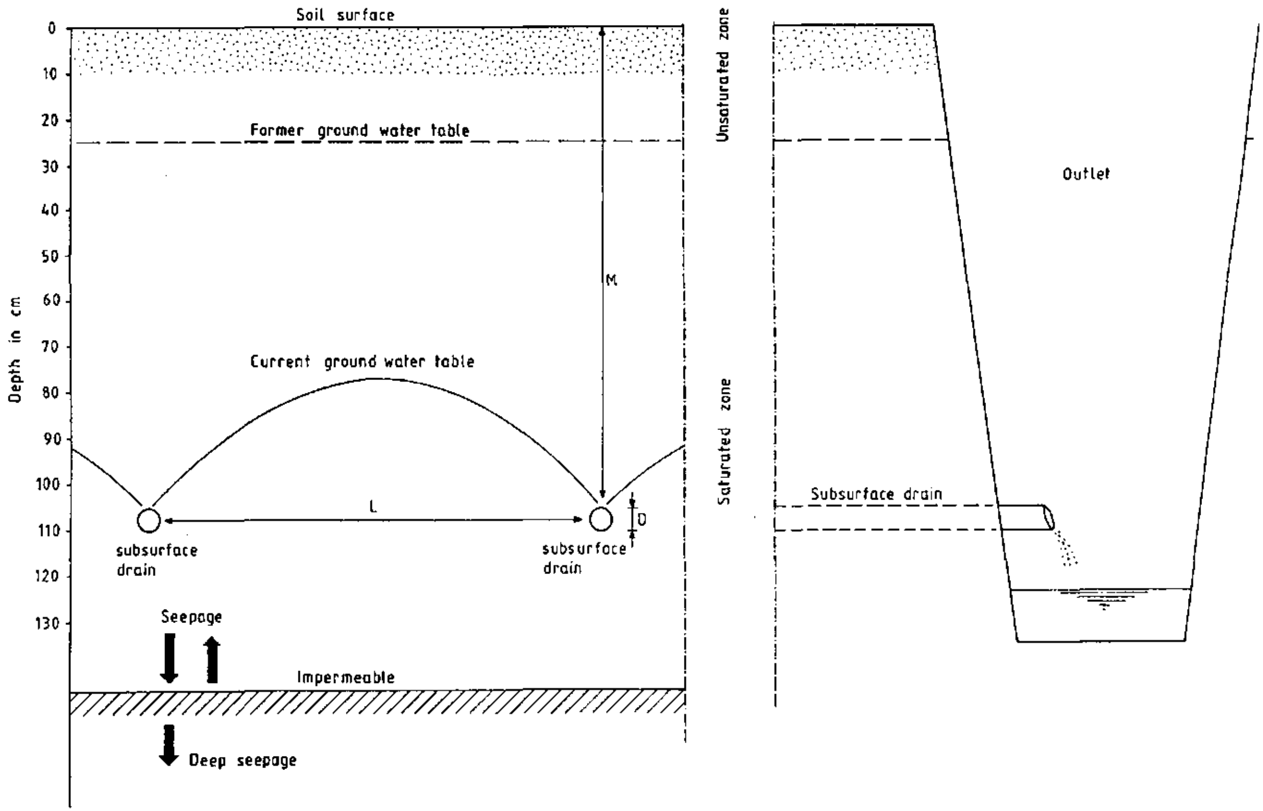


Figure 4.1 Schematic of a subsurface drainage system.
[x] L, D and M may vary according to Soil Characteristics of the field.

States economic incentives to drain wetlands were originally established by the federal government to stimulate agricultural production and provide for economic growth in rural areas (Danielson and Leitch, 1986). As we are entering the new decade it is becoming increasingly apparent that the previous approaches to agricultural development are no more sustainable. At stakes are issues of concern to all of us. According to van den Ban (1987) in Europe, the effect of highly productive agricultural practices have caused not only concerns to environmentalists but also to the rural population themselves whose livelihood is dependent on soil, water and the genetic diversity of flora and fauna.

Currently, as a result of those views and approaches to agricultural land use, most advanced agricultural societies are faced with a new socio-economic order that is characterized by a surplus agricultural sector and an over-burdened environment. In response to this new socio-economic order, private and public decision makers are both becoming increasingly concerned with the nature of agricultural development and its various components such as agricultural drainage.

The central issue is that, in the past most decisions on agricultural development (including drainage projects) were made in an environment where a single perspective on an individual's interest (in economic terms) was expected to create a dynamic effect that would result in a positive growth and prosperity. This approach was deficit because it lacked certain considerations for the long-term cause-effect structure of the process (e.g. reclamation of peat lands for agricultural uses in the Netherlands). This shortcoming was however, mainly due to lack of a clear understanding of various linkages that were involved in such decisions. For example, in the case of agricultural drainage which is considered as an important soil-water management technique, most often its important biophysical cause-effect structure and impacts were not taken into account as a holistic process. Consequently, most environmental aspects were ignored because they were considered as external factors. The reason why environmental factors were ignored was due to the fact that some economists and land use planners strongly believed that the only concern in decisions involving artificial drainage was the final benefits to farmers without much recognition of the cause-effects involved in the process. In reality, drainage benefits to farmers is only one of the components of a complex biophysical cause-effect structure that governs what happens to the farm and its surrounding area once the excess moisture is removed from the soil profile. In essence, changes in the soil-moisture regime of an area will have several impacts on the project area and its surroundings, one of which may be increased agricultural productivity on the land. Hence it is very important to recognize how changes due to artificial drainage affect the ecosystem collectively. This knowledge would enable planners and/or public decision makers to weigh options without overlooking any.

Therefore, the main point in this section is that past insights show that any decision on artificial drainage, given the complexity of our ecosystem, must consider the entire system or assume a high risk of breakdown in the long run. Because of the biophysical cause-effect structure and impacts of artificial drainage on the surrounding areas, its implementation may cause conflicts with other land uses. This is particularly true in environmentally sensitive areas where a reduction in the soil-moisture level may have a deleterious impact on the area's ground-water table and its landscape attributes including fauna and flora.

Hence to avoid some of the problems associated with a unisectoral view and analysis on agricultural drainage as a soil-water management practice, there is a need for developing a holistic (systemic) approach to its impacts. A systemic approach to impacts of agricultural drainage will consider its agricultural perspectives (Farmer's and societal), while also recognizing its other impacts within the context of a holistic cause-effect structure in the planning process.

4.4 Biophysical cause-effect structure of drainage

Artificial drainage involves a complex process that the investigator refers to, as the biophysical cause-effect structure of drainage and its impacts. This process comprises several components that include hydrological, biological, ecological, and finally economic linkages. These linkages are interrelated and their individual or collective impacts are observed when the first linkage is set in motion (Figure 4.2).

The system depicted in Figure 4.2, indicates that basically a decision on agricultural drainage investment is influenced not only by the farmer but also by society. In this figure society is shown as a complex system with varying goals and objectives that may differ with respect to space and time factors. Society through its collective action (mostly common in democratic systems) can influence a farmer's decision through planning instruments (shown in Figure 3.2) that include different public offices or interest groups. For example, if society considers food self-sufficiency to be an immediate priority, then the elected representatives of society members will enact policies that will favor agricultural expansion. This objective could be achieved by providing incentives for reclaiming marginal lands or improving drainage efficiency of existing farmlands, as happened during the last forty years in Europe and North America. On the other hand if society perceives nature conservation or outdoor-recreation as an immediate need, then the elected representatives of people will introduce legislation and guidelines that would restrict any modifications of environmentally sensitive areas through drainage and reclamation.

Now the question remains how do we know if a drainage project is useful or harmful with respect to sustainable land use or agricultural decisions. In order to be able to answer this question land use planners, farmers, and the public at large must have some knowledge of the cause-effect structure and impacts of drainage.

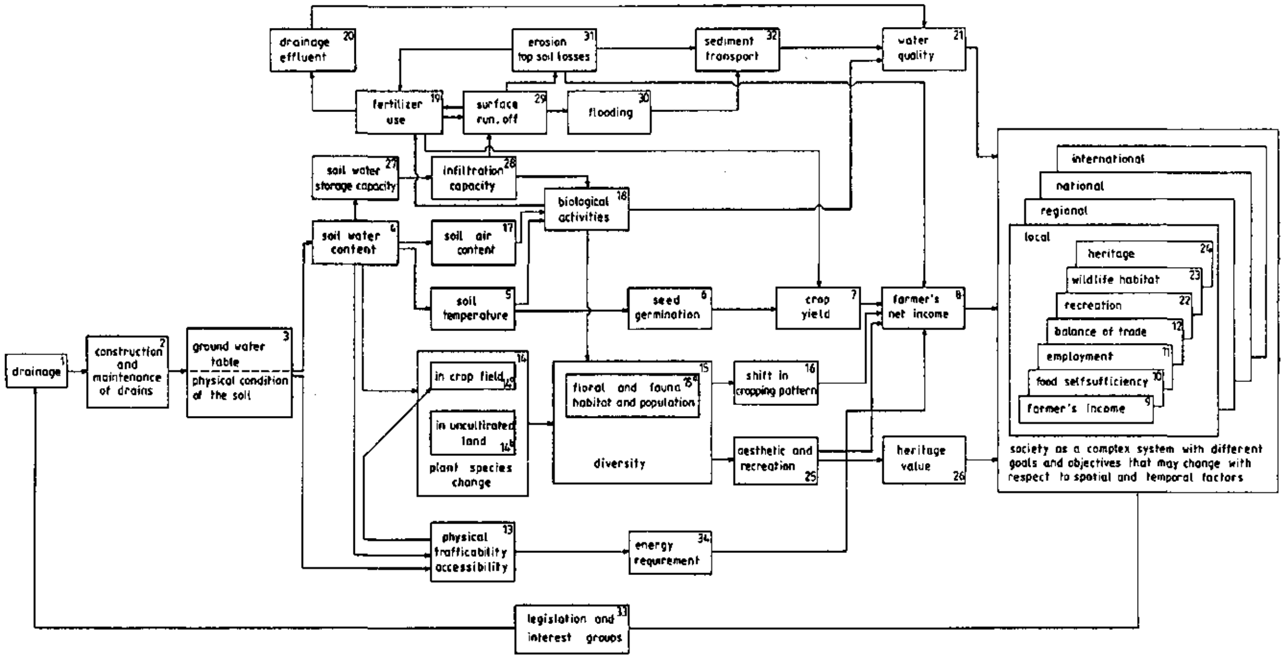


Figure 4.2 Biophysical cause - effect structure of drainage impacts.

The cause-effect guideline enables farmers, and public planners to determine whether or not agricultural drainage can alleviate the problem at hand (e.g. excess moisture in agricultural fields)without too much cost to society. In other words how would a drainage project in an area increase farm productivity without a negative impact on the ground water regime of the surrounding area. Therefore, what is needed is a comprehensive knowledge of the biophysical cause-effect structure and impacts of drainage.

The knowledge of these linkages will facilitate conceptualization of appropriate frameworks to assess economic aspects of agricultural drainage. An objective economic valuation relies critically on understanding and measuring the physical, chemical, and biological effects of the complex cause-effect structure of artificial drainage and its impacts. In general, economic valuation is the last step in the analysis (Hufschmidt et al., 1983). For this reason, an account of these linkages will be provided here. However, before describing these linkages it is essential to remind the reader that the numbers assigned to different components of Figure 4.2, are only means to separate different linkages. Further, owing to the existing interconnections between these linkages some of the numbers assigned to blocks (boxes) may be repeated in more than one case. In addition it must be mentioned that these numbers do not represent any hierarchial order.

4.4.1 Hydrological linkages

The hydrological linkage is undoubtedly the most important one in the biophysical cause-effect structure of drainage and its impacts as it sets in motion the entire system. Technically, once drainage systems are constructed or installed, gradually the ground water level starts falling in the soil profile. This drop in ground water level is either through gravitational or mechanically enhanced movements of water (boxes 1&2). By lowering the ground water level, physical conditions of the soil are changed (box 3), and in turn, the soil water content decreases (box 4). Lower soil water content improves soil temperature by allowing more pore spaces to be filled by air (box 5). Better aeration of the soil enhances seed germination and consequently increases crop yields (boxes 6 & 7). Increased crop yield not only influences farmer's income directly, but contributes to an aggregate economic chain-effect at different levels of the economy (boxes 8, 9, 10, 11, & 12). Important contributions of the agricultural sector to other sectors of the economy for accelerated growth are numerous, such as increased production of food for domestic consumption and export, outflow of capital for investment in other sectors, and an increase in consumer demand in the agricultural sector for the goods and services produced by other sectors (Stevens and Jabara, 1989).

Timeliness of field work operations is another aspect that is directly related to hydrological linkages of drainage. The removal of excess moisture from the soil profile allows the soil surface to dry faster. This in turn facilitates trafficability and movement of farm equipment and machinery on the soil surface, especially during seedbed preparations (boxes 4 & 13).

Improved timeliness of planting and harvesting is one of the most important benefits of agricultural drainage, particularly in areas which are characterized by high rainfall during planting and harvesting time, short growing seasons, and capital-intensive and technologically advanced agricultural system (e.g., corn-belt areas in the U.S. and Canada, and vegetable-growing areas in the Netherlands). Under these conditions, drainage usually helps farmers to get into the field earlier, and to harvest their crops on time (Smith, 1972). Based on considerations of soil-water regimes and water-table levels at several sites in the U.K., Armstrong (1986) estimated drainage benefits, in terms of increased working days during the growing season, to be 84 days. This indicates why workability constraints on wet, undrained lands may result in no crop at all if access to fields, particularly during growing or harvesting periods, is prevented due to a high water table.

Better trafficability on the field due to artificial drainage also involves the efficiency of machinery use (box 34). Farming in humid regions, characterized by heavier soils, necessitates the use of powerful and consequently expensive farm machinery. Under these circumstances drainage improvement not only means that farm machinery and equipment are not bogged down in the field, but also indicates that smaller and consequently less expensive tractors can accomplish the same job at a lower cost (Trafford, 1970; Irwin, 1987). The use of lighter machinery could also prevent or reduce certain types of soil degradation such as soil compaction.

The hydrological linkage of artificial drainage is also responsible for plant species changes in crop fields (boxes 14, 14a, 15, 15a & 16). In humid regions, artificial drainage will facilitate a greater flexibility of cropping and tillage (e.g., a shift from lower value crops such as pasture to higher value crops like corn or soybeans), and/or better crop-rotations (Briggs and Courtney, 1985).

Hence, agricultural drainage can have a profound effect on the diversity and possibility of a shift in cropping pattern. The ability to adopt new crops and to rotate them enhances the effectiveness of soil conservation methods such as intercropping, or double cropping. Numerous studies in Canada and the U.S. have indicated the important role of conservation tillage in reducing soil erosion and chemical losses in runoff (e.g. Miller et al. 1982; Wall et al. 1982; Ketcheson, 1977; Ketcheson, 1980; Wall et al. 1985; Vyn et al., 1982; Vyn, 1987; Christensen and Norris, 1983). However, it is reported that acceptable crop yield under conservation tillage depends mostly on soil type and its drainage characteristics. In other words conservation tillage is not suitable for soils with high clay content unless there is adequate artificial drainage. A well drained soil allows more rotation and enhances production under no tillage agriculture. Van Doren et al. (1976) has reported that continuous corn under no-tillage on poorly drained soil reduces crop yield significantly.

With regard to a shift in cropping pattern, in an investigation conducted in eastern Ontario, McCaw (1984) found that installing tile drainage mostly benefited farmers who changed their cropping pattern by shifting from low to high value crops. Most farmers of the region are unable to grow cash crops such as corn efficiently on poorly drained soils.

4.4.2 Biological linkages

By removing excess moisture from saturated soil profiles, agricultural drainage creates more empty pore spaces that allow entry of oxygen in the soil (box 17). The increased soil aeration and temperature enhances microbial activities in the soil (box 18). Increased microbial activity in the soil is responsible for better mineralization and decomposition processes. For example, increased microbial activity enhances nitrogen mineralization leading to a reduction in nitrogen fertilizer use (box 19). Crop production under waterlogged conditions requires additional doses of nitrogen fertilizers to offset the harmful effect of poor drainage (van Hoorn, 1958). Improved decomposition and mineralization are also known to be responsible for changing organic phosphorus found in decaying vegetation into dissolved inorganic phosphate ions that are biologically available for plant uptake (Clark, 1985). More efficient uptake of nutrients enhances crop growth and increases productivity (boxes 19 & 7).

4.4.3 Ecological linkages

To attempt to farm many poorly drained soils without artificial drainage would result in total crop loss in some years and severely reduce yields in others (Skaggs and Gilliam, 1986). However, artificial drainage may not be desirable ecologically, particularly in environmentally sensitive areas, owing to its negative impacts caused by its hydrological and biological linkages. Some of these negative impacts are listed below:

(a) removal of water and entry of oxygen in reclaimed peat lands (boxes 4 & 17) causes oxidation of peat and humus. Furthermore, draining some wetlands (even a small pothole in the middle of the field) that have accumulated iron pyrite (FeS_2) under waterlogged conditions cause FeS_2 to be oxidized to soluble iron and sulfuric acid.

$$2FeS_2 + 7O_2 + 2H_2O \text{-----}> 2FeSO_4 + 2H_2SO_4 \qquad 4.1$$

Iron usually gets deposited as colloidal iron hydroxide (Ochre) in drainage effluent and sometimes blocks subsurface drainage tubes within a year or two of installation. The sulfuric acid decreases soil pH and thus adversely affects crop yield or increases costs of soil management.

In some newly reclaimed soils, substantial amounts of calcium carbonates are required to neutralize the soil's acidity (Bradshaw and Chadwick, 1980). Moreover, concentration of these soluble chemicals can also affect water quality down stream (boxes 18 & 21). Increased acidity in rivers and lakes on account of drainage effluent can have an impact on wildlife habitats of a region and hence reduce recreational and heritage values of environmentally sensitive areas and their surroundings (boxes 20, 21, 22, 23, and 24). Gosling and Baker (1980) reported incidents of fish kills in the Norfolk boards (U.K.) on account of drainage water.

(b) as mentioned earlier the biological linkage of artificial drainage is responsible for a better nitrogen mineralization. However, this characteristic of artificial drainage may have a deleterious impact on the environment because it increases the discharge of nitrate into waterways. Movement of nitrates from agricultural fields through drainage effluent is an important factor in non-point pollution in water ways (boxes 18, 19, 20, and 21). It is said that the amount of nitrate present in the drainage effluent is dependent on several factors, including rate of nitrogen fertilizer application and types of crop grown (Muir et al., 1976; Pratt and Adriano, 1973; Skaggs and Gilliam, 1986).

According to Skaggs and Gilliam (1986) artificial drainage increases nitrate movement from agricultural fields even when no additional fertilizer is applied. Moreover, because drainage allows intensive farming, nitrogen losses in drainage waters may be compounded.

c) Some environmentally sensitive areas, particularly wetlands are unique ecosystems that support highly varied flora and fauna that can range from deep-rooted trees (especially in tropics) to insectivorous plants such as bladderwort, from insects to birds, and reptiles to mammals (Clark, 1978; Crow and Macdonald, 1978; Weller, 1981; Thompson, 1987). Hill (1976) reported that many game animals depend on wetlands because of their importance as cover. Wooded wetlands of the Great-Lakes States and Eastern Canada are known as a cover area. It is important to stress that changes in the soil water content is not the only factor that changes the ecosystem. Too often it is the combined effect of drainage and intensive farming that causes severe damages.

Artificial drainage, owing to its hydrological linkages can, profoundly alter the diversity of flora and fauna of these ecosystems and surrounding areas (boxes 14, 14b, 15, and 15a). Stewart and Lance (1983) reported several changes in the floral and fauna populations of peat moorlands at Glenenay in Ireland due to drainage and other agricultural management practices. Briggs and Courtney (1985) cited several examples to illustrate similar changes. Apparently in Europe reclamation and drainage of wetlands in various parts of the continent has not only changed plant species (from hydrophilous to mesophylous) but it is also threatening the existence of many reptiles, amphibian and water fowls. Drainage of wetlands generally caused a serious decline in the numbers of some mammals species in Europe (Briggs and Courtney, 1985). Their list of endangered mammals include: the Pyrenean desman (Gatemys pyranaicus), the southern water shrew (Neomys amomalus), the beaver (castor fiber), and the European mink (Mustela lutreola). The otter (lutra) is also said to be under pressure due to loss of habitats on account of drainage and reclamation, among other things.

The loss of landscape features of environmentally sensitive areas and their surrounding undoubtedly undermines their aesthetic, recreational, and heritage values at different levels (i.e. local, national and international) of society (boxes 25, 26, 22, 23, and 24).

d) Unlike all the above cited negative ecological impacts of drainage there are some positive impacts as well. For example, increased water storage capacity of the soil enhances the infiltration of water into the soil and as a result surface runoff is reduced (boxes 27, 28, and 29). Reductions in surface runoff decreases the chances of flooding and erosion (boxes 30 and 31). In an experiment on hilly silty-clay soils in Italy, Chisci and Zianchi (1981) found that the amount of over-land flow and the resulting soil losses were much lower on drained plots.

Flooding and erosion during seedbed preparation are responsible for seed, pesticide, fertilizer, and topsoil loss and transport into the water system. Thus by reducing surface runoff from agricultural land, drainage can reduce sediments transport and consequently non-point pollution of water bodies (boxes 32, and 21). Irwin (1987) noted that erosion from a sandy loam soil can be reduced by a factor 10 with subsurface drainage. As a result artificial drainage can minimize certain costs that are associated with the loss of top soil and the displacement of seeds, fertilizers, and pesticides due to surface runoff, and erosion. Consequently, these cost savings not only influence farmers' income (boxes 31, 19, 8 & 31, 8), but will have an indirect influence on the regional and national economic structure of the agricultural sector.

4.4.4 Economic linkages

Economic linkages of agricultural drainage are in a way the synthesis of all the previous linkages and their translation into a common denominator, such as Dollars or Guilders, from farmer's and/or societal perspectives. Consequently, it involves input data and decision guidelines (framework) that are needed in order to weigh different (positive and negative) components of all the earlier linkages.

The above linkages include both farmers, and society at large. However, they can be affected quite differently. Therefore, land use decisions concerning agricultural drainage as a soil-water management technique within the context of sustainable development, must ultimately be examined from two perspectives, that of the farmer and that of society at large. Furthermore, it must also include the environmental perspectives, particularly those involving wetlands. These are needed for valuation of benefits and costs of wetlands.

Value is a relative term or an absolute weight and judgement that one attaches to his or her preferences. Relative values are often subjective and vary according to personal characteristics of the observer, whereas absolute values are determined as a result of some empirical or systemic observation. However, the formidable challenge facing economists, environmentalists and land use planners is how to express and compare the value of agricultural and environmental benefits. As far as valuation of agricultural benefits are concerned there seems to be very little problem. This is primarily due to the nature of agricultural goods and services that allows them to be valued by the interaction of supply and demand in the market. But the evaluation process becomes very complicated for environmental goods and services. The reasons for this complexity is rooted in, firstly, the nature of environmental services, that is the "public good" characteristics of those services which limits the ability of economists to determine their maximum level of exploitation in a standard (micro) economic analysis. The second limitation involves an old argument that nature is a gift of God, and as a result it is a priceless commodity. Thus, this argument suggests that the intrinsic values of environmentally sensitive areas including wetlands should not be expressed in monetary units. The third aspect is the passive view of some scientists, including environmentalists that "environmental services do not lend themselves to economic analysis" (Martin, 1985). The "common property" characteristic of most environmental resources concomitant with the aforementioned arguments have been collectively responsible for over-exploitation of environmental resources to the extent that some have been lost forever. During the past few decades most economists and planners viewed environmental services as external effects in their development models and this way sacrificed environmental quality for economic growth and development.

However, as most land use decisions are still primarily based on economic considerations, some economists along with environmentalists and land use planners are trying to adopt some methods for the valuation of environmental services. The most common techniques are based on the opportunity cost method. These methods include willingness to pay, travel-cost method, the preventive expenditures method, replacement-cost approach, the property value method, and finally the survey method. Obviously, each of these methods have certain advantages and/or disadvantages. As discussion on the merits and demerits of each method have already been presented elsewhere (e.g., Hufschmidt et al., 1983; Mitchell, 1986), they will not be repeated here.

4.5 Agricultural perspectives on drainage

Agricultural perspectives on drainage are usually those that are in favor of drainage improvements for increasing agricultural productivity. These views are shared by; (a) most farmers, particularly those in humid areas who invest in artificial drainage to increase their agricultural production and as a result their net income, and (b) regional and national agricultural lobbies that represent and protect farmers interests within society. Therefore, in this section the importance of drainage is examined from farmer's and societal point of view.

4.5.1 Farmer's point of view with respect to drainage

The farmer's common perception of drainage benefits can be portrayed in a schematic representation (Figure 4.3). This representation illustrates how drainage can influence farmer's income by changing the physical and biochemical factors that are involved in the complex soil-water-plant interrelationship. Figure 4.3, also indicates that there are some secondary economic benefits associated with farm drainage investments (van Vuuren and Jorjani, 1986). In general farmer's perspectives on agricultural drainage follows a basic economic principle that requires net revenues to be maximized. Hence farmers invest in agricultural drainage systems to increase their net benefits. Mathematically, this can be expressed as:

$$N_b = f(Y, P, C) \qquad 4.2$$

Since

$$Y = f(L, K, l, M, X_i, ..., X_n)e \qquad 4.3$$

Then

$$N_b = Y(P - C) \qquad 4.4$$

Where:

N_b=Net benefits (monetary unit/ha),

Y=Crop yield (kg/ha),

P=Price per unit of output (monetary unit/kg),

C=Costs of production per unit of output (monetary unit/kg),

L=Land (monetary unit/ha),

K=Capital (monetary unit/year),

l=Labor (man/hour),

M = Management skill variable that is expressed either as an index or a ratio,

X_i, ..., X_n = Variable inputs such as fertilizer, pesticides etc. (e.g., kg/ha),

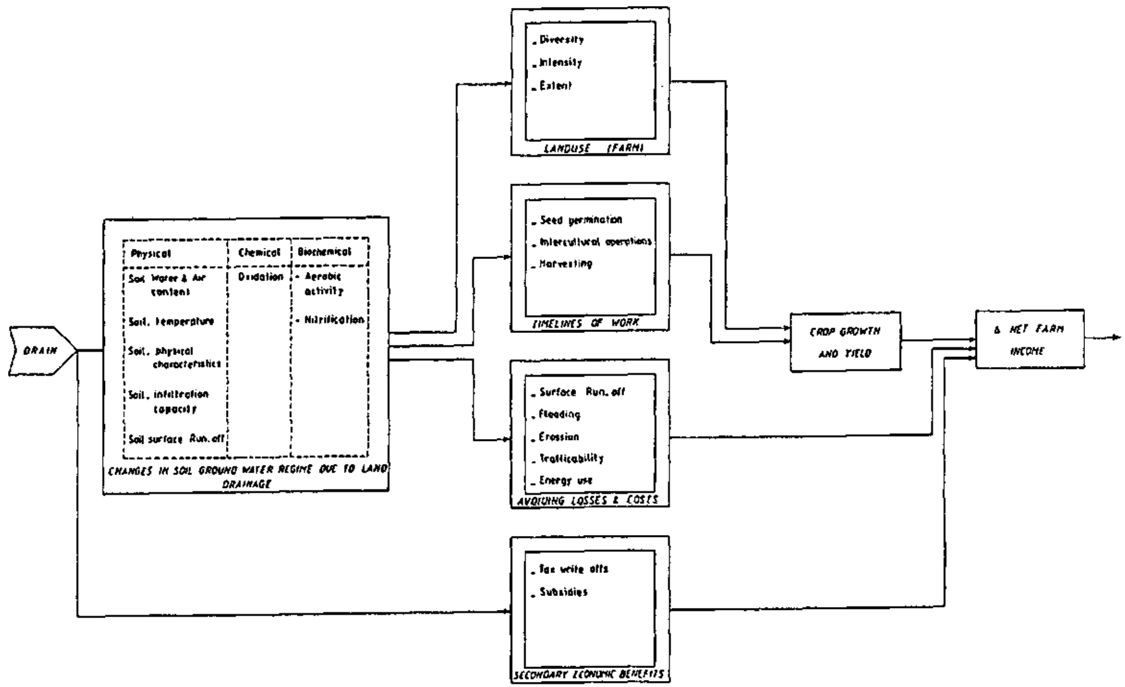
e = The error term.

Farmers can increase their net benefit by manipulating either **Y** or **C** of the above functional form. As discussed earlier, agricultural drainage is an input that can help increase farmer's benefits through its biophysical cause-effect structure.

4.5.2 Societal point of view with respect to drainage

The general societal objectives of drainage are directly related to societal goals at the time. For example, during the last few decades when agricultural and economic growth was the prime societal goal, most community or regional drainage programs were under taken with the aim to either (a) strive for food self-sufficiency (e.g., by increasing the area under cultivation) or (b) to maximize efficiency in terms of higher productivity (e.g., by reducing costs, and risks associated with poor drainage). Such societal goals are usually enacted by a democratically elected administration at the time and are carried through by appropriate government departments. For example, the Common Agricultural Policy (CAP) in Western Europe was a collective action by a number of democratically elected governments in order to increase agricultural productivity in their respective countries. Besides common agricultural policies sometimes a country may introduce regional agricultural programs that reflect those societal goals. As an example, nearly three decades ago, when societal goals were agricultural development and economic growth, Ontario attempted one such a program through a federal-provincial agreement. This program, known as Agricultural Rehabilitation and Development Administration (ARDA), was initiated in 1966 and continued till 1979.

Figure 4.3 CONTEXT OF DRAINAGE IN FARMERS' PERSPECTIVE



This federal-provincial program, which aimed at rehabilitation and development of the agricultural sector, comprised several components one of which dealt with agricultural drainage. Today, much of the development in Ontario's agro-food industry and its related services are attributable to the ARDA program.

In addition to the above-mentioned objectives and programs, sometimes society may have goals that are simply more than just agricultural development and economic efficiency. For example, correction of adverse income distribution may be the most important socio-economic priority in a society. In this case the criterion for optimality is generating benefits that will likely affect the lower-income groups of a community. Consequently, this objective receives a greater weight than generating benefits that might only affect the higher-income members of a society. The Eastern Ontario Development Program (also known as Eastern Ontario Subsidiary Agreement) was an example of such societal objectives. This program replaced the ARDA program in 1979 and was concluded in 1984. The program's mandate was to improve Eastern Ontario's economy by encouraging developments in urban and rural areas of the region where income levels were well below the provincial averages (Department of Regional Economic Expansion, 1980). This program allocated $14 million to the agricultural sector and, within that, $11 million was assigned for improvements of the drainage-system infrastructure in Eastern Ontario.

Another example is the case of Ijsselmeerpolders in the Netherlands where nearly 165 thousand hectare of land was gained from reclaiming an inland extension of the North Sea (Schultz and Verhoeven, 1987). The development of Ijsselmeer was initiated during periods of severe national economic and social hardship. Food shortages during WW I and the severe storm flood of 1916 made the Ijsselmeer development a national priority. In view of the difficulties that the Dutch society was expressing during periods of depression (the period between the two world wars), in 1918 the Zuiderzee Act was passed by parliament. The project objectives were mainly to increase protection against flooding, to improve water management and finally to enlarge the area of farmland (Schultz and Verhoeven, 1987). Indeed nearly 74 percent of the total land created in IJsselmeer has been allocated to agricultural production. Although the exact contributions of such societal objectives and public programs are rarely available, there is no doubt that they can influence the general state of the economy through a system of economic chain-effects (Eichner, 1985). From a broad macro-economic point of view, drainage programs, and the resulting increased agricultural productivity, can influence levels of national output, agricultural commodity prices, employment, international accounts surpluses or deficits, and government budget surpluses or deficits (through changes in tax revenue). The essential links between agricultural growth and national economic development have been elucidated by several development experts who have demonstrated how the increased flow of agricultural product is necessary to support other sectors of the economy and vis-e-versa (e.g., Johnston and Mellor, 1961; Jorgenson, 1961; Stevens and Jabara, 1988). There are several forces that produce intertemporal variations in regional and national economic states during and after implementation of regional drainage programs that have significant impacts on the time-stream of macro-economic benefits:

1. changes in employment and the number of workers choosing to relocate their families to communities near drainage projects;

2. changes in the rate of purchase of goods and services; and

3. variations in the rate at which the service sector adjusts to changes in basic human activities.

There are a number of frameworks, simple to more complex, that may be used for appraising the effects of regional development policies such as drainage programs at the macro-economic level (e.g., Hoffman and Jorgenson, 1978; Fitoussi, 1983; and Shoven and Whalley, 1984). It is possible to determine the effect of a drainage program on variables such as levels of national income, interest rates, prices and wages (McNertney, 1980).

4.6 Environmental perspectives

Environmental perspectives on drainage are those that are shared by environmentalists and naturalists who argue that since the inception of the post WW II recovery programs in North America, Western Europe, and Japan most valuable environmentally sensitive areas, especially wetlands have been modified. Consequently, by pointing out the ecological importance of these environmentally sensitive areas they try to discourage drainage activities there. However, most of these counter drainage activities are limited to industrialized countries where there is currently an over supply of most agricultural products. Drainage activities in non-industrialized countries are usually less controversial due to several reasons, the most important one being the exigency for achieving food self-sufficiency in those countries.

In order to provide a balanced view on the biophysical cause-effect structure of agricultural drainage and its impact, this section attempts to discuss ways of internalizing some of the externalities of agricultural drainage. The focus is on wetlands. In this process the objective is to highlight the income generating potential of these ecosystems that are said to be threatened by increased drainage activities. Identifying these income generating potentials would enable economists to develop, as far as possible, a more market oriented set of indicators for various services that these unique ecosystems can provide. These indicators can be used in land use decision analyses that involve drainage programs in industrialized as well as non-industrialized countries.

Currently, most land use planners and environmentalist are expeditiously trying to draw enough public attention so that a new pricing mechanism that will recognize environmental products or services as market commodities can be put in place (Blunden and Curry, 1988; Wilson, 1989; Crosson and Rosenberg; 1989).

Hence, similar to previous discussion on agricultural perspectives, in this section the environmental aspects are examined. However, before doing that a brief background discussion on wetlands may enhance the appreciation for this discussion.

Wetlands are formed in and on soils that impede water movement, and from which outflow does not take place as rapidly as inflow. Depending on particular ecological circumstances, wetlands can vary from a deep-water marsh, a spring-fed swamp forest, or an edge of a lake, to a simple pothole in an agricultural field. In the development of any kind of wetland, the presence of trapped water initiates and supports the formation of hydric soils and thereby dominance of either hydrophytic or water-tolerant plants. Some of Ontario's wetlands are unique ecosystems that support highly varied flora and fauna. Some are extremely important for feeding, nesting and resting of many rare species of migratory birds. Wetlands in Northwestern and Eastern Ontario provide some of the prime duck-producing areas of the North-American continent (Hammack et al. 1974).

According to IIED and WRI (1987) wetlands are among the most productive ecosystems in the world, producing greater net primary productivity per unit area than any other natural system except perhaps tropical rain forests and coral reefs. Net primary productivity is the amount of energy stored as organic matter less the cost of respiration required to produce it (Likens, 1975).

Besides being aesthetically pleasing, wetlands are an important component of the hydrologic cycle and water balance where they occur. Wetlands are natural filters that can be used to process waste water. Thus wetlands provide many scientific, recreational, and economic opportunities that unfortunately have not been fully recognized and measured. Due to inadequate knowledge and data, farmers and public planners have been unable to quantify many of the numerous benefits of wetlands. Consequently, unlike many other land uses, benefits of wetlands have often been diminished in private or public decision-making where wetland conservation is being weighed against competing uses. Agriculture is one of the major threats to wetland conservation, but wetlands may also be modified by such factors as changes in sewage-effluent discharges and growth of tourism. Let us now look at the major components of farmers' and societal perspectives on wetland conservation.

4.6.1 Farmer's point of view with respect to wetlands

Often, farmers are interested in the income-generating potential of a wetland. Consequently, to increase or prolong their income from wetland resources, they are willing to maintain the capacity of that resource if it can produce some marketable fauna- and flora- related goods and services over time. The income-generating potentials of wetlands can vary according to their specific types and features. For example, income-generating potentials of eutrophied kettle lakes that contain pulstrine and locustrien wetlands on upland areas may be quite different from lowland riverain wetland systems because of the specific type of flora and fauna that they support (Morrison 1979). Some wetlands, particularly those which are located close to open water, can provide excellent opportunities for sports (e.g. fishing, and hunting) and camping activities. Other wetlands are known for their capacity to serve as biological and chemical oxidation basins. Certain types of wetlands can perform significant hydrologic functions that include flood control, water storage, and storm protection. In Ontario, some wetlands store water during spring melt and seasonal storms, and gradually release the stored water into waterways. There are certain other benefits such as scenic vistas that can be derived through direct contact with a wetland. These benefits are sometimes referred to as non-consumptive uses of wetlands.

Whatever the type of wetland may be, farmers might consider the income generating potentials of such services. Hence, a farmer's perspective may be mathematically expressed as follows:

$N_b = g(V_w, P, C)$ 4.5

since

$V_w = k(R, P, H, E, S, I)$ 4.6

therefore

$N_b = (V_w * F) - C$ 4.7

where:

N_b = farmer's net benefit (monetary unit/ha),
V_w = value of the wetland (income-generating potential per ha),
R = recreational services (no. of permits/day),
P = pollution-abatement services (unit of volume/year),
H = flood-control services (unit of ha/year),
E = scientific and research services (no. of visits/day),
S = scenic vistas (no. of visits/day),
I = institutional benefits (no. of management agreement programs/year),
F = fees or prices (monetary unit/unit of services), and
C = total costs (monetary unit/per unit of services provided).

It must be noted that equation (4.6) is based on following assumptions: (a) these services are mutually exclusive, and (b) all these services occur in the farm and the farmer has a control over them.

Of course, the economic value (V_w) of a wetland depends on factors such as size of the wetland, and the specific characteristics of each service.

The above equations suggest how a farmer can increase his net benefit (N_b) by providing one or more wetland services for a given set of fees at any time. A farmer can also increase his net benefit by minimizing costs. However, beyond a certain minimization level, the quality of wetland services might be diminished, and the farmer may not be willing to manipulate his costs further. Instead, the farmer will try to maintain and prolong the availability of these services.

4.6.2 Societal point of view with respect to wetlands

Unlike those for drainage, societal perspectives on wetlands have been rather narrow. A survey in Ontario, designed to evaluate wetland values and land owners' attitudes, revealed that a majority of landowners had a limited awareness of wetland values (Kreutzwiser and Pietraszko, 1986). In responding to the question of wetland values, 40% of the surveyed farmers were unable to articulate any reason for supporting wetland values, and 42% were able to suggest only one wetland benefit related to wildlife or water resources. This apparently limited societal (i.e. the group of farmers surveyed) concern for wetlands is due to several reasons: (a) wetlands have traditionally been considered as obstacles to agricultural development; for a long time the notion of a wetland as a valuable renewable resource was ludicrous; and (b) for the last few decades, most economic decisions concerning wetland exploitation were made within an economic system where its members favored agricultural productivity more than environmental quality. Some of the agricultural policies of the EEC are known for this built in bias in favor of agricultural development (e.g., Black and Bowers, 1981; Turner et al, 1983; Bowers and Cheshire, 1983; Nature Conservancy Council, 1984; Bowers, 1985; Blunden and Curry, 1988). Besides these and the narrow development objectives of the post-war years that gave decision making a decidedly agricultural and industrial bias, the general public's unawareness of the income generating potentials of environmental services seemed to be partly responsible for this perspective on wetlands.

In response, some environmentalists (with the help of economists) have been trying to provide a bridge between the environmental and economic aspects of wetlands. Using economic principles such as opportunity cost and willingness to pay, the environmental values of wetlands can be translated into monetary units. It seems that this monetization has enabled society to begin to recognize the economic value and the expected performance of wetlands better. For instance in the U.K., a farmer was recently awarded a management-agreement contract of £300,000 annually for 27 years to refrain from draining 700 ha of marshland for agricultural uses. Although contracts of this size are rare, they can have a significant impact on a farmer's perspective on wetlands. Cooperative management programs for wetland conservation are becoming popular among Canadian farmers too. For the last few years, Wildlife Habitat Canada has approved a number of "Cooperative Habitat Projects" in different regions of Canada including Ontario. The main purpose of these cooperative projects are to protect and manage Canada's rare ecosystems (WHC, 1986). Some of these projects involve private landowners. In addition to these cooperative management programs, some Canadian farmers may very soon enjoy special economic incentives such as tax benefits and mortgage relief for habitat retention (WHC, 1986). Moreover, recently the World Bank and WWF and a few other international organizations are experimenting with a new idea that involves swaping debt for environmental management. Although the idea has worked in a few isolated cases where the management of rain forests have been accepted by international organizations instead of repayment of a loan by certain Latin American countries, it is definitely demonstrating that how tax payers of a third country may get involved in purchasing the option or bequest value of environmentally sensitive area elsewhere.

4.7 Summary

Agricultural drainage is an important soil-water management technique which is required for efficient agricultural production in both humid and arid regions in order to avert harmful effects of waterlogging and salinization. Agricultural drainage involves a complex process that in this thesis is referred to as the "biophysical cause-effect structure of drainage and its impacts". This process comprises several components that include (a) hydrological, (b) biological, (c) ecological, and finally (d) economic linkages. THe linkages are interrelated and their individual or collective impacts (different positive and negative impacts) are observed when the first linkage is set in motion.

To create a sufficient level of awareness of the extent and impact of agricultural drainage within the context of sustainable agricultural development, further investigations are urgently needed. These investigations must focus on the biophysical cause-effect structure of drainage and its impacts in the ecosystem.

Agricultural development can indeed take place without a detrimental (or at least minimum) effect on the environment. According to Davis (1987) the public must be aware of the fact that development and conservation have to go hand in hand within the framework of an integrated approach to environmental management. At this time of fundamental transition in technologies , climatic and societal goals, both farmers and public decision makers must be informed about the importance of sustainable agricultural development. What is needed is a holistic approach that accounts for hydrological, biological, ecological, and economic linkages of agricultural drainage with respect to temporal and spatial variations. This approach is imperative to the ability of private and public decision-makers in assessing positive and negative values of agricultural drainage relative to other land use options, particularly with respect to wetlands.

CHAPTER 5

THE FRAMEWORK

5.1 Introduction

The framework presented here is based on a systemic approach to the economics of subsurface drainage with a focus on sustainable development. According to Iakimets et al., (1987) a holistic approach to sustainable agricultural development is a process by which most effects that are currently regarded as externalities (e.g. environmental effects in economic models) become endogenized. This approach is viewed as an appropriate way to explain the interdependencies among basic natural resources such as wetlands and agricultural production. As described in the previous chapter, this systemic view is a theoretical concept that focuses on the biophysical cause-effect structure of subsurface drainage and its impacts from agricultural and environmental perspectives.

The basic premise of this new approach is based on two main issues:

1. In the past most economic frameworks for assessing economic benefits of agricultural drainage considered environmental aspects as external factors. Endogenization of these externalities is likely to be the most promising way to clarify the interdependencies among agricultural and environmental linkages of agricultural drainage. This is primarily due to the fact that this systemic approach will enable researchers, planners, and farmers to realize that cause-effect structure of drainage is a network of all possible costs and benefits at micro and macro levels. Hence drainage projects should only be under taken if the foregone benefits (in sustainable agricultural development we are ultimately concerned with society at large) of not draining an environmentally sensitive area are less than the forthcoming benefits of reclamation.

2. Due to the multifactor soil-water-plant and land utilization relationships involved in agricultural drainage it is incorrect to evaluate benefits of drainage from a single perspective. Therefore, by synthesizing the required technical information (soil, water, crop, and land utilization) a more reliable decision-making guideline can be developed.

Hence, the theoretical framework presented here is an illustrative model approximating complex processes of agricultural drainage in a holistic manner. This is achieved by adopting a System of Performance Indicators (SPI) which is designed to evaluate trade-offs between agricultural drainage and wetland conservation from farmer's (micro) and societal (macro) perspectives. The SPI was developed during the author's internship at IIASA where he worked with a number of scientists including environmentalists.

The SPI (Figures 5.1a and 5.1b) is a rather simplistic technique whereby the monetary equivalent of each indicator's performance can be estimated. In other words SPI attempts to express all effects of a drainage project in one unit. This will allow a relatively less complicated comparison of all costs and benefits of drainage from different perspectives. Furthermore, the SPI also takes into account the spatial and temporal characteristics of the process.

With regard to the choice of environmental indicators, their list is based on a review of several wetland functions and services that have been suggested in the literature. Moreover, most of these indicators are mutually exclusive. Although this aspect may help to minimize chances of double counting, it is no guarantee that it may not occur. In fact double counting is likely to occur when societal perspectives on wetlands are monetized. Further, wetland services are assumed to be occurring on farmer's property. It should also be noted that societal perspectives are simply an aggregate of micro level perspectives.

FIGURE 5.1a. A SET OF PERFORMANCE INDICATORS FOR EVALUATING THE EXPECTED PERFORMANCE OF AGRICULTURAL DRAINAGE PROGRAMS FROM FARMER'S PERSPECTIVES.

AGRICULTURAL INDICATORS

a) Physical production
b) Change in cropping pattern
c) Planting and harvesting
d) Cost avoidance benefits
e) Machinery use
f) Indirect economic benefits

ENVIRONMENTAL INDICATORS

a) Recreation
b) Waste assimilation and pollution abatement
c) Flood control
d) Research
e) Scenic vistas
f) Institutional benefits

FIGURE 5.1b. A SET OF PERFORMANCE INDICATORS FOR EVALUATING THE EXPECTED PERFORMANCE OF AGRICULTURAL DRAINAGE PROGRAMS FROM SOCIETAL PERSPECTIVES

AGRICULTURAL INDICATORS

a) Productivity and efficiency
b) Employment
c) Augmentation of land
d) Balance of payments

ENVIRONMENTAL INDICATORS

a) Biological
  - Biotic communities
  - Endangered species
  - Adsorption and assimilation

b) Hydrological
  - Water storage
  - Flood and storm control

c) Recreational
  - Wildlife
  - Sports

d) Heritage

5.2 Conceptual background

Decisions are choices among existing options and future potentials in the face of uncertainty. Decision-makers, implicitly or explicitly, evaluate the expected performance of a system of interest in response to at least two action alternatives, in terms of one or more factors or performance indicators (Figures 5.1a & 5.1b). Systematic analyses of decision problems on natural resources and environmental matters often seek to:

1. Expand the menu of feasible alternatives that decision-makers can consider (through creative option generation);

2. Expand the array of performance indicators available for use by decision-makers in their evaluations of alternative actions;

3. Define the performance indicators in quantitative terms that are meaningful to decision-makers and amenable to current (or developable), defensible projection techniques; and

4. Quantify the performance of each alternative in terms of each indicator in a manner that adequately addresses temporal and spatial variability.

Most decision problems on natural resources or environmental matters involve several conflicting interests. Single-individual decision-makers being advised by single analysts about personal decision questions represent fairly straight-forward (yet difficult enough) analyses; but when many parties are involved in trying to persuade the same system in different directions, the need for clever, applied systems analysis is paramount. An example of the latter is the conflict between farmers and agricultural agencies on one hand who promote broad-scale drainage of potential cropland, and naturalists and environmentalists on the other hand who argue for wetland preservation. From a broad societal perspective, there are cogent arguments both for and against both drainage and wetland conservation.

In terms of the framework sketched herein (Figure 5.1a & 5.1b), the nature of the conflicts over natural-resources development and environmental quality can be characterized as follows:

1. Not all parties evaluate alternatives using the same performance indicators for the system of interest, nor using the same variables representing those indicators. Indeed, the bounds and structure of the problem system among parties usually do not coincide. An effective analysis for conflict-resolution purposes should attempt to include the main factors of all interests in the problem at hand.
2. Not all parties are willing to explore system performance to any but single alternatives predetermined to be preferable. For example, an environmentalist is predetermined to accept an indicator that only reflects benefits of wetlands. An effective analysis for conflict-resolution purposes should examine at least the preferred alternative of each interest, but should also seek to create new options that perhaps occupy some form of middle ground and thus may satisfy most or all parties, or indeed that are improvements over all other alternatives for all parties.

These suggestions are not comprehensive solutions to all conflict-ridden natural resource and environmental problems. For example, the process of evaluation in decision-making requires implicit or explicit weighing of the indicators by which system response to action alternatives is gauged. This study does not deal with considerations of quantification of relative weights and the use of different (implicit) weights among conflicting parties. Neither does it deal with considerations of the processes whereby decision-makers are advised, interested parties are consulted or ignored, and decisions are made. The study simply attempts to provide a framework that (a) broadens the array of indicators that might be considered in drainage vs wetland-conservation decisions, (b) broadens the array of alternatives that might be considered, and (c) ensures that analyses of the merits and demerits of draining land for agricultural purposes provide system-response projections for all identified performance indicators for all identified alternatives. However, in applying this framework, the study attempts to quantify at least two agricultural indicators. A complete test of the framework was beyond the scope and resources of this thesis.

5.3 System performance indicators (SPI)

Alternative actions with regard to agricultural drainage need to be evaluated in terms of a range of biophysical, social, and economic indicators. These indicators must be able to reflect the complex biophysical cause-effect structure of agricultural drainage and its impacts from farmer's and societal perspectives. Within each perspective, there must be a set of indicators that correspond to agricultural and environmental aspects of drainage impacts. Figures 5.1a & 5.1b represent such a set of performance indicators that can be used for evaluating the expected performance of agricultural drainage from different points of view. As shown in Figures 5.1a and 5.1b each perspective includes a list of indicators that can express positive and/or negative impacts of agricultural drainage in a manner that is consistent with the biophysical cause-effect structure that was discussed in the previous chapter. The underlying assumption here is that all these indicators can be translated in a single monetary unit. In order to be able to quantify this set of performance indicators in monetary terms certain resources are required. These resources include input data and a framework. On the basis of a priori it is possible to formulate an appropriate framework. However, collecting all the needed input data, particularly the biophysical and socio-economic data requires sufficient resources.

With regard to some of the agricultural factors, particularly those from the farmers' perspective are readily quantified and easily monetized. This is mainly due to the fact that most needed input data are available or can be collected from farmers in certain regions. Furthermore, most agricultural indicators are measurable in market prices. On the other hand because a number of wetland conservation benefits (e.g., biophysical indicators) are not marketable in the conventional sense, other methods such as the opportunity cost, and the replacement cost may be used for monetizing them. However, most of these methods are not attractive from economic theory. But each of these methods may prove very useful as the first step toward estimating wetlands conservation benefits particularly when biological input data are limited or simply not available.

According to Lietch and Shabman (1988) from economics point of view wetlands are considered as a composite asset that through their ecological and hydrological functions provide a variety of services valued by people. Some resource economists believe that unless there is a structured way that includes several aspects such as property rights and the relative social costs and benefits of wetlands their correct valuation is not possible. Without wishing to accept or refute these arguments (which is beyond the scope of this thesis) the main purpose of this section is to develop a system of performance indicators whereby costs and benefits of ecological, biological, and hydrological functions of wetlands can be expressed in a common denominator that is money. Because of the global distribution and international importance of wetlands this method allows wetlands costs and benefits to be quantified uniformly. That means whether we use market prices in a market economy (e.g. willingness to pay) or shadow prices in a centrally planned economy, costs and benefits of wetlands will be expressed in monetary units. This aspect is extremely important when cross boundary wetlands of international importance are involved in land use conflicts.

Whether or not environmental indicators can be quantified and monetized, they should at least be discussed in qualitative terms so that researchers are encouraged to eventually develop a universal approach for quantifying conservation benefits.

Thus from a practical point of view the study focused on what was possible to measure within the scope of this research. Consequently, a framework was developed for quantifying two of the agricultural indicators from the farmers' point of view, namely changes in physical production (crop yield) and cropping pattern. However, in order to provide some background information (particularly for future studies and further analysis) about the remaining indicators, the study presents a theoretical discussion based on the available body of literature as to how some of these indicators may be quantified.

5.4 Farmers' perspective

Agricultural indicators

a) Physical production

Changes in physical production resulting from agricultural drainage can be estimated as the difference in total physical productivity (TPP) of two production functions (Jorjani, 1982). This change in physical production can be translated into monetary values using specific agricultural commodity prices.

A production function attempts to estimate the contribution of inputs to crop productivity. Because of complex multifactor soil-water-plant and land utilization (management) interrelationship involved in agricultural production, the functional form for calculating the crop yield due to drainage must include several variables. These variables can be summarized in three main categories; soil, climate, and management factors.

The soil factor includes some of the inherent characteristics or properties of a specific soil. The underlying assumption here is that drainage benefits will vary according to different soils. For example, drainage benefits are expected to be higher in areas where natural drainage is poor, than in regions where natural drainage is rapid. Furthermore, benefits may also vary with regard to different soil types. As discussed in the beginning of Chapter 4, the ability of water to move more freely in certain soils is due to natural characteristics of their parent material. That means whether or not the soil is permeable. For example, coarse-textured soils because of the large size of their particles (e.g. sands) allow a better water movement in the soil. On the other hand, fine-textured soils due to the small size of their particles (e.g. clays) restrict water movement in the soil profile. Despite this general rule, poor drainage may even occur on coarse-textured soils. This phenomenon occurs when: a) an impervious subsoil is situated under the soil layer, and b) the coarse-textured soil is situated in a low-lying or depressional topography. Therefore, it is very common that a soil, because of its texture is classified as well drained yet it suffers from poor drainage conditions (due to one of the above mentioned reasons) particularly during wet season. Drainage investment costs are usually lower on lighter soils than on heavier ones. Therefore, soil types can influence the stream of benefits that result from drainage investment. Soil types can be included either as an actual (e.g., percentage of clay content) or proxy values (e.g., index or dummy variables) that explain most of these soil properties.

Similarly, climate parameters can play an important role with regard to the need for artificial drainage. In humid regions, climatic changes are known to be responsible for crop yield reductions on soils with shallow ground water levels. Higher precipitation levels particularly during planting time can cause considerable yield losses due to either inability to plant seeds (owing to wet conditions of the field) or on account of poor seed germination. Little or no precipitation during the growing season may cause moisture stress on drained fields where ground water tables have artificially been lowered. Hence, in order to determine the impact of drainage on physical crop yield it is also imperative to determine the effect of climatic parameters on yield.

Management is also an important factor influencing yields due to agricultural drainage. For example, agricultural creates an ideal environment in the soil profile which allows intensive or diversified methods of farming.

However, the intensity or diversity of farming and the resulting change in physical yield are dependent upon skills and knowledge of the individual farmer.

Hence, the production function for measuring the changes in physical yield due to drainage will be based on the inferred plant-soil-water interrelationship and the knowledge of managerial skills of the farmer. Thus the most important factors that may influence yield are identified and their actual values or proxies will be substituted in the model. Some variables such as precipitation levels are based on observed behaviour of the stochastic nature of rainfall over a specific time period and in a specific unit such as mm/day. On the other hand some variables such as natural drainage classes of the soil and soil type can be expressed as either a continuous value (e.g. a pre-calculated soil profitability index) or as a discrete value (e.g., dummy variable). A dummy variable is a parameter that indicates a subjective value (e.g., drained and undrained; clay or sand etc.) and is incorporated in the model so as to obtain different intercepts. These intercepts distinguish between different conditions that dummies are set to measure.

The production function can be specified according to the desired level of accuracy and the availability of data. For example, whether or not a model will have a specific form such as linear or quadratic. Thus, depending on the specific conditions of a project at hand and the a priori a production function can be formulated. Two production functions will then statistically estimate the combined effect of the factors included in the model on crop yield, one with, and the other without artificial drainage. Incorporating parameters such as soil properties and climatic changes in the model allows a prediction of incremental crop yield due to agricultural drainage over a wider range of spatial (various locations and soil types) and temporal (short or long-term) variations.

For the theoretical discussion of the approach suggested in this section a simplistic general model is presented. Mathematically this model can be expressed as:

$$Y_d = f(S, D, P, M) + e \qquad 5.1$$

Where:

Y=crop yield (kg/ha), S=soil type expressed as a dummy (i.e. if soil=clay then $S=1$, else $S=0$), D=soil natural drainage as a dummy (i.e. if D=poorly drained then $D=1$, else $D=0$), P=precipitation (mm/day or month), M=managerial skill parameter (expressed as an index or dummy variable), e=error term, and the subscript $_d$ denotes drainage code. That is, if $d=1$ then Y=drained, and if $d=0$ then Y=undrained.

Thus the incremental crop yield on account of drainage can be calculated as:

$$I = Y_1 - Y_2 \qquad 5.2$$

Using market prices this incremental crop yield can be translated into monetary units.

Therefore:

$$B_N = I * P_Y - E \qquad 5.3$$

Where:

I=incremental crop yield on account of drainage (kg/ha), B_N =net benefits (monetary unit/ha), P_Y =output price (monetary unit/kg), E=costs associated with the additional yield including trucking, insurance (monetary unit/kg) and also the annual maintenance cost of the artificial drainage system (s/ha/year). Fixed costs that are common on both drained and undrained land are not taken into account. Drainage investment cost will be included in the economic analysis where by using Internal Rate of Return (IRR) method the viability of the investment is determined. IRR is defined as that discount rate which makes the net present value of the investment equal to zero. Mathematically it is expressed as:

$$I_0 = \Sigma B_N/(1+i)^t \qquad 5.4$$

Where:

I_0=initial investment cost \$/ha, B_N =average annual net benefit per hectare, i=internal rate of return (IRR), T=time span during which the investment lasts.

The final decision on the viability of drainage investment is made by comparing the calculated IRR with the prevailing interest rate (r) in the market. If IRR $>r$ then investment is economically viable. If Irr $<r$ then drainage investment is not profitable.

An schematic presentation of the entire procedure for calculating the economic value agricultural drainage is given in Figure 5.2.

b) Change in cropping patterns

Essentially, any change in cropping pattern (e.g., from low to high value crops) will have a significant impact on a farmer's income. This change in income can be estimated through market prices, using conventional accounting procedures. These accounting procedures involve computations of average annual revenues for both low and high value crops, comparison of these revenues in order to obtain the difference (i.e. net revenue), and finally using the calculated net revenues for assessing the viability of drainage investment with respect to a change in cropping pattern. Mathematically, the average annual net revenue can be expressed as follows:

$$N_R=[Y_nP_n - i_n]-[Y_oP_o - i_o] \qquad 5.5$$

Where:

N_R=average annual net revenue (monetary unit/ha), Y_n=total yield of the new crop (kg/ha), P_n=average price of the new crop (monetary unit/kg), and i_n=production cost of the new crop (monetary unit/ha) excluding the cost of land. Drainage costs are incorporated in the calculation of revenues and costs of the new crop in the same manner that was illustrated in section (a).

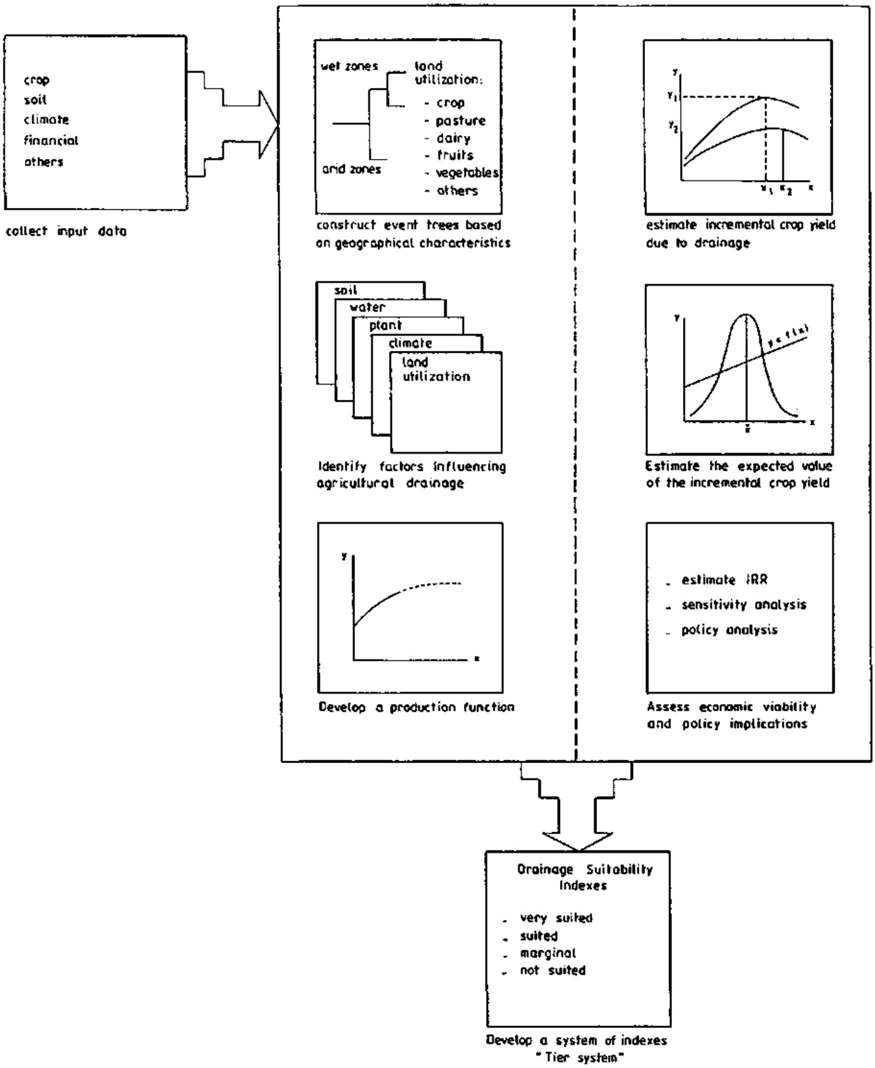


Figure 5.2 A schematic presentation of a framework to assess the economic value of agricultural drainage under different agroclimatic and soil conditions

Similarly Y_o, P_o, and i_o are total yield of the old crop (kg/ha), average price of the old crop (monetary unit/kg), and production cost of the old crop (monetary unit/kg) respectively.

The procedure for analyzing the economic viability of drainage investment for a change in cropping pattern will be the same as the method adopted for the economic analysis of changes in physical yield (section a).

c) Planting and harvesting

In temperate zones where the growing season is shorter and as a result working days are limited, a crop's success or failure depends largely on the timeliness of farm operations. Delays in seedbed preparation, planting, fertilizing, and ultimately harvesting can influence the total physical production and consequently farmer's income. Van Die et al.,(1977) reported that in southern Ontario corn yields decrease at the rate of one bushel per day if planting is delayed after May 10. Therefore, by using changes in the physical yield, one can monetize the impact of agricultural drainage on timeliness of farm operations.

d) Cost avoidance benefits

Agricultural drainage has several indirect benefits that are associated with avoidance of certain costs. For example, there are costs associated with the loss of top soil (e.g. loss of seeds, fertilizers, and chemical agents) due to surface runoff, caused by poor natural drainage conditions of the soil. These costs are usually measured either in terms of additional cost of inputs or reductions in crop yields. In either case, market prices are used to quantify these costs. For example, Clark (1985) noted that costs associated with cropland erosion in the U.S. are estimated to be between 1.1 to 1.3 billion U.S. dollars annually. Estimates of these expenses in Ontario can be obtained from County

Agricultural Representatives and individual farmers. In the Netherlands, Schouten et al. (1985) has provided an inventory of the occurrence of water-caused erosion in South-Limburg and its economic impacts.

e) Machinery use

Farming in humid regions, particularly areas that are characterized by heavier soils, necessitates the use of powerful and consequently expensive farm machinery. Under these conditions drainage can reduce specific machinery costs by providing a better trafficability and/or traction on the farmland. Using conventional market prices, the impact of agricultural drainage on machinery costs and farmer's total cost can be estimated.

f) indirect economic benefits

Indirect benefits are known to be quite substantial for some farmers. Some of these benefits accrue as additional income due to tax write-offs and have already been estimated for different farm-income brackets in Canada (Van Vuuren and Jorjani, 1986).

Environmental indicators

Some scientists bemoan the deficiencies of attempts to value environmental resources (Kellert, 1984). However, with recent advances in environmental research technology and the increasing public awareness of environmental services, new methods are being tested for evaluating economic value of environmental resources have been overcome. In some recent studies (e.g. Walsh et al., 1984 and 1985; Roy, 1986; van Vuuren and Roy, 1989), the recreational value of natural habitats including wetlands has been measured using the willingness-to-pay method.

The contingent valuation method (CVM) is another technique frequently used in environmental studies. If CVM is designed properly, it can be used as an effective tool to estimate economic value of a particular environmental resource. However, too often these survey methods are subject to several biases including hypothetical, strategic, and information biases (Loomis and Walsh, 1986). For this reason a modified contingent value method (MCVM) with the following characteristics is suggested here: (a) systematic design to cover several interdisciplinary aspects of wetland conservation, (b) questions would be motivation- oriented so that it is known why respondents value certain benefits of wetlands more than others, and (c) utility orientation; that is, how much a respondent is willing to pay for those identified goods and services. To remove some of these biases, what is needed is a multidisciplinary questionnaire that is sent to a representative sample in society. Questionnaires must be prepared by a group of scientists (including social scientist who know questionnaire methodology) and field workers who are familiar with hydrological, biological, ecological, and economic aspects of agricultural drainage and wetland conservation. If MCVM is successful it can be repeated at least for 10 years. Such a long-term survey creates a pooled time-series and cross-section data base which will clearly indicate special preference of different members of society, and moreover, it will also uncover shifts (if any) in societal perspectives concerning wetlands and nature conservation.

Adjusted Avoided Replacement Cost (ARC) is an alternative method to quantify minimal values of wetlands in the absence of the required biological input data. ARC is a method that is based on the concept of preventive expenditures method. Mathematically it can be expressed as:

$$B_k = [\, Y_i - (\, R_j + L_n)] \qquad 5.6$$

subject to $Y_i > R_j$

$$R = u(F_C + V_C) \qquad 5.7$$

$$L = q(C^1_R + C^2_R) \qquad 5.8$$

where:

NB_k= net benefit of the Kth wetland in a region (monetary unit/ha),

Y_i= the i^{th} income generating potential of a wetland (monetary unit/ha),

R_j= the j^{th} cost of replacement (reconstruction) of a wetland (monetary unit/ha),

L_n= the n^{th} cost of restocking a wetland (monetary unit/ha),

F_C and V_C= Fixed and variable cost of physical replacement (reconstruction) of a wetland (monetary unit/ha),

C^1_R and C^2_R= costs of restocking fauna and flora population of a wetland (monetary unit/unit, e.g., per unit of live fish, plant, birds etc.)

The following is a list of some possible environmental income-generating indicators and methods used to monetize these indicators. Here the assumption is that most of these services occur on a private property or an area that belongs to the government. Although government owned land is considered as a public property, the government can utilize land resources according to the profit motive in a sustainable manner. Furthermore, as unorthodox as it may seem, the thrust of the following section is to provide a list of some of the, often unfamiliar, wetland services and a qualitative discussion as to how they may be monetized. This is a timely approach to draw some attention to the environmental cause-effect structure of agricultural drainage and its impacts with regard to wetland conservation. However, it must be noted that since the purpose of this qualitative discussion is to list all environmental indicators some double counting may occur. Therefore, in practice this must be avoided so as not to exaggerate environmental weights of a project.

a) Recreation

The fees that consumers are willing to pay for specific recreational goods and services are determined through the market, for example, a fee could be levied for angling in a farm wetland. The concept of willingness to pay has been used by several researchers to estimate the economic value of recreational services of wetlands in Ontario (e.g., Roy, 1986).

b) Waste assimilation and pollution abatement

Waste-assimilation and pollution-abatement services are either used by the farm itself or by other parties. To monetize these benefits, in the former case one can utilize the principle of opportunity cost and calculate the monetary benefits. In the latter case, since these services are provided for a fee that reflects willingness to pay, market prices can be used for calculating benefits.

c) Flood control

The previous argument holds for flood control as well. If a farmer is the consumer of these services, the cost of the next best alternative (in this case a flood-control structure for damage avoidance in the farm) can be used for estimating the monetary value of such services. Similarly, if it is another party, the party's willingness to pay can be used to monetize the value of flood-control services.

d) Research

Scientific and educational services can be provided for a fee which is determined through either the medium of market or shadow prices. Shadow prices in this case imply the cost of a similar research facility (e.g. a simulated wetland in the laboratory). In either case, it is possible to translate these services into monetary terms.

e) Scenic vistas

Viewing scenery is a non-consumptive use which is generally measured in monetary terms either through market prices (i.e., the availability of and demand for scenic-viewing opportunities in a region) or consumer's willingness to pay. These services are becoming increasingly popular particularly in areas where migratory waterfowl can be viewed from specially designed observatory posts. Some of these places are part of a national park where an entrance fee is charged for every visit. In either case, the cumulative monetary value of these services can easily be quantified.

f) Institutional benefits

Institutional benefits are predetermined financial compensation paid by either public or private agencies to farmers. Most of these benefits are already in monetary units.

In addition to income generating environmental indicators there are some non-income generating indicators, too. Non-income generating benefits are usually expressed either as existence value (e.g., the benefits from simply knowing that a habitat exists) or as option values (i.e., the assurance of future uses). Both of these values can be quantified in terms of willingness to pay.

5.5 Societal perspectives

Agricultural indicators

a) Productivity and economic efficiency

Productivity and efficiency benefits can be measured in terms of value added or Gross Domestic Product (GDP). For this calculation one may assume GDP to consist of net farm income before depreciation, interest payments, wages, and rent payments. GDP measures how much greater the value of the farm output is than the value of purchased variable inputs.

b) Employment

i. Primary employment

The impact of land-use actions on primary employment (including both temporary and permanent) can be measured in terms of the cumulative number of employees and/or the wages earned. It is important to note that the impact of a land use project on the employment situation of a region depends on several factors such as the current employment market situation as well as where the project is located. Statistics on the number and the wages of these groups are readily available.

ii. Secondary employment

To quantify secondary benefits, detailed empirical research is needed. The required additional research should first extricate the impact of a land-use action in a region from other variables that effect employment at various levels, and, second, identify additional manpower required to handle the increased productivity or diversity on account of that land-use action.

c) Augmentation of land

If the objective of a drainage and reclamation project is only to create additional land for agricultural and non-agricultural uses then market prices of land and its potential to produce goods and services, can be used for translating the impact of agricultural drainage on this indicator into monetary terms. However, in monetizing this indicator double counting must be avoided.

d) Balance of payments

The impact of different land-use actions on a country's balance of payments can also be measured in terms of import replacement, i.e., the amount that would have been spent on imports had certain actions not taken place. In addition to import replacement, export earnings resulting from those actions are also considered as direct economic consequences. Whether import replacement or export earning, both values are already expressed in monetary terms. However, if these have already been added to output value, then they should not be counted again.

Environmental indicators

As described in section 5.1 societal perspectives on wetlands are the aggregate values of all the individual perspectives. These aggregate values can be grouped as follows:

a) Biological indicators

Biotic communities Due to serious gaps in knowledge concerning values of flora and fauna, it is very difficult to monetize the value of most biotic communities. However, using the concept of willingness to pay, one can determine the option and existence value of certain biotic communities that are affected by land-use-related actions.

Endangered species To determine a monetary value of endangered species, some analysts have used the option- and existence-value methods. Although these methods do not reflect the true value of rare flora and fauna, their use as common economic indicators has become popular.

Adsorption and assimilation The monetization of this function is relatively easy because of the availability of input data concerning the next best alternative, that is, a sewage treatment plant. Using the opportunity-cost method, the monetary value of this function can be estimated.

b) Hydrological indicators

Water storage The opportunity-cost (or replacement-cost) method can also be applied here for estimating the monetary values of this function. As discussed earlier, the monetary value of the water-supply function of a wetland can be expressed as the cost of providing water from the next best source. Using this method, water-storage values (when actually measured for each wetland) can be translated into monetary units. For example, if a wetland in Eastern Ontario can supply **V** litters of water per day at a cost of **C** per unit, these values can be compared with those of the next best source (well), the cost of which might be greater than **C**.

Flood and Storm control The flood-control capacity of a wetland depends largely on its structure and water-holding capacity. One of the few methods developed for estimating the monetary value of this wetland function is the wind-damage distance-decay function suggested by Farber (1987). However, since flood- and storm-control functions can also be provided by flood-control structures, the replacement-cost concept can be applied to monetize this natural function. This estimation procedure would involve some capital budgeting.

c) Recreational

Wildlife The recreational value of wildlife can be monetized using the concept of willingness to pay (Roy, 1986).

Sports Valuation procedures for sport functions of wetlands include the concepts of willingness to pay (e.g. for fishing or canoeing) or the opportunity cost. In either case, some capital budgeting will be required.

d) Heritage indicators

The heritage aspects of natural resources, described here as aesthetic, conservation, and vicarious values, are very complex and difficult to monetize mainly because every individual's perception of these values is unique. However, since society can be seen as comprised of groups of individuals, their cumulative perception can represent the societal scale of heritage values.

There are procedures and methods to quantify the societal perception of heritage values of natural resources such as wetlands. The willingness of a society to pay for the option and existence of such resources (in the form of direct and indirect monetary contributions) is indeed the best measure of their monetary value. However, these may not necessarily be a true representation of the actual societal perception of such resources. To determine these values better, more detailed and comprehensive approaches are needed. Although some authors (e.g., Kellert, 1984) bemoan the deficiencies of attempts to value such resources, with recent advances some inadequacies in valuing environmental resources have been overcome. In recent studies by Walsh et al. (1984; 1985), the values of wilderness and wild and scenic rivers were measured using the willingness-to-pay method. The contingent-valuation method is another technique commonly used in environmental studies.

5.6 spatial and temporal characteristics of the framework

The underlying economic assumption for this framework is that a drainage improvement or wetland conservation is socially desirable if by the improvement/conservation everyone can be made better off or at least some are made better off while no one is made worse off. For example, the Management Agreement Program in the Netherlands is drawn up with the purpose of achieving a balance between the interest of agriculture and nature and landscape conservation in environmentally sensitive areas (Ministry of Agriculture and Fisheries, 1987).

The decision for adopting choices concerning drainage improvements/conservation is based on a simple micro-economic concept that requires the expected benefits of the activity (to drain or not to drain) to be greater than its expected costs (Figure 5.3). As shown in simplified and general form in Figure 5.3, each investment alternative involves streams of costs and benefits over time. The benefit stream is $\mathbf{B_t}$ and the cost stream $\mathbf{C_t}$. The difference between benefits and costs is the net benefit stream $\mathbf{NB_t}$ which is frequently negative in the initial stages of a project. This is primarily due to the fact that most of the capital expenditure takes place at that time.

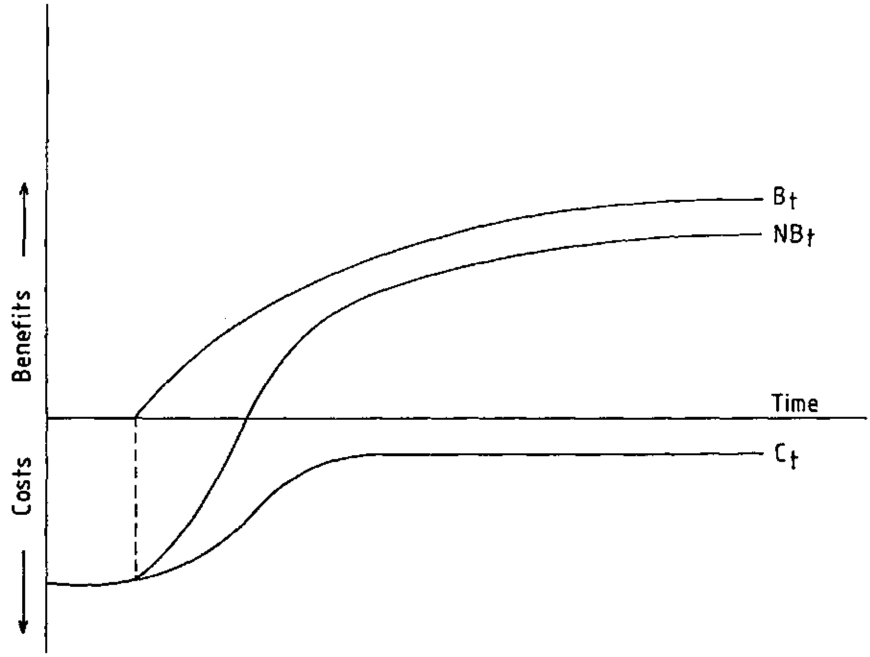


Figure 5.3 Costs and benefits of drainage.
Source : Hufschmidt et al. 1983.

Thus the biophysical effects of drainage and its further impacts can be expressed in terms of indicators that are weighted by implicit (e.g. shadow prices) or explicit (e.g. market prices) monetary values. These weights can then be amalgamated into two economic measures: cost and benefits. However, these measures can be influenced by variations due to geographic characteristics of an area (spatial), and changes on account of time preference or sustainability (temporal). Consider the shape of curves presented in Figure 5.3, for every individual in various locations and periods of time. Thus, the spatial and temporal factors will have a substantial influence on the monetary value of indicators discussed in this report. Within the context of this framework these two characteristics can be elaborated as follows.

5.6.1 Spatial considerations

Agricultural characteristics of each region are unique due to variability in agroclimatic and soil conditions. So, each region can only support specific crops and types of tillage. Therefore, potential benefits of drainage improvements will be different in each region due to spatial variability. For example benefits of drainage improvements in the low-lying clay areas of Southwestern Ontario, (e.g. Kent, Essex, and Lambton counties) would be very much different from those in grasslands of Eastern Ontario where the soil is inherently poorly drained. In the case of low-lying clay areas, drainage improvement will reduce surface runoff and soil erosion, and hence reduce loading of non-point sources of pollution in the Great Lakes. In the case of grasslands, drainage improvements would allow a shift in cropping pattern (i.e., a change from pasture and hay to corn or other cash crops). There is also an interaction between drainage improvements and tillage practices. Conservation-tillage practices on fields with better drainage are known to improve crop yields (Bryant et al., 1987).

By the same token, as demonstrated in previous examples, each wetland would have a different income-generating and conservation potential. Similarly, the importance of a wetland must be examined with respect to geographic variations and its potential functions. For example a large swamp in Bruce county (Greenock Swamp, nearly 7,300 ha), has several functions such as secondary sewage treatment, source of water, and natural habitat for several species of waterfowl and mammals. On the other hand, a small pothole on a private property in Eastern Ontario may have only quite limited functions such as simply a seasonal source of drinking water for the farm cattle. These variations could be more pronounced if we compare wetlands of Southwestern Ontario with those in Manitoba.

5.6.2 Temporal consideration

Temporal variability with respect to agricultural perspectives of drainage improvements is much easier to measure. Jorjani (1982) examined the temporal aspect of drainage by using a long-term climatic data set for estimating benefits of drainage over 50 years. However, in the case of environmental perspectives this aspect is more difficult to measure because of the virtual absence of biological input data (particulary over time) in some areas. In some countries biological aspects of natural environments such as wetlands are not monitored at all. However, with the knowledge gathered from certain areas it is possible to simulate and predict the temporal impact of certain actions such as lowering groundwater levels in an area.

5.7 The interaction between spatial and temporal considerations and levels of planning

The inferences concerning the biophysical cause-effect structure of drainage and its impacts are not only affected by factors such as spatial and temporal variability but can also be influenced by different levels of project planning. Hence, it is important to remember that the spatial and temporal characteristics of the framework could vary when different levels of planning are taken into consideration. With respect to agricultural drainage and wetland conservation there are at least three levels of decision-making that should be examined in terms of spatial and temporal variability.

5.7.1 The private level

The private level of planning involves a few basic indicators, and because it is limited to a specific, limited geographic area (e.g. a single farm), it involves the temporal aspect alone. Projects at this level usually include activities that might concern a pothole, a wooded wetland, and a wet spot on a private property. Effects of any activity at this scale are usually very localized, and their costs and benefits are more likely to be viewed from the landowner's perspective. For example, if the landowner decides to reclaim the pothole or wooded wetland in his property for agricultural uses, he will only consider the immediate benefits of his action within the next 20-40 years. In determining these immediate benefits the individual may apply a method similar to the one described above in Section 5.4 and quantify returns on his investment over the economic life time of the project.

By the same token, the environmental impact of his action will also be somewhat localized (although in some cases it may extend beyond the boundary of his farm), depending on the nature (i.e. seasonal or permanent) and size of the wetland and his farm. As an example, if the only benefit of that wetland is a seasonal source of drinking water for his cattle during the summer period, then that would be the only cost or foregone benefit of reclaiming those wetlands from that farmer's point of view. Consequently the farmer might be willing to consider the foregone benefits of that service as an additional cost, besides the installation and maintenance cost of drainage. However, it must be noted that the foregone benefits of this service will vary with respect to the geographic location of the farm. A seasonal source of drinking water for the farm cattle during the summer period is economically much more valuable in the Canadian prairies than in the watershed plains of Southwestern Ontario.

Thus, at this level of decision-making the decision and its impacts are perceived to be localized and are primarily influenced by the owner. In a market-oriented economy, the owner is the sovereign decision maker of the enterprise and consequently is only willing to maximize his own welfare.

5.7.2 The regional level

Planning at the regional level involves the examination and measurement of several interrelated indicators on a large scale from both spatial and temporal points of view. At this level decisions are to be made about one or several projects with associated programs that are to be undertaken over a large geographic area and a period of several years. Examples are numerous; for instance currently in Ontario, there is a regional project called the Soil and Water Environmental Enhancement Program (SWEEP) that has been specifically designed to service a large region in Ontario. The SWEEP's general objectives are: to reduce phosphorus loading of Lake Erie, and to protect agricultural productivity in Southwestern Ontario by minimizing the harmful effect of soil erosion and degradation. This region is an important watershed which is being adversely effected by urban and agricultural uses that involve a significant amount of urban-industrial wastes and agricultural chemicals. Overland flow, surface runoff and intensive agricultural activities have been recognized as responsible for the greatest amounts of non-point-source pollution, particularly phosphorus loads in this region. Given the nature of this problem, which is related to water-caused soil erosion from agricultural fields, an improved on-farm drainage system may reduce phosphorus loading while improving agricultural productivity at the same time. Decisions concerning this choice (i.e. improving on-farm drainage efficiency), would require a detailed analysis of the biophysical effects of drainage in the context of the SWEEP.

To carry out this analysis using the framework presented in this paper, one has to gather adequate climatic, biological, agricultural, and financial records to be able to examine both agricultural and environmental perspectives.

In doing so, first the study area (i.e. Southwestern Ontario) would be divided into several farms or geographic locations. In other words, a geographic grid is formed, and homogeneous blocks with similar geographic characteristics are grouped together. The grid can be based on a number of criteria, for example soil type, natural soil-drainage characteristics, and soil topography. If data on all or some of these criteria are collected from regional soil maps, then the scale of the grid must comply with that of the soil map. Forming these grids would facilitate a systematic micro-analysis similar to the one discussed earlier. This way, all the costs and benefits of improved on-farm drainage can be estimated from different individuals' points of view. Since not all the individual farms or blocks of the geographic grid are identical, there will be several profit and cost curves with different shapes. Given the plummeting cost of commodity prices and increasing cost of drainage investments, it may happen that in some cases the basic micro-economic concept discussed earlier may not hold. This means that because the cost of drainage investment would be higher than its revenue over 20 to 40 years, which is the economic life time of the drainage system, most farmers would be reluctant to adopt drainage as a conservation practice. Since this may not be an optimal solution from a societal point of view, the second phase of such an analysis will focus on those cost and benefit curves collectively. This means we would concentrate on all the macro, on-site, and off-site use values that include the intrinsic, interpersonal, and intergenerational environmental aspects of on-farm drainage as a conservation practice for reducing surface runoff, soil erosion, and non-point pollution in this particular case. Thus one would try to maximize societal benefits collectively and in a manner whereby no one is worse off (through compensation programs currently in use in Netherlands and a few other West European countries) over a long period of time as long as societal goals remain unchanged. Currently, societal goals dictate that the environment must be protected for its long- term benefits. This goal indicates that society is willing to subsidize some of the farmers of a region who would otherwise be economically unable to invest in drainage as a conservation practice as an individual investor. Hence, the spatial and temporal aspects of regional plans require a two-tier approach for the economic evaluation of a drainage proposal. In this process, the collective impacts of human action are systematically evaluated from the lower level (micro), and then are amalgamated into an integrated (macro) level which would attempt to maximize societal welfare over a long period of time. This way, every indicator is evaluated from a societal perspective and not only from individual decision-makers points of view. Consequently, some of the factors that have a profound impact on these indicators, such as temporal variability, will be analyzed over a longer period of time.

5.7.3 The national level

Planning at the national level involves decisions on the part of one or several mission-oriented ministries at the national or interprovincial levels, where national objectives are formulated and implemented at the regional, provincial, and private levels. Similar to the regional planning level, national plans also consist of a set of separate programs or projects that are distributed geographically over the nation or province and scheduled for undertaking over a long period. National projects require the aggregation of knowledge of agricultural and environmental indicators. Thus, in valuating these indicators a wider geographic variation and a long-term time preference or project life- time are taken into consideration and aggregated accordingly. As an example, a massive reclamation program such as the Isselmeerpolders project in the Netherlands involves several national and provincial authorities which may have different mandates but follow one national objective, that is, augmentation of the land base for increased economic growth and efficiency. In other words, the principal ministries will try to maximize overall societal welfare by aggregating all the cost and benefit curves so that no individual is worse off. Notwithstanding this level of decision-making being quite broad, it sometimes has a built-in bias (i.e. the concept of a sovereign decision-maker) that may not necessarily maximize societal welfare at the global level. For example, if the Brazilian government decides to reclaim a large part of its tropical rain forest for agricultural purposes, to boost agricultural productivity, it may be a maximizing decision from the national point of view, but it would be an environmental disaster from global perspectives. For this reason, whenever the spatial and temporal effects of these types of projects tend to go beyond the political boundaries of the decision-maker, some international agencies or even interest groups desire to intervene to avoid certain global environmental disasters.

5.8. Summary

Every society, particularly those with limited or less suitable land base, are faced with the basic problem of allocating limited land resources to many different uses. These different land uses are by no means the ultimate objective, rather they are the means by which a society can govern its land resources in the pursuit of more fundamental objectives such as overall growth and development.

Economically allocating land resources to one sector obviously, reduces the availability of land resources for use in other sectors. But in some instances pursuit of one objective (e.g., food self sufficiency) may involve sacrifice in other objectives (nature conservation).

Hence, there are trade-offs between various uses of land. A decision has therefore to be made as to how land resources are to be allocated to sometimes competing uses without compromising the overall societal goal which is in most case long-term economic growth and development. Therefore, studies on the socio-economic aspects of land use systems are absolutely essential to help members of a society better understand the trade-offs among different land uses. Currently, this is becoming increasingly important because of the new focus on "sustainable development" .

Results of these studies can provide decision-makers with necessary input data that are required for development of new or modified guidelines for land use. The framework presented in this chapter is a holistic approach and especially designed to address land use decisions involving agricultural drainage from farmers and societal perspectives. It is a holistic approach because it endogenizes environmental aspects that were previously left out in most economic studies of agricultural drainage. What the framework offers is a System of Performance Indicators (SPI) that includes both agricultural and environmental indicators of the biophysical cause-effect structure of agricultural drainage and its impacts. The SPI is designed to evaluate trade-offs between agricultural drainage and wetland conservation from farmers' and societal perspectives in one single unit, that is money. This unisectoral approach allows farmers and land use planners to express all the indicators in a single denominator and consequently quantify costs and benefits without scaling or measurement biases. In testing the SPI, there are no major difficulties in monetizing most agricultural indicators. However, the difficulty arises when environmental indicators have to be monetized. Most environmental indicators are not amenable to quantification by the conventional market systems. Hence, testing the entire SPI may require additional resources for collecting biological data pertaining to environmental indicators. Nevertheless, the thrust of this chapter is that whether or not environmental indicators can be quantified and monetized, they should at least be discussed in qualitative terms. This would allow farmers, scholars, and public planners to at least recognize the entire cause-effect structure and its indicators.

CHAPTER 6

CASE STUDIES

6.1 Introduction

In an attempt to test the theoretical framework presented in chapter 5, several issues such availability of data, financial costs of a comprehensive analysis, and the time constraint of the Ph.D. program were taken into consideration. With regard to availability of input data, contacts with Rijksdienst voor de IJsselmeerpolders (RIJP) in the Netherlands, and Ontario Ministry of Agriculture and Food (OMAF) in Canada revealed that some agricultural input data pertaining to crop productivity on account of on-farm subsurface drainage improvements could be obtained. In the Netherlands the RIJP authorized the use of an experimental data set that was based on drainage experiments with apple trees on marine clay soils which are the predominant soil in most fruit growing areas of the Netherlands. In Canada, OMAF provided farm records representing corn yields on subsurface drained and undrained fields in eastern Ontario.

In relation to the environmental component of the framework a wetland of provincial importance in Ontario was considered as a possible site for collecting relevant environmental data (Jorjani and Duinker, 1989). However, due to lack of funds and time limits of the Ph.D. program, it was realized that the environmental component of the framework could not be tested within this thesis. Moreover, due to the prohibitive cost of collecting macro economic input data societal perspectives of the framework could not be tested either. To test the entire framework more resources are required.

Hence, in view of these considerations the case studies focussed on an empirical analysis that incorporated two components of the framework which involve farmers' perspectives on agricultural drainage (i.e. boxes 1-7, 16, and 8 of figure 4.2). These included: a) changes in physical production, and b) changes in cropping pattern due to subsurface drainage. Details about these analyses and their findings are given in the subsequent chapters. However, in order to enhance the appreciation of these case studies and their significance, the present chapter is designed to provide a brief description of each site from where input data was collected for the analyses.

6.2 R18 of IJsselmeerpolders

6.2.1 IJsselmeerpolders

The name "IJsselmeerpolders" is consist of three components "IJssel-meer-polders" that collectively refer to a very unique area in the Netherlands. IJsselmeer means Lake Yssel, and polders are pieces of low-lying land that have been reclaimed from sea. A more technical definition of polders by Segeren (1980) describes a polder as " a level area which has originally been subject, permanently or seasonably, to a high water level (ground water or surface water) and is separated from the surrounding hydrological regime, to be able to control the water level in the polders (ground water or surface water) independently of the surrounding regimes".

Hence, IJsselmeerpolders are a series of newly augmented land that were developed from reclaiming the former Zuider zee (South Sea), an inland extension of the Noordzee (North Sea) in Northwestern part of the Netherlands (Figure 6.1).

The development of IJsselmeerpolders was initiated on the basis of an imaginative plan of a Dutch engineer, Dr. Cornelis Lely (1854-1929) during periods of sever national economic and social hardship (e.g. van Duin, 1986; Schultz and Verhoeven, 1987). The original objectives of the Zuider zee project were set as: a) to protect the surrounding areas against flooding and improve their drainage, b) to create a fresh water basis, and c) to develop more fertile agricultural land that will provide permanent employment.

In order to achieve these objectives the comprehensive plan of Lely officially began in 1913. The final plan of Lely included: a) the construction of a barrier dam from the coast of North Holland via the island of Hieringen to the coast of Friesland (Figure 6.1), and b) the reclamation of 5 polders in IJsselmeer (Table 6.1).

Table 6.1 Construction and development period, and reclaimed areas of IJsselmeerpolders

POLDERS	DIKE CONSTRUCTION	DEVELOPMENT PERIOD	AREA ha
Wieringermeer	1927-1929	1930-1940	20,000
Northeastern polder	1936-1940	1942-1962	48,000
Eastern Flevoland	1950-1956	1957-1976	54,000
South Flevoland	1959-1967	1968- still on-going	43,000

Modified from Schultz (1987)

Table 6.1 indicates that by adopting Lely,s plan Dutch government created 165,000 hectare of new land through drainage and reclamation within nearly half a century. It must be mentioned that the original plan included reclamation of an additional polder known as "Markerwaard" which currently is suspended due to special considerations for environmental aspects of the IJsselmeer (Yssel Lake).

In earlier stages of land use development process in IJsselmeer polders much of the land was allocated for agricultural uses (Table 6.2). However, in

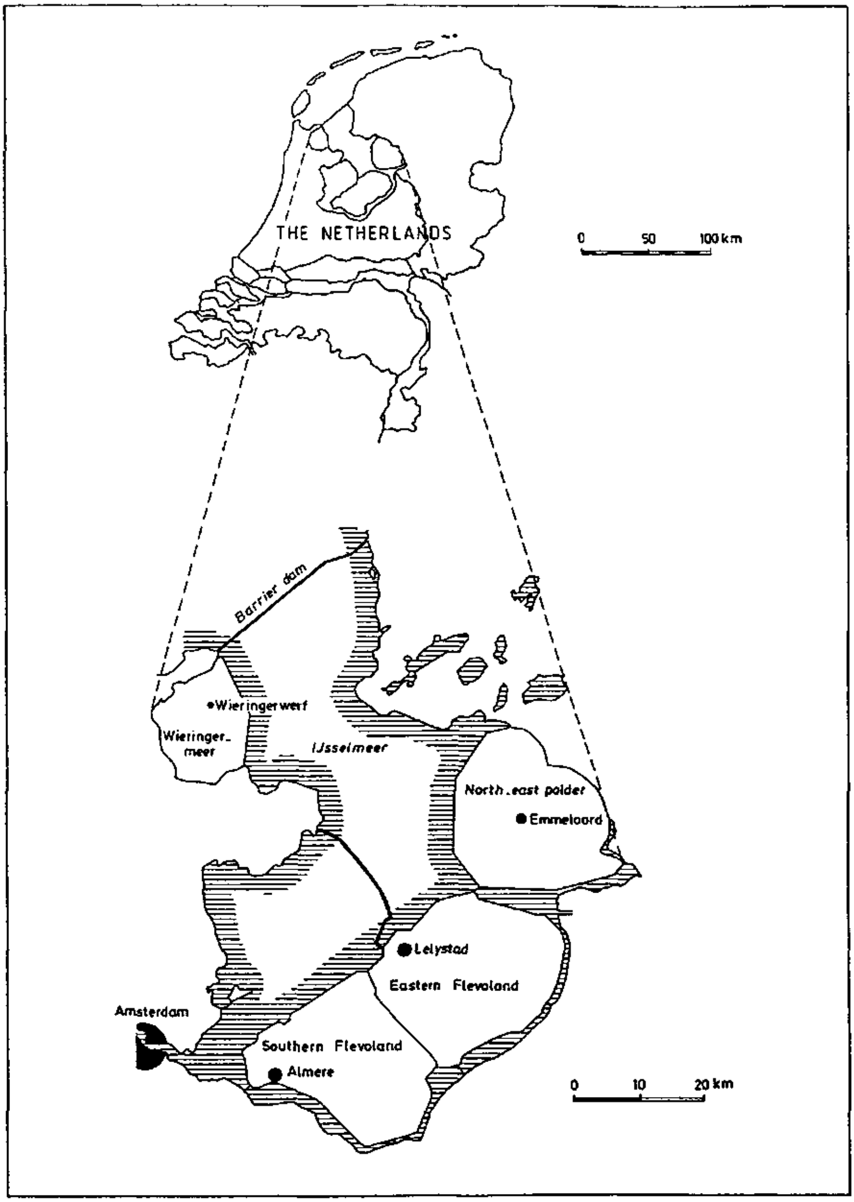


Figure 6.1 IJsselmeerpolders in Northwestern Holland

response to societal changes of the early 1970s, the focus of land use in IJsselmeerpolders shifted to more integrated approach. As shown in Table 6.2 this new approach included agricultural and urban development in conjunction with nature conservation and outdoor recreation components of land use.

Table 6.2 Land use pattern in the IJsselmeerpolders

Polders	LAND USES IN PERCENTAGES OF THE TOTAL AREA				
	A	**B**	**C**	**D**	**Total**
Wieringermeer	87	1	3	9	100
Northeastern polder	87	1	5	7	100
Eastern Flevoland	75	8	11	6	100
Southern Flevoland	50	25	18	7	100

A=Farm Land, **B**=Residential areas, **C**=Woods and nature reserves, **D**=Canals, main ditches, dikes, and roads.
Modified from Schultz (1987).

6.2.2 The experimental field R18

In 1964 a 5 hectare ground water level experiment field was established in East Flevoland polder, referred to as **R18**. The objective was to obtain more information about drainage requirements of fruit trees on young marine clay soils. The decision to carry out this experiment was a response to some of the problems that apple growers had encountered in the Northeastern polder that was developed earlier. These problems were mainly poor growth, low yields and irregular pattern of production from year to year (Visser, 1983). Most of these problems were associated with poor drainage of the fields.

In view of these problems, the design of the experimental field was based on a system of soil moisture regimes that ranged from 0.40, 0.70 and 1.00 to 1.30 meters below the soil surface. In order to reflect the Dutch climatic pattern, a higher ground water level was maintained from november to march. The remaining months were considered as the summer period. Given these conditions 11 soil moisture regimes were laid out in duplicate. Details about these experiments have been described elsewhere (e.g. Visser, 1983; Visser and Jorjani, 1987; Jorjani and Visser, 1989). Figure 6.2 illustrates the scheme adopted for this experimental field. The experiment was carried out for 12 years under management of the IJsselmeerpolders Development Authorities and was continued until 1980 for additional experiments under management of the Instituut voor Bodemvruchtbaarheid (Delver, 1986). During these periods numerous experiments were carried out in **R18**. Some of the data pertaining to apple production under different soil moisture regimes and nitrogen fertilizer treatments collected at **R18** were used for testing one of the components of the framework presented in chapter 5. The results of statistical and economic analyses that were carried out on these input data will be presented in chapters 7 and 8.

6.3 Eastern Ontario

Geographically eastern Ontario is a narrow eastward stretch of southern Ontario into an area which is situated between Ottawa and St. Lawrence rivers (Figure 6.3). As shown in Figure 6.3, Eastern Ontario comprises 12 counties and regional municipalities with a total land supply of nearly 2.9 million hectares (Land Evaluation Group, 1983). A general outlook of land resources in eastern Ontario is given in Table 6.3. As indicated in Table 6.3, much of the total land supply in most counties in eastern Ontario is available for agricultural uses. However, the availability of land for agricultural uses in counties that are situated on the Canadian Shield (Precambrian Shield) is limited owing to the shallowness of soils. These counties include Renfrew, Frontenac, Lanark, Leeds, and Lennox and Addington. Generally speaking the physiography of the region

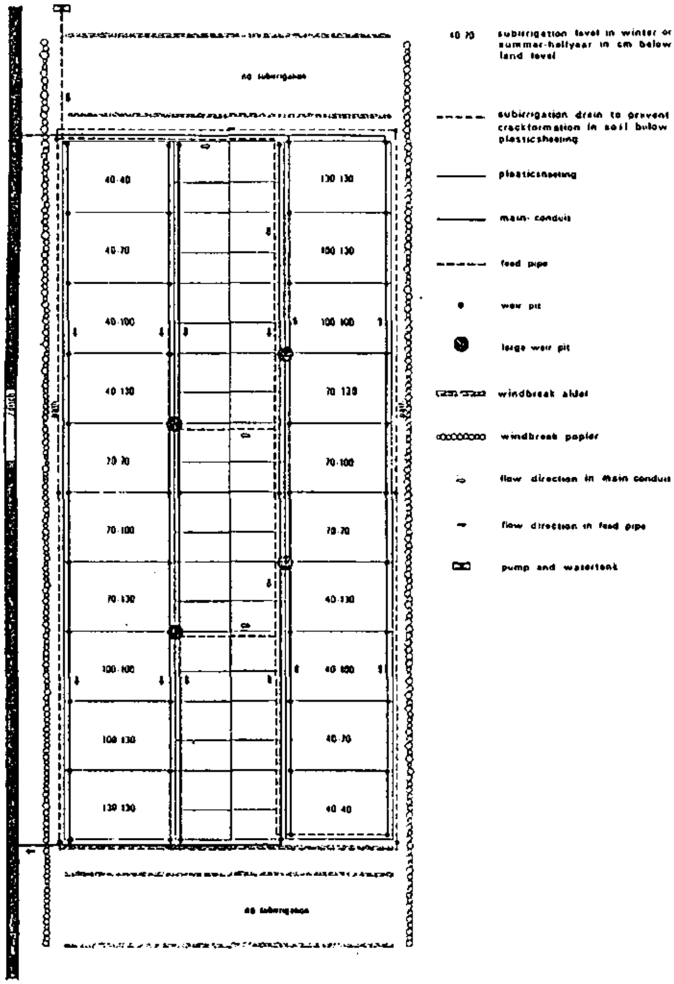


Figure 6.2 Schematics of the layout of R18

is largely a result of glacial activities during the last Ice Age (OMAF and OMNR, 1982). According to a classification of major soil regions of Canada, eastern Ontario is classified under the St. Lawrence region (Agriculture Canada, 1987).

This

Table 6.3 A general outlook of land resources in eastern Ontario

County or regional municipality	A (000) ha	B (000) ha	C (000) ha	D (000) ha
Dundas	103	71	24	8
Frontenac	380	57	3	293
Glengarry	125	72	39	14
Grenville	119	64	38	17
Lanark	306	60	42	204
Leeds	218	82	53	83
Lennox and Addington	284	79	44	161
Ottawa-Carleton	280	144	88	48
Prescott	126	80	31	15
Renfrew	749	107	135	507
Russell	77	48	26	3
Stormont	105	58	31	16
TOTAL	**2,872**	**922**	**581**	**1,369**

A=Total land supply, B=Land available for agricultural uses, C=Land unavailable for agricultural uses, D=Unmapped and unclassified areas, and waterways.
Modified from Land Evaluation Group (1983).

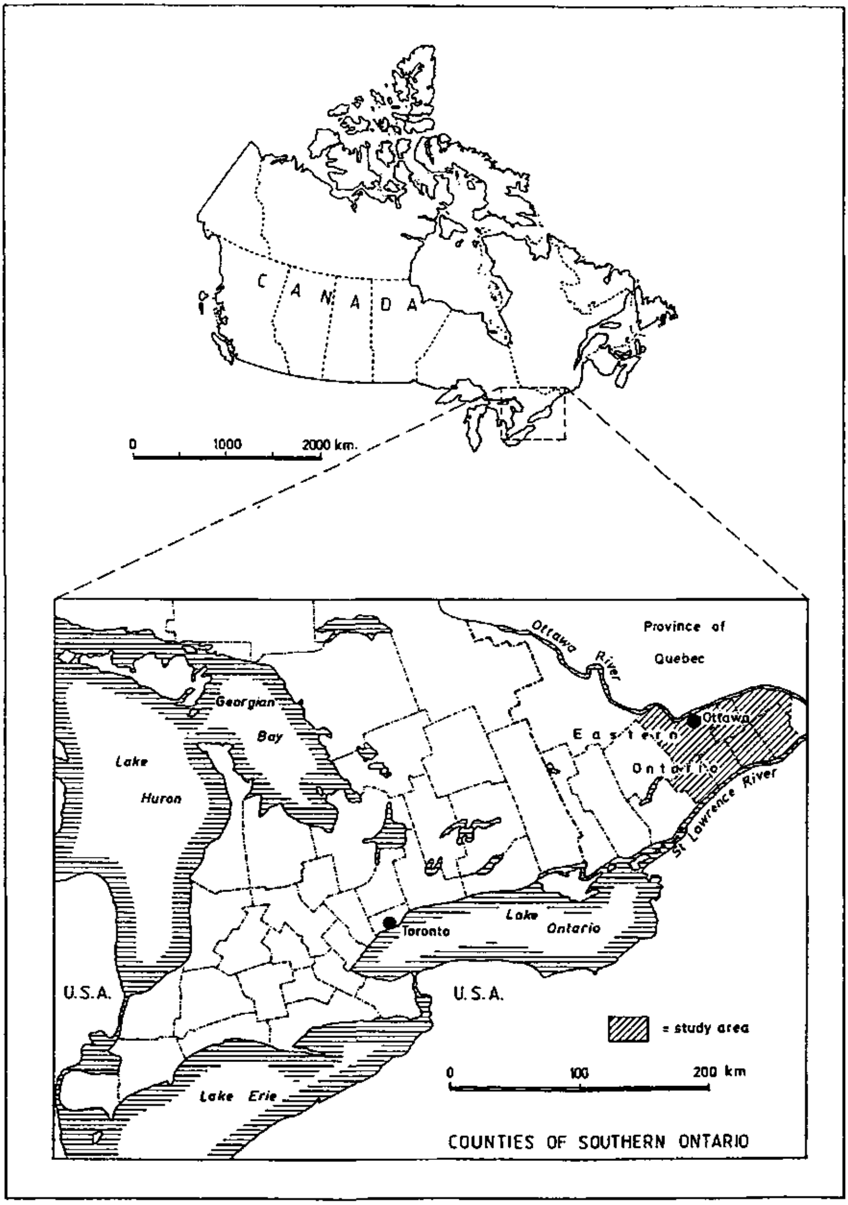


Figure 6.3 Eastern Ontario

means in upland areas the land is undulating and the soil is generally coarse-textured, and in low lands the land is smoother and level. Moreover, it is characterized by a high percentage of silt and clay deposits (Agriculture Canada, 1987). Specifically, sands, clays, and loams are present throughout the region (OMAF and OMNR, 1982). With regard to drainage conditions in the region it is reported that nearly one-third of the available land for agriculture in eastern Ontario has excess moisture for crop production (Land Evaluation Group, 1983). Poor natural drainage conditions in eastern Ontario occurs even in sandy soils that are situated on sand plains because of the closeness of ground water to the surface (OMAF and OMNR, 1982). Despite restricted drainage conditions in eastern Ontario, the region (with the exception of the areas located on the Canadian Shield) is considered as an agricultural area (OMAF and OMNR, 1982). However, agriculture in this region began as a support industry, to supply food and raw materials, to the lumber camps that were established in the upper Ottawa Valley (OMAF and OMNR, 1982). In those earlier days agriculture in eastern Ontario was characterized with mix farming. But, with the decline of the lumber industry in the region dairy farming emerged as the main agricultural activity. Currently, because of the improvements in municipality outlet drainage systems (as a result of Eastern Ontario Subsidiary Agreement) and introduction of new varieties of grain corn and soybeans, cash crops are also grown in this region.

Data provided by OMAF includes farm records of corn yields obtained from artificially (subsurface) drained and undrained lands. OMAF also provided some soil information representing soil types and natural drainage conditions of the farms from where corn yield records were collected. However, as this soil information only included Glengarry, prescott, Russell, Dundas, and Ottawa-Carleton the case study was limited to farm records representing these regions. Using these records two components of the SPI (Figure 5.1a) were tested. The results of these tests are provided in chapter 9.

CHAPTER 7

A STATISTICAL ANALYSIS OF THE EFFECT OF DRAINAGE CONDITIONS AND NITROGEN FERTILIZER ON APPLE PRODUCTION

7.1 Introduction

Apple production plays a significant role in the Dutch fruit industry. During 1984 apple production contributed Dfl 213 million to the Dutch economy (Centraal Bureau voor de Tuinbouwveilingen, Productnota Appelen, 1987). Climatic conditions and soil characteristics greatly influence the types of apple cultivars to be grown, orchard structure, cost of farm operation, and ultimately the farmers' income. In Holland, poor natural drainage is often considered as one of the major constraints involved in fruit production. Climatic fluctuations are known to be responsible for apple yield reductions on soils with shallow ground water levels (Delver, 1986). Shallow ground water levels and inadequate drainage cause poor root development, among other things, and consequently restrain the uptake of nutrients from the soil. Hence, this complex cause and effect relationship can adversely affect yields (e.g. Sieben 1951; Van Hoorn, 1958; Visser, 1964; Kowalik, 1982). In order to avoid yield losses on poorly drained clay soils, artificial drainage and additional nitrogen fertilizer are required to provide enough air and nutrients for the development of apple trees. However, in reviewing the relevant literature Jorjani et al. (1988) have noted that additional nitrogen fertilizer may affect fruit quality. Experiments suggested a relationship between the increased application of nitrogen fertilizer and the increased incidence of shrivelling and russeting, decreased fruit firmness, and poor storage quality of apples. This chapter is an attempt to quantify the overall effect of drainage, nitrogen fertilizer treatments and climatic variability on the growth and production of apples in the IJsselmeerpolders. However, The main emphasis here is to develop a model to estimate the statistically expected incremental fruit yield on account of improved drainage conditions. The economic aspects of this investigation are discussed in chapter 8.

Therefore, this chapter is designed to quantify the overall effect of drainage, nitrogen fertilizer and climate on growth and production of apples. Unlike an earlier investigation by Hogg (1970) that only focused on the relationship between climatic factors and apple growth, the present study attempts to ascertain the combined effect of soil and climate. In this chapter the term soil moisture regime and drainage will be used as synonyms.

7.2 Material and methods

7.2.1 Layout of experiment and data

Because of the high price of the lands in newly reclaimed polders, there is a tendency towards an intensive form of cultivation. following the introduction of fruit growing in the newly reclaimed North-East polder around 1950 apple production gained momentum in later polders too. After an initial success it was found that the higher apple yields, due to improvements in production techniques, did not keep pace with that in other regions in the country. This was mainly attributed to poor aeration of the newly reclaimed soil (van der Molen and Sieben, 1955). Research projects were set up to investigate the influence of soil moisture regimes on apple yields and the physical characteristics of the soil. The experimental field "R18" in the Eastern Flevoland polder (drained in 1957) was one of those projects designed to examine apple yield responses to various soil water depths and nitrogen fertilizer treatments. The experiment was limited to two apple cultivars namely, Cox's Orange Pippin (Cox's) and Golden Delicious (Golden). A detailed description of the experiment has been given by Visser (1983), and by Visser and Jorjani (1987). The schematic view of the layout of the experimental field with different ground water regimes was presented in chapter 6 (Figure 6.1). Although the R18 experiment included 11 soil moisture regimes (SMR), the data used in this study represent only the 5 most important ones. The selected regimes are comparable with the soil drainage classes, poorly drained, imperfectly drained, moderately drained, well drained, and very well drained. In this experiment the water level was constantly controlled and in dry periods water was applied through the drainage system. These soil water table depths were in winter and summer respectively 0.4-0.4, 0.4-1.3, 0.7-0.7, 1.3-1.3, and > 1.3-1.3 meters. The seasonal variation was chosen in order to comply with the prevailing natural conditions in Holland of high water levels in winter, and deeper water tables in summer. Each plot was split into three subplots for different nitrogen fertilizer treatments: no fertilizer (0N), normal or moderate (1N), and twice normal rates (2N). Cox's Orange Pippin (Cox's) and Golden Delicious (Golden) on M9 rootstock were planted at an inter row distance of 4 meters, and 2.5 meters within rows, a year after project commencement in 1965. The experiment had two replicate plots of each treatment. Data compiled for this investigation were yield per plot of 8 trees (kg/ha), and average shoot growth for a seven year period from 1969 through 1975.

7.2.2 Methodology

The growth and development of apple trees can be considered as a system comprising several subsystems. The main subsystems (production factors) known to influence apple production may be listed as: genetic characteristics of graft and rootstock, soil characteristics, climatic fluctuations, and management practices. Adverse weather conditions and their interaction with the above factors are responsible for a large proportion of the observed variations in quality and quantity of apples produced. Hence, in investigating variations in apple yields due to changes in certain production factors, the impact of the climatic factors, particularly during crucial stages of growth, must be considered (Delver, 1986; Landsberg, 1977; Pereira, 1975; and Hogg, 1970). In view of this important climatic influence the methodology for this investigation comprised several steps including analysis of variance and testing of a production function. These analyses may be considered as steps in the process of developing a sufficient understanding of the "apple production" system which is needed to construct a model that could predict incremental apple yields due to agricultural drainage. Hence, with theoretical criteria provided by various disciplines, the relationships involved in apple production can first be identified and then relevant variables chosen according to their importance. Subsequently, these important variables and their interrelationships are combined into a system model which will determine the combined effect of these variables on apple productivity. In principle, two types of models can be distinguished:

- Conceptual models, in which the elementary processes are analyzed, generalized and combined;

- Black box models, where the significant factors are traced and combined into a single explanatory relation.

Because a conceptual model of the complicated phenomena involved in apple production is beyond the scope of our investigation, instead we limited ourselves to the second type of models. The general form of such a model may be written as:

$$Y=f(P,B,C,E)+e \qquad 7.1$$

If:

$$Y=Y_{dr}-Y_{udr} \qquad 7.2$$

Thus:

$$Y=g(P, B, C, E)+e \qquad 7.3$$

Where: Y=Apple yield, P=Physical factors, B=Biological factors, C=Climatic factors, and E=Economic factors (e.g. costs of drainage installation), e=Error term, Y_{dr}=Apple yield from drained plots, and Y_{udr}=Apple yield from undrained plots.

The basic factors are not independent. Any change in these parameters would not only increase or decrease Y, but would also affect the influence of other parameters, in other words, interactions are to be expected. Unlike annual crops, apple yields often show more pronounced variations from year to year. Some cultivars follow a biennial cycle, while others show more irregular variations. According to Landsberg (1977), much of the fluctuation in apple production is due to the fact that, the apple is a perennial fruit tree, and the physiological effects in one season influence its performance in the next season. For example, the average number of apples per tree shows large yearly fluctuations (e.g. Abbott, 1984; Landsberg 1977, 1979). This relationship has been attributed almost without exception to changes in weather conditions and their influence on insect activities during the pollination period. Essentially, cross-pollination is required for fruit set (Forsline et al., 1983). Abbot (1984) reported that temperature has a marked effect on the growth rate of fruitlets, and ultimately the fruit number. Furthermore, sometimes changes in the average yield of apples are caused by a phenomenon called biennial bearing (e.g. Jonkers, 1979; Delver, 1986, 1987). Biennial bearing is an inherent characteristic of certain fruit trees and is known to be responsible for alternating high and low production cycles. Therefore, in statistical analysis of apple production data representing several years one must be aware of this phenomenon which may cause a bias in the results. In order to avoid such biases certain yield indexes are used. Application of these yield indexes might provide a more reliable result as it may reduce a possible bias on account of biennial bearing. In an attempt to test this presupposition the following yield index suggested by Delver (1986) was used:

$$Y_{index}=100*(Y_{t-1}-Y_t)/(Y_{t-1}+Y_t) \qquad 7.4$$

Where: Y_{index}=Yield index, Y_t=Apple yields in the current year and Y_{t-1}=Apple yields in the previous year. This index can vary from 0 to 100, indicating regular to extreme biennial bearing respectively. In this chapter, the influence of agricultural drainage, N-fertilizer, and climatic changes on productivity are of special interest. For many crops empirical linear or quadratic production functions have been published (e.g. Visser and Kowalik, 1974; Feddes et al., 1978; Jorjani, 1982; Van Vuuren and Jorjani, 1984; Jorjani and Irwin, 1985; Kowalik, 1986). By linear regression, coefficients are obtained for weighing the influences of the explanatory variables. In the case of this investigation nitrogen is known to have beneficial effects at low application rates, and negative effects (especially on fruit quality) at high dosages. Therefore, the production model chosen here is quadratic with respect to nitrogen fertilizer, and linear with regard to various climatic factors.

$$Y_S = \beta_0 + \beta_1 N + \beta_2 N^2 + X_i C_j + ... + X_r C_k + e \qquad 7.5$$

Where:

S=1 to 5, denoting a specific drainage class:

1=Poorly drained,

2=Imperfectly drained,

3=Moderately drained,

4=Well drained,

5=Very well drained; and

$\beta_0, \beta_1, \beta_2, X_i, ... X_r$=Regression coefficients,

N=Nitrogen fertilizer (Kg/ha),

C_j ... C_k=Climatic variables, and

e=Error term.

Therefore, if

Y_1=Yield from well drained soil, and

Y_2=Yield from poorly drained soil.

Then,

$$I=Y_1-Y_2 \qquad 7.6$$

Where: I=Incremental apple yield emanating from drainage, with respect to poorly drained and well drained soils.

In order to test this model 13 climatic factors were selected on the basis of a priori knowledge and comments provided by pomologists (Hopmans, 1986). These climatic factors included the average precipitation levels, minimum and mean temperature during budding, full blooming, and fruitlet and fruit growth and development, both in the current and the previous year. Using a correlation matrix, finally ten statistically independent crucial climatic variables were selected for the model. Because of the limited number of cases and the large number of independent variables the model was tested by using a stepwise regression procedure. By adopting this procedure it was expected that only those climatic variables that significantly contribute to the explanation of variations in the average yield of apples will eventually appear in the model.

In view of the above considerations, the following statistical treatments were applied to the data:

1. Analysis of variance, applied to apple yields and shoot growth, as explained by the differences in SMR, N, Years, and their interaction,
2. The same analysis, applied to yield indexes (Eq. 4) to eliminate the effect of biennial bearing,
3. Regression analysis, to obtain the coefficients of the chosen production function (Eq. 7.5).

7.3. Results and discussion

7.3.1 Analysis of variance, of apple yields

Yield data of Cox's and Golden apples were tested against soil moisture regime, nitrogen fertilizer treatment, yearly effects (i.e. Changes in yield from year to year), and their respective interactions (Table 7.1).

TABLE 7.1. ANALYSIS OF VARIANCE, EXAMINING THE VARIATION IN AVERAGE YIELD OF APPLES WITH RESPECT TO SOIL MOISTURE REGIMES (SMR), NITROGEN FERTILIZER TREATMENTS (N), AND YEARLY FLUCTUATIONS (YEARS).

A. Dependent variable-Average yield of Cox's Orange Pippin Kg/ha

SOURCE	DEGREES OF FREEDOM	F-VALUE	CRITICAL LEVEL (SIGNIFICANCE)
(SMR)	4	445.89	0.0001
(REPLICATE)	1	0.90	0.3964
ERROR 1	4		
(N)	1	89.22	0.0002
(N)*(SMR)	4	8.53	0.0186
ERROR 2	5		
(YEARS)	6	38.04	0.0001
(YEARS)*(SMR)	24	1.41	0.1854
ERROR 3	30		
(N)*(YEARS)	6	12.69	0.0001
ERROR 4	24		
ERROR 5	100		

B. Dependent variable-Average yield of Golden Delicious Kg/ha

SOURCE	DEGREES OF FREEDOM	F-VALUE	CRITICAL LEVEL (SIGNIFICANCE)
(SMR)	4	17.61	0.0084
(REPLICATE)	1	2.50	0.1887
ERROR 1	4		
(N)	1	134.12	0.0001
(N)*(SMR)	4	54.94	0.0003
ERROR 2	5		
(YEARS)	6	19.30	0.0001
(YEARS)*(SMR)	24	0.49	0.9606
ERROR 3	30		
(N)*(YEARS)	6	2.20	0.0781
ERROR 4	24		
ERROR 5	100		

Significance levels to be compared with 5

The results of this analysis suggested a significant relationship between the yield of apples and the main factors tested in the experiment. Because investigations of this nature on apple trees are very rare it was not possible to compare these findings with data given in the literature. In order to better understand the nature of these significant relationships, the average yields from different plots and subplots were grouped together and examined accordingly (Table 7.2). As shown in Table 7.2, there is a notable positive response of apple yields to drainage, particularly on the (0N) subplots. This effect however, was more systematic in the case of Golden apples. Moreover, by comparing the average yield figures on the (0N) subplots it is also found that the waterlogged condition during summer has an adverse effect on the yield of apples, especially in the case of Cox's. An increase in summer water table depth from 40 to 130 cm (i.e. from very poorly to poorly drained) caused a 45% and 26% increase in the average yield of Cox's and Golden apples respectively. A similar increase in the water table depth during winter, equivalent to a change from poorly to well drained conditions, resulted in an additional 15.5% and 9% increase in

TABLE 7.2. AVERAGE YIELD OF APPLES (Kg/ha over the years 1969-1975) WITH RESPECT TO DIFFERENT SOIL MOISTURE REGIMES AND NITROGEN FERTILIZER TREATMENTS*

(SMR)	(N)					
	(0N)	(1N)	(2N)	(0N)	(1N)	(2N)
	Cox's			Golden		
1. VERY POORLY DRAINED (40-40 cm)	16694	30787	29417	30919	43145	43321
2. POORLY DRAINED (40-130 cm)	24250	27676	28524	38977	40445	42447
3. MODERATELY DRAINED (70-70 cm)	24445	30825	31648	40165	43528	43000
4. WELL DRAINED (130-130 cm)	28021	29197	31522	42516	42818	43817
5. VERY WELL DRAINED (no subirrigation)	26117	31233	30699	43836	45326	46828

* Although the project began in 1965, the actual production did not start until 1969. The initial 3 years were therefore, not included in the analyses because there were hardly any yields. For details see Visser (1983).

the yield of Cox's and Golden apples. The highest levels of average yield for Cox's and Golden apples were reached on the very well drained soils of (1N) and (2N) subplots respectively. These findings suggest that apple trees planted in marine clay soils require a relatively deep ground water level (well to very well drained conditions) during both winter and summer months. Concerning the significant impact of N-fertilizer it was interesting to note that a moderate application increased the yield of Cox's apples on the very poorly drained soil by 84% (Table 7.2). On the very well drained soils this effect on the Cox's yield was only about 20%. In the case of Golden apples the corresponding figures were nearly 40% and 3.5% respectively. These results indicate that a moderate application of nitrogen fertilizer would reduce the harmful effect of shallow ground water table level, particularly in the case of Cox's. This significant relationship between N-fertilizer application and the yield is consistent with the results of an earlier investigation on arable crops in the Niew Beerta experimental field by Van Hoorn (1958). The observed significant yearly variations in the yield of apples (Table 7.1) were consistent with results obtained elsewhere by Coppock (1964), Hogg (1970), Luckwill (1975) and Pereira (1975). Using the yield index (Eq. 4) instead of the actual yield figures had only a slight effect on the overall results of this analysis (Table 7.3). However, by comparing these results with those of Tables 7.1 and 7.2 it can be noted that the indexing procedure caused the interaction between yearly effect and variations in the soil moisture regimes to become significant. One of the likely explanations for this phenomenon is that although in this experiment ground water levels were maintained at a fixed level, climatic factors did have some significant influence on the SMRs. This significant impact could have been caused by differences in factors such as evapotranspiration, soil moisture status, and other climatically induced physical changes.

7.3.2 Analysis of variance, of shoot growth

From this analysis (Table 7.4) it was found that the average shoot growth was also significantly influenced by (SMR), (N), and (Years). A closer

TABLE 7.3. ANALYSIS OF VARIANCE, EXAMINING THE VARIATION IN THE INDEXED AVERAGE YIELD OF APPLES WITH RESPECT TO SOIL MOISTURE REGIMES (SMR), NITROGEN FERTILIZER TREATMENTS (N), AND YEARLY FLUCTUATIONS (YEARS).

A. Dependent variable=Indexed yield of Cox's Orange Pippin Kg/ha

SOURCE	DEGREES OF FREEDOM	F-VALUE	CRITICAL LEVEL (SIGNIFICANCE)
(SMR)	4	21.88	0.0056
(REPLICATE)	1	5.10	0.0868
ERROR 1	4		
(N)	1	238.64	0.0001
(N)*(SMR)	4	20.67	0.0026
ERROR 2	5		
(YEARS)	6	33.80	0.0001
(YEARS)*(SMR)	24	4.43	0.0001
ERROR 3	30		
(N)*(YEARS)	6	18.13	0.0001
ERROR 4	24		
ERROR 5	100		

B. Dependent variable=Indexed yield of Golden Delicious Kg/ha

SOURCE	DEGREES OF FREEDOM	F-VALUE	CRITICAL LEVEL (SIGNIFICANCE)
(SMR)	4	70.77	0.0006
(REPLICATE)	1	6.32	0.0657
ERROR 1	4		
(N)	1	229.41	0.0001
(N)*(SMR)	4	93.31	0.0001
ERROR 2	5		
(YEARS)	6	8.69	0.0001
(YEARS)*(SMR)	24	2.31	0.0156
ERROR 3	30		
(N)*(YEARS)	6	2.63	0.0422
ERROR 4	24		
ERROR 5	100		

Significance levels to be compared with 5

look at the average shoot growth (Table 7.5) reveals that the lowering of the summer ground water table from 40 to 130cm depth caused a more than twofold increase (112.3%) in the Cox's shoot growth. A similar lowering of the ground water level during winter caused an additional increase of 9% in the average shoot growth. The same change in SMR resulted in only 57% and 9.1% increase in the average shoot growth of Golden apples. These figures indicate that Cox's vegetative growth can be more negatively influenced under waterlogged conditions, particularly during the summer period. With regard to the effect of nitrogen fertilizer the significant relationship found here is consistent with earlier results elsewhere (e.g. Zeiger, 1978). However, from the present data it follows that in response to a moderate application of nitrogen fertilizer Cox's vegetative growth on very poorly and very well drained soils increased by 112% and 18% respectively. The response of Golden apples to the same treatment was 57% and 15% increase in average shoot growth.

7.3.3 Production functions

The parameters of the chosen production function, as found by multiple regression analysis for each SMR, are given in Table 7.6. In our data most coefficients of the quadratic term (N^2) were not significant. Two of the significant ones represented the very poorly drained soils for both cultivars. The reason for the general lack of a significant quadratic relationship is perhaps due to the fact that only three levels of nitrogen were used. Consequently, in most cases an optimum was never reached or missed (Table 7.2).

Of the climatic variables, the values for the current year, as well as those of the preceding year were investigated. Results of this analysis revealed that the two apple cultivars responded in a different way to climatic variables. It was noted that Cox's yield was quite sensitive to the average temperature in the current spring under all drainage conditions. Except for the very well drained plots, the average yield of Cox's apples responded significantly to the current winter average minimum temperature, and the preceding year's (lagged)

TABLE 7.4. ANALYSIS OF VARIANCE, EXAMINING THE VARIATION IN AVERAGE SHOOT GROWTH OF APPLES WITH RESPECT TO SOIL MOISTURE REGIMES (SMR), NITROGEN FERTILIZER TREATMENTS (N), AND YEARLY FLUCTUATIONS (YEARS).

A. Dependent variable=Average shoot growth of Cox's Orange Pippin m/tree

SOURCE	DEGREES OF FREEDOM	F-VALUE	CRITICAL LEVEL (SIGNIFICANCE)
(SMR)	4	41.64	0.0016
(REPLICATE)	1	0.27	0.6288
ERROR 1	4		
(N)	1	64.68	0.0005
(N)*(SMR)	4	1.88	0.2522
ERROR 2	5		
(YEARS)	6	31.35	0.0001
(YEARS)*(SMR)	24	0.66	0.8526
ERROR 3	30		
(N)*(YEARS)	6	2.04	0.0995
ERROR 4	24		
ERROR 5	100		

B. Dependent variable=Average shoot growth of Golden Delicious m/tree

SOURCE	DEGREES OF FREEDOM	F-VALUE	CRITICAL LEVEL (SIGNIFICANCE)
(SMR)	4	33.30	0.0025
(REPLICATE)	1	2.50	0.7463
ERROR 1	4		
(N)	1	36.66	0.0018
(N)*(SMR)	4	1.14	0.4348
ERROR 2	5		
(YEARS)	6	12.65	0.0001
(YEARS)*(SMR)	24	1.94	0.0427
ERROR 3	30		
(N)*(YEARS)	6	14.90	0.0001
ERROR 4	24		
ERROR 5	100		

Significance levels to be compared with 5

value of the average minimum temperature during the blooming time. A full account of this intricate cause-effect structure involving Cox's flower bud formation and blooming patterns is provided elsewhere (e.g. Landsberg 1977; Abbott, 1984). In the case of Golden apples the most important climatic variable was found to be the preceding year's value of mean precipitation during the month of May. It was also found that there was a significant positive relationship between the preceding year's value of the average spring temperature and the average yield of Golden apples on very poorly, poorly, and moderately drained plots. Considering the fact that this positive relationship was not observed on plots with an adequate drainage it may be inferred that the effect might be related to soil temperature. It will be very difficult, however, to find an explanation for such delayed effect on yield.

TABLE 7.5. AVERAGE SHOOT GROWTH OF APPLES (m/tree over the years 1969-1975) WITH RESPECT TO DIFFERENT SOIL MOISTURE REGIMES AND NITROGEN FERTILIZER TREATMENTS

(SMR)	(N)					
	(0N)	(1N)	(2N)	(0N)	(1N)	(2N)
	Cox's			Golden		
1. VERY POORLY DRAINED (40-40 cm)	37.28	74.85	75.50	51.21	78.07	79.14
2. POORLY DRAINED (40-130 cm)	79.14	106.92	80.57	80.50	89.42	90.57
3. MODERATELY DRAINED (70-70 cm)	78.00	117.28	137.00	85.50	102.21	103.78
4. WELL DRAINED (130-130 cm)	86.21	102.71	124.78	87.85	96.50	103.78
5. VERY WELL DRAINED (no subirrigation)	88.14	104.00	107.35	89.00	102.85	102.00

TABLE 7.6.A. Estimated regression coefficients of average yield of Cox's Orange Pippins apples in (kg/ha) with respect tc nitrogen fertilizer treatments and climatic variables for different soil moisture regimes.

Explanatory variables	Regression Coefficients	SOIL MOISTURE REGIMES				
		40-40 cm	40-130 cm	70-70 cm	130-130 cm	no subirrigation
Constant		95854.28	82649.68	88446.50	136235.08	83169.20
Lagged minimum			-6669.53	-7377.71		-12974.07
temperature in winter (°C)		(7.85)	(5.84)	(4.46)	(2.52)	
Lagged minimum		4318.37	7510.32	6208.70	5878.81	
temperature in May	(°C)					
Lagged average						11007.26
spring temperature	(°C)	(-10.27)	(-13.83)	(-11.31)	(-13.46)	(-12.02)
Lagged winter					-214.85	
mean precipitation	(mm)				(-3.08)	
Current winter						-259.86
mean precipitation	(mm)					(-4.96)
Lagged May			150.64	150.10	-98.64	
mean precipitation	(mm)		(1.94)	(1.69)	(3.26)	
Current May						
mean precipitation	(mm)					
N		129.11	26.01	37.77	22.22	86.46
Linear term of nitrogen		(5.98)	(3.83)	(5.83)	(2.54)	(2.98)
N^2		-0.30				-0.37
Quadratic term of N		(-3.73)				(-2.22)
R-Square		0.84	0.90	0.87	0.87	0.88
Number of cases		42	42	42	42	42

Critical values in parentheses to be compared with $t_{42}^{.05}$ =1.68 (one sided t-test) and 2.02 (two sided t-test)

TABLE 7.6.B. Estimated regression coefficients of average yield of Golden Delicious apples in (kg/ha) with respect to nitrogen fertilizer treatments and climatic variables for different soil moisture regimes.

Explanatory variables	Regression Coefficients	SOIL MOISTURE REGIMES				
		40-40 cm	40-130 cm	70-70 cm	130-130 cm	no subirrigation
Constant		-124506.33	-8847.21	97829.18	-34282.37	-42722.60
Lagged minimum					8284.57	
temperature in winter (°C)			(-4.10)			
Lagged minimum		10679.21			8705.63	12235.06
temperature in May (°C)					(2.28)	
Lagged average		10135.59	18298.33	8762.67		
spring temperature (°C)				(-4.20)		
Lagged winter		385.42				309.70
mean precipitation (mm)		(3.13)				(4.16)
Current winter			-501.60	-646.83		
mean precipitation (mm)			(-9.02)	(-8.97)		
Lagged May		-349.45	-799.11	-652.25	-472.30	-323.86
mean precipitation (mm)		(-8.32)	(-11.98)	(-16.64)	(-9.77)	(12.96)
Current May						
mean precipitation (mm)						
N	.	121.44	20.36	44.04		19.56
Linear term of nitrogen		(3.85)	(2.64)	(1.96)		(2.01)
N^2			-0.29		-0.15	
Quadratic term of N		(-2.54)		(-1.54)		
R-Square		0.78	0.92	0.91	0.85	0.88
Number of cases		42	42	42	42	42

Critical values in parentheses to be compared with $t_{42}^{.05}$=1.68 (one sided t-test) and 2.02 (two sided t-test)

7.4. Summary and discussion

The overall conclusion emerging from these analyses is that the average yield of both cultivars was significantly influenced by the main factors tested in the R18 experiment. It was interesting to note that where as Cox's apple responded more positively to drainage improvements, their influence was found to be more systematic in the case of Golden apples, particularly on the (0N) subplot. It was also found that Cox's apple responded more favorably to a moderate application of nitrogen fertilizer both on very poorly drained and very well drained plots. In an attempt to minimize chances of a possible bias due to the effect of biennial bearing an indexing procedure was tested. However, except for an interaction between the yearly effect and variations in drainage classes (YEARS*SMR), this indexing procedure did not cause any statistically notable changes in the overall results.

With regard to the relationship between the vegetative growth of apple trees and the main soil-water management factors tested here it was found that, while both cultivars responded significantly to changes in those factors, the response of Cox's average shoot growth was more notable. For example lowering of the summer ground water table level in the absence of nitrogen fertilizer caused more than a twofold increase in the Cox's average shoot growth. The same process resulted in only 57% increase in the case of Golden apples. Similarly, in response to a moderate application of nitrogen (1N subplots), Cox's vegetative growth on very poorly and very well drained soils increased by 112% and 18% respectively. The same treatment in the case of Golden apples brought about a 57% and 15% increase.The five production functions representing different drainage levels were able to explain about 80 to 90% of the variations in yield. Only a few models involved a quadratic N-term of statistical significance. These represented very poorly drained soils. A likely explanation for the lack of significant N^2 coefficient is the paucity of data. In the R18 experiment only 3 levels of nitrogen fertilizer treatments were tested. Therefore, it is likely that on most SMR plots the optimum was not reached. The highest yields for Cox's and Golden were found on the very well drained soils with (1N) and (2N) fertilizer treatments. In testing different crucial climatic periods it was found that each cultivar had a distinct characteristic. For example, in the case of Golden apples the last year's value of the average precipitation level was found to be statistically the most important climatic variable in all the five production functions representing different drainage levels. This relationship implies that the average yield of Golden apple is negatively influenced by the amount of precipitation during the month of May of the previous year.

As a final generalization about the results of these series of analyses it can be inferred that there is a complex multifactor relationship involved in apple growth and production which is all too easy to be misinterpreted. First of all, not all apple cultivars can be expected to respond in a similar way to different soil water management practices. Furthermore, some apple cultivars are significantly influenced by seasonal variations. With regard to soil-water management, it must be noted that, although application of nitrogen fertilizer may alleviate the harmful effect of shallow ground water levels, it may adversely affect the yield and especially the quality of apples produced (Jorjani, et al. 1988). Excessive application of nitrogen fertilizer will bring about more vegetative growth at the expense of the fruit yield, and an increase in pruning cost. Hence, in developing a production prediction model for apples these complex interrelationships must be taken into consideration.

CHAPTER 8

AN ECONOMIC ASSESSMENT OF SUBSURFACE DRAINAGE IMPROVEMENTS AND NITROGEN FERTILIZER TREATMENTS IN APPLE ORCHARDS

8.1 Introduction

Apple production in Holland has always been associated with major production risks that are linked to the agroclimatic and soil characteristics in this part of Europe. Climatic variations are known to be responsible for some of these risks, particularly on soils with shallow ground water table levels. A review of these changes by Delver (1986) revealed that water-caused damages due to excess precipitation during crucial growth stages occurred once every 3 to 4 years in the last 30 years. In addition to physical damage to the standing fruit tree, especially during the blooming period, excess precipitation is also responsible for the prolonged water-logged conditions in many orchards with heavy soils. Waterlogging induces several adverse processes in the soil, one of which is denitrification. This process, which takes place under anaerobic conditions, causes loss of nitrates, which are reduced to nitrogen gas. Moreover, other processes involving nitrogen compounds are retarded. Because of these processes additional nitrogen fertilizer is needed to offset the harmful effects. Other fruit production risks associated with excess soil moisture and shallow ground water tables are related to poor root development and the occurrence of certain production patterns that adversely effect apple yields. Visser (1968) reported that poor drainage conditions had an adverse impact on the incidence of "Cox's disease" and the resulting production losses. In order to alleviate these production risks fruit growers in areas with poorly drained clay soils have always used additional doses of nitrogen fertilizer. Increased application of nitrogen is known to have a positive impact on the growth of apple trees (Van Giffen, 1974; Zeiger, 1978; Visser, 1983; Delver 1986).

However, studies in Holland and elsewhere have indicated that increased application of nitrogen fertilizer is linked with a number of side effects that might actually cause reductions in fruit grower's income. Increased nitrogen fertilizer application in apple orchards has been found to be responsible for increased shrivelling, russeting, decreased fruit firmness, and poor storage quality (van der Boon et al. 1970; Slager, 1972; Zeiger, 1978; van Wijk, 1982; Visser, 1983). Occurrence of these problems can have a profound impact on fruit growers' income particularly if apples are produced for the fresh market. Another negative aspect of increased rates of nitrogen application is that it may cause a vigorous vegetative growth at the expense of fruit production efficiency (Delver, 1973, 1987). The undesirable increase in the vegetative growth not only reduces fruit yields, but also increases certain expenses such as pruning costs.

Because fruit growers are concerned with the most efficient use of their resources, insights into the complex interaction between soil moisture regime, nitrogen fertilizer rates and farmer's revenue are needed. This chapter is designed to examine the economic impact of subsurface drainage and application of nitrogen fertilizer on production of apples that are grown under prevailing agroclimatic conditions of the newly reclaimed polders where the predominate soil is calcareous marine clay. In this study additional economic benefits on account of tax write-offs and subsidies were not included. These aspects are complex and warrant a separate investigation.

8.2 Data and methods

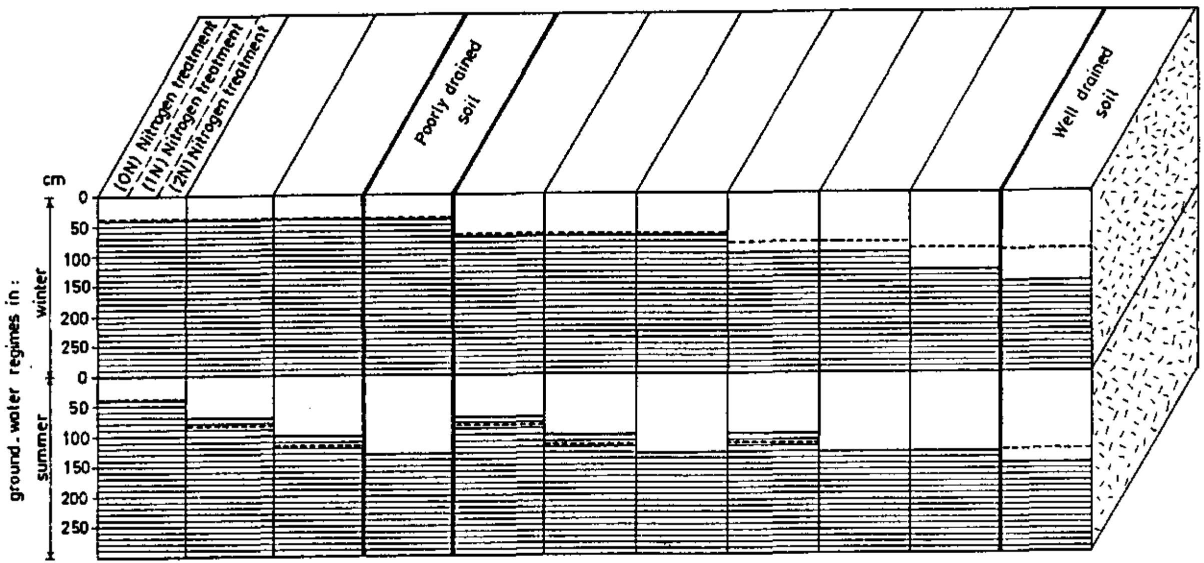
Experimental data

Data were obtained from an experiment at the IJsselmeerpolder Authority's experimental farm in East Flevoland, referred to as **R18**. The experiment was set up in 1964, with the main purpose to investigate the drainage requirements of apple trees on marine calcareous soils. This experiment was carried out on 11 plots with different ground water regimes that

were maintained through a network of drainage and subirrigation systems. Because the soil's capacity to release nitrogen depends on its drainage conditions, each drainage plot was split into 3 subplots with different nitrogen fertilizer treatments so that the effect of nitrogen could be separated from drainage impacts.
This experiment was carried out for nearly 16 years on two apple cultivars namely, Cox's Orange Pippins (Cox's) and Golden Delicious (Golden), that were grafted onto M9 rootstocks.

Details of this experiment are given elsewhere (e.g. Visser, 1983; Delver, 1986; Visser and Jorjani, 1987; Jorjani and Visser, 1989). A summarized schematic representation of the experiments' layout is provided in Figure 8.1.

This study used annual production data from plots with 0.4 metres of ground water depth in winter, and 1.3 meters in summer (0.4-1.3 meters), and the "no subirrigation" plots, which had water tables of > 1.3 meters depth throughout the year. The first plot was assumed to represent an apple orchard with a poorly drained marine clay soil, and the second plot was hypothesized as a well drained orchard on the same soil. Other conditions on both orchards were held equal. The average annual production data were obtained from two separate reports of the R18 experiment documented by Visser (1983), and Delver (1986). Table 8.1 gives the list of these average annual data. The average yield was estimated on the basis of average weight and average number of apples in kg/tree. During this analysis these yield figures were converted into per hectare basis by multiplying these values by the number of trees in one hectare (i.e. 880 trees/hectare). The average shoot growth was estimated for each tree on the basis of random measurements recorded from sampled trees. The proportion of yield that was graded as class 1 apples was used as an index for fruit quality. This quality grading was carried out according to auction criteria and after storage. For this grading trial, Cox's apples were stored for 3 months in regular cold storage. Golden apples were kept for 5 months in an oxygen controlled storage facility.



Legend:
——— Water-level in drains (drainage level) in cm below the surface.
------- Average groundwater level between drains in cm below the surface
For details see Visser (1983)

Figure 8.1 schematic representation of the R18 with its 11 soil moisture regime experimental plots and the nitrogen treatment subplots during 1964 through 1980.

Because no consistent financial data were kept at the **R18**, relevant financial input data were obtained from alternative sources. For example, average apple prices were obtained from the Centraal Bureau Tuinbouwveilingen (CBT). Similarly, estimates of apple production costs were obtained through personal communications (Joosse, 1987), from the Proefstation voor de Fruitteelt in Wilhelminadorp (PFW). Additional input data representing the ratio between shoot growth and the required pruning hours, and some records of the storage and quality assessment of apples were obtained from the Cooperative Auction in Geldermalsen (1987), and through personal communications.

Table 8.1. LISTS, AND CHARACTERISTICS OF THE EXPERIMENTAL DATA OBTAINED FROM THE R18.

Type of data	Period data collected	No. of years	Unit
Average yield of apples	1967-1980	14	kg/ha
Average shoot growth of apples	1969-1975	7	cm/tree
Percentages of class 1 apples	1969-1973	5	% of yield

Methods

Subsurface drainage due to its biophysical cause-effect structure is expected to improve apple yields in orchards with poorly drained marine clay soils. During certain periods of the year the rainfall exceeds evapotranspiration creating excess water over and above the storage capacity of soils. Under these conditions this excess moisture fills all the soil pores and prevents the apple tree roots from being adequately aerated, a necessary condition for growth and productivity. Fruit trees in general need a deep rooting system for greater anchorage against the wind. Subsurface drainage is the most effective technique to minimize production risks associated with excess moisture and shallow ground water table. The differences in yield on account of drainage are, therefore, mainly linked with the time during which the ground water table is closest to the surface. Changes in physical yield on account of subsurface drainage can be estimated in two ways: (a) as the difference in the total physical productivity (TPP) of two production functions estimating crop yields under drained and undrained conditions, and (b) if there are enough yield records (at least 10 years), as the actual difference between recorded drained and undrained yields. Using one or a few successive years of yield records is not long enough to reflect climatic influences on crop yields. Benefits of subsurface drainage are expected to be higher during wet years. During dry years subsurface drainage may not be needed at all. For this investigation because there were 14 years of yield records, the latter was applied so that the economic impact of drainage could be estimated for each nitrogen fertilizer treatment.

In determining the profitability of drainage an investment analysis was carried out. This investment analysis was based on several pieces of information: 1) net cash revenue from the investment, 2) the cost of drainage investment, 3) the real interest rate or discount factor which relates the rate of return of drainage investment to the general rate of return to capital in the economy, and 4) an investment planning horizon.

Net cash revenues or cash flows resulting from drainage investment were estimated for each year in the life of the
drainage investment with respect to different nitrogen fertilizer treatments. The economic life time of this drainage project was assumed to be 15 years (although in reality it may exceed this period). This corresponds with some of the common planning horizons for apple orchards in Holland. As the annual yield data represented only 14 years of records, the mean value of apple yield over those available years was taken as a proxy record for the 15th year. In selecting the appropriate real interest rate the opportunity cost of capital was taken into consideration. However, this value is seldom known with any degree of accuracy. For this reason the current interest rate paid on saving accounts (4%) was taken as the real interest rate.

The standard for decision making was based on the Internal Rate of Return (IRR). IRR may be defined as that rate of discount which makes the present value of the net revenue flow equal to the investment cost. Mathematically IRR may be written as:

$$NPV = \Sigma N_R/(1+i)^t - Io = 0 \qquad 8.1$$

$$IRR = \Sigma N_R/(1+i)^t = Io \qquad 8.2$$

$$N_{R,} k_j = [(Y.P_y) - C] \qquad 8.3$$

$$P_y = f(Q, T) \qquad 8.4$$

$$C = h(C_y, C_m) \qquad 8.5$$

$$Y = Y_{DRAINED} - Y_{UNDRAINED} \qquad 8.6$$

Thus:

$NR = f(Y, P_y, C)$ 8.7

Where: **NPV**=Net Present Value in Dfl, N_R=Net Revenue in Dfl, **IRR**=is NPV set equal to zero and solved for **i**, the discount factor in percentages, P_y=Price of Apples in Dfl/Kg, **C**=Total cost in Dfl/kg, **Q**=Quality classes of apples in percentages of total production apples, **T**=Time of sale i.e before or after storage or others, C_y=Production costs in Dfl/kg, C_m=Marketing costs in Dfl/kg, **Y**=Incremental apple yield due to drainage.

In an attempt to examine different financial scenarios several pricing systems were used for calculating the net revenue. These included, average prices based on quality aspects such as grade of apples, average current prices, and after storage prices. Most of these prices were obtained from the CBT.

Assuming that most production costs remain the same on both drained and undrained orchards, only additional costs associated with drainage investment and with the incremental apple yield were included. These costs were: drainage installation cost estimated to be Dfl 2500/ha (in the year "0" of the investment planning horizon) with 10 meters distance between the laterals, annual drainage maintenance cost estimated at 2.5% of the installation cost, and cost of pure nitrogen fertilizer at Dfl 1.57/Kg. Other yield related production costs such as pruning and picking expenses were calculated on the basis of a ratio that represents the efficiency and amounts of man/hour work required. This ratio is applied by the PFW in their economic analysis of apple production. Similarly hail insurance fee and marketing costs were obtained from either auction centres or the PFW. Due to an existing lag in some of the input prices (i.e. prices that represented previous years) an inflation rate of 6% was used to make these prices current.

8.3 Results and discussion

The profitability of drainage in apple orchards is affected by several physiological and economic factors in the environment that determines yield, production costs, and revenues. Therefore, a number of scenarios were analyzed in order to assess the effect of these factors. This type of analysis usually requires a highly sophisticated model that would capture all interactions among factors to be analyzed. An integrated model using a SAS routine was written for this analysis. Formation of different scenarios for this study was based on factors that ultimately influence fruit growers' net revenue. These were: 1) quality aspects of apples which included a set of prices that were based on the taste and the shape of apples, and 2) other prices and costs which involved items such as a single price (for mix-grades of apples), and production and marketing costs. These alternative calculations were carried out not only to determine different IRRs but also to estimate the most profitable level of nitrogen fertilizer. In these analyses the response of each cultivar to drainage and application of nitrogen fertilizer was also examined.

Scenario 1: Quality aspects

Demand for fresh market apples is profoundly affected by taste and appearance of apples. Auction prices are normally based on quality aspects that include factors such as the physical appearance and storage characteristics of apples. The physical appearance of an apple is judged on the basis of its color, shape and roughness of its skin. The storage characteristics of an apple are determined on the basis of its keeping quality with respect to certain physiological breakdowns that affect taste and appearance. Better quality apples always fetch a higher price. However, producing quality class apples requires the right proportion of inputs. To test the effectiveness of drainage and different nitrogen fertilizer applications on fruit quality, and ultimately on the fruit growers' net revenue, the percentage quantities of class 1 and the remaining classes were estimated. Because the quality estimates were based on 5 years data, the calculated mean net revenue over those five years was used as the yearly cash flow over the economic life time of the investment. In other words, a constant cash flow was assumed for the remaining 10 years. An inflation rate of 6% was used in order to make adjustments for annual fluctuations.

Results of the quality analysis (Table 8.2) revealed that the economic viability of drainage investment for Cox's apples was much higher when normal doses of nitrogen fertilizer (1N) were applied. The level of profitability declined on the (2N) subplots where twice the normal rates of nitrogen fertilizer were applied. Higher doses of nitrogen fertilizer are not only costly but also cause more rigorous shoot growth that results in higher pruning costs. Most important, higher doses of nitrogen fertilizer effect the quality of apples produced (Visser, 1983). The latter is evident in the case of Cox's apples on the drained plot (Table 8.3). As shown in Table 8.3 in the case of Cox's an additional dose of nitrogen fertilizer from (1N) to (2N) levels on drained plots caused a reduction in the proportion of class 1 apples. Cox's response to higher doses of nitrogen fertilizer was somewhat mixed on undrained plots. According to Visser (1983) the notable decline in the proportion of class 1 apples obtained from those plots was due to a recurring case of bitterpit in nearly every year, resulting in a lower price. This is evident in the lower value of gross mean revenue of Cox's apples on the (1N) subplot of the undrained plot (Table 8.4).

Table 8.2. NET REVENUES AND INTERNAL RATES OF RETURN OF SUBSURFACE DRAINAGE AND NITROGEN FERTILIZER TREATMENTS GIVEN ACCORDING TO QUALITY CLASSES*

	COX'S ORANGE PIPPINS		GOLDEN DELICIOUS	
	NET REVENUE Dfl/Ha	IRR %	NET REVENUE Dfl/Ha	IRR %
NFT				
0N	1081.0	43	2106.0	84
1N	2884.0	115	652.0	25
2N	306.0	9	1795.0	72

* The economic life time of the project is 15 years. NFT=nitrogen fertilizer treatments, 0N=no nitrogen fertilizer, 1N=normal or moderate application of nitrogen fertilizer, and 2N=twice normal rates.

Table 8.3. AVERAGE YIELD OF APPLES (kg/ha) AND AVERAGE PROPORTION OF YIELD AS CLASS 1 APPLES (kg/ha) ON DRAINED AND UNDRAINED PLOTS WITH RESPECT TO DIFFERENT NITROGEN FERTILIZER TREATMENTS.

DRAINAGE	i. AVERAGE YIELD OF APPLES (kg/ha)					
	COX'S			GOLDEN		
	(0N)	(1N)	(2N)	(0N)	(1N)	(2N)
Drained	29761.6	33158.4	33844.8	45249.6	47256.0	48417.6
Undrained	26681.6	29814.4	30659.2	39934.4	41395.2	42662.4

DRAINAGE	ii. PROPORTION OF YIELD AS CLASS 1 APPLES (kg/ha)					
	COX'S			GOLDEN		
	(0N)	(1N)	(2N)	(0N)	(1N)	(2N)
Drained	18067.9	19233.6	17732.5	41232.7	34768.7	37999.8
Undrained	15046.8	13953.4	16272.4	35466.1	33600.9	34112.23

Table 8.4. MEAN GROSS REVENUES OF APPLE PRODUCTION BASED ON QUALITY CLASSES (Dfl/ha), OVER A 15 YEAR PLANNING HORIZON, WITH RESPECT TO DRAINAGE AND NITROGEN FERTILIZER TREATMENTS.

DRAINAGE	MEAN GROSS REVENUES (Dfl/ha)					
	COX'S			GOLDEN		
	(0N)	(1N)	(2N)	(0N)	(1N)	(2N)
Drained	11346	12359	11808	17171	15243	16321
Undrained	10203	9412	11439	15002	14529	14464

The problem of bitterpit did not occur as frequently on plots planted with Golden apples. The results of this analysis also revealed that the Golden performs relatively well on marine clay soils. As shown in Table 8.3 average yields of Golden apples are generally much higher than those of the Cox's. Furthermore, in comparison with the Cox's, Golden apples responded differently to the application of nitrogen fertilizer. The better quality of Golden apples of the (0N) subplot caused the IRR to reach as high as 84% (table 8.2). A closer examination of the mean gross revenues presented in Table 8.4 indicates that, undoubtedly, the proportion of Golden apples obtained from the (0N) subplot was much higher and as a result higher revenues were obtained. The higher returns of Golden over Cox's particularly on drained plots, could be attributed to a significant relationship between the application of nitrogen fertilizer and the skin color of Golden apples. Visser (1983) has reported that, Golden apples with a yellowish skin color at the time of harvest have a better taste than the ones with a bright green color. In **R18** experiment the percentage of Golden apples with a bright green color was relatively lower on the (0N) subplot and higher on the (2N) subplot.

Scenario 2: Quality aspects excluded

To determine the profitability of drainage without considering quality, a single pricing system was adopted for calculating the annual cash revenue. The single price means the negative effect of higher nitrogen application is not a concern. Only total yield matters and that is attained through higher rates of nitrogen fertilizer.

The results of this analysis indicated that omitting grading aspects caused a considerable reduction in IRRs of both apple cultivars on the (0N) subplot (Table 8.5). The internal rate of return for Golden apples was also lower on the (2N) subplot. This implies that excluding quality measures tends to even out (or neutralize) the impact of higher priced class 1 apples. This is primarily due to the fact that since all classes of apples are mixed they are priced at a lower level and as a result net revenue changes considerably.

Nevertheless, despite these changes in net revenues Cox's apples remained profitable on the (1N) subplot with a normal level of nitrogen fertilizer. The internal rate of return for

Cox's apples on the (2N) subplot increased more than 2.5 times without the quality classes. This was primarily due to relatively higher average yields of Cox's on the (2N) subplot (Table 8.3) that resulted in higher revenue in the absence of quality classes (Table 8.6).

Table 8.5. NET REVENUES AND INTERNAL RATES OF RETURN OF SUBSURFACE DRAINAGE AND NITROGEN FERTILIZER TREATMENTS GIVEN WITHOUT QUALITY CLASSES*

	COX'S ORANGE PIPPINS		GOLDEN DELICIOUS	
	NET REVENUE Dfl/Ha	IRR %	NET REVENUE Dfl/Ha	IRR %
NFT				
ON	796.0	31	1242.0	50
1N	1729.0	69	1291.0	52
2N	622.0	24	1455.0	58

*The economic life time of the project is 15 years, **NFT**-nitrogen fertilizer treatments, **ON**-no nitrogen fertilizer, **1N**-normal or moderate application of nitrogen fertilizer, and **2N**-twice normal rates.

With regard to Golden apples, excluding quality aspects caused more than a double increase in the IRR on the (1N) subplots. This was mainly due to the notable difference in yields (Table 8.3) on account of drainage on the (1N) subplot. The results of this analysis also revealed that although profitability of Golden apples was high on all nitrogen fertilizer treatment subplots, the highest level of IRR was observed on the (2N) subplot. This is partly due to higher mean gross revenue of Golden apples on the (2N) subplot of the drained plot (Table 8.6). As shown in Table 8.6 the mean gross revenue of Golden was the highest on the (2N) subplot of the drained plot. The lower value of the mean gross revenue of Golden apples on the (2N) subplot of undrained plot may have been due to higher pruning costs. The average shoot growth on this plot was relatively higher than on the (1N) subplots (visser, 1983).

The overall conclusion emerging from this analysis suggests that the application of nitrogen fertilizer on drained and undrained plots increased the overall production of apples irrespective of their size and other quality aspects. However, the differences in yield on account of drainage on different nitrogen fertilizer treatment subplots were mixed.

Table 8.6. MEAN GROSS REVENUES OF APPLE PRODUCTION WITHOUT QUALITY CLASSES (Dfl/ha), OVER A 15 YEAR PLANNING HORIZON, WITH RESPECT TO DRAINAGE AND NITROGEN FERTILIZER TREATMENTS.

DRAINAGE	MEAN GROSS REVENUES (Dfl/ha)					
	COX'S			GOLDEN		
	(ON)	(1N)	(2N)	(ON)	(1N)	(2N)
Drained	11910	13176	13320	11602	11957	12086
Undrained	11052	11384	12635	10297	10603	10569

Scenario 3: After storage prices

Due to the increased supply of apples during the harvest time apple prices are usually not very attractive at that time. Therefore, most apple growers prefer to store their product and market it later when prices are higher. These days however, apple growers seldom store their product at the farm. In the Netherlands there are several cooperative cold storage centers where modern storage facilities are provided. For example, the cooperative auction center in Geldermalsen provides cold storage facilities at the rate of Dfl 3.04/box for the first 3 months, and Dfl 0.11/box for the additional months. A box may contain 20 to 25 kg of apples. Cox's apples are usually stored for 3 months and Golden apples for 5-6 months.

To test the interrelationship among impact of drainage investment, nitrogen fertilizer, and the time of selling apples, after-storage prices were used for this analysis. Furthermore, in this analysis yearly incremental net benefits over 14 years were used instead of gross mean revenue as a cash-flow stream over economic lifetime of the project. However, since only 14 years of yield records were available the mean value of yield over that period was used for the 15^{th} year.

The main purpose of this analysis was to determine changes in net revenue on account of drainage conditions and application of nitrogen fertilizer, using yearly records. In order to carry out this test annual after-storage prices and storage costs were included.

Results of this analysis revealed that in the case of Cox's drainage investment paid back only when moderate doses of nitrogen fertilizers were applied (Table 8.7). Drainage investment for Cox's apples did not pay on the (0N), and the (2N) subplots. This was mainly due to the reason that with the exception of the first few years, most of the yield differences between drained and undrained plots on (0N) and (2N) subplots were not statistically significant

(Table 8.8). This was verified by a 't' test (Sachs, 1982). As shown in Table 8.9 the lower yields of Cox's on the (0N) and (2N) subplots of the very well drained plot resulted in lower net revenues.

In the case of Golden, both the (1N) and (2N) subplots turned out to be the most profitable investment strategy with respect to drainage improvements and nitrogen level. Profitable rates of IRRs were noted for other subplots as well. These high rates of return for the (1N) and (2N) subplots were mainly due to relatively higher yields of Golden apples on drained plots. These results indicate that Golden apples respond much better to drainage on marine clay soils if adequate amounts of nitrogen fertilizer are added. On average yields of Golden apples were much higher than that of Cox's under different drainage and nitrogen fertilizer conditions.

Table 8.7. INTERNAL RATES OF RETURN OF SUBSURFACE DRAINAGE AND NITROGEN FERTILIZER TREATMENTS WITH RESPECT TO AFTER STORAGE PRICES*

	COX'S ORANGE PIPPINS	GOLDEN DELICIOUS
	IRR %	IRR %
NFT		
0N	-	63
1N	55	78
2N	-	78

*The economic life time of the project is 15 years.

TABLE 8.8. ANNUAL YIELD RECORDS OF APPLES ON DRAINED AND UNDRAINED PLOTS WITH RESPECT TO DIFFERENT NITROGEN FERTILIZER TREATMENTS.

YEAR	i. ANNUAL YIELD RECORDS OF COX'S APPLES (kg/ha)					
	DRAINED			UNDRAINED		
	(ON)	(1N)	(2N)	(ON)	(1N)	(2N)
1967	1496	2024	1672	2024	1936	1496
1968	6512	5544	5192	6248	3256	3608
1969	28248	31768	32736	22264	26664	29920
1970	34232	39424	39952	29920	34408	31416
1971	35112	38104	38544	31328	36344	35728
1972	14784	18304	17952	16896	14520	19976
1973	36432	38192	40040	33000	37136	36256
1974	7304	21560	18920	8448	15224	14256
1975	26312	33264	26664	29216	31323	34848
1976	10912	7744	8888	11088	12496	15840
1977	47432	46904	42240	47168	50600	47344
1978	38808	40480	38104	41008	39864	41184
1979	42416	46464	30800	38368	31240	42680
1980	37928	39600	36080	38720	33792	35640

YEAR	ii. ANNUAL YIELD RECORDS OF GOLDEN APPLES (kg/ha)					
	DRAINED			UNDRAINED		
	(ON)	(1N)	(2N)	(ON)	(1N)	(2N)
1967	5544	6336	6600	4752	5280	5104
1968	8448	10296	12056	5456	5544	6424
1969	28952	29920	31856	23232	24552	29744
1970	44880	46552	48400	32912	32824	35376
1971	62128	65384	65912	59312	60280	61512
1972	50952	54472	54296	47872	50776	50600
1973	39336	39952	41624	36344	38544	36080
1974	33792	35816	40128	28424	31856	36520
1975	48136	46552	45760	44704	44000	47872
1976	35904	41624	39776	32472	45144	43736
1977	53064	53944	51568	54912	52624	55176
1978	49368	49544	47696	51480	54472	55528
1979	64680	61424	66176	61336	58692	62216
1980	49984	49544	50512	47696	50512	46376

TABLE 8.9. ANNUAL NET REVENUES OF APPLES (Dfl/ha) ON DRAINED AND UNDRAINED PLOTS WITH RESPECT TO DIFFERENT NITROGEN FERTILIZER TREATMENTS.

YEAR	ANNUAL NET REVENUES OF APPLES (kg/ha)					
	DRAINED			UNDRAINED		
	COX'S			GOLDEN		
	(0N)	(1N)	(2N)	(0N)	(1N)	(2N)
1967	-810.09	-192.42	-131.72	-217.37	4.52	86.94
1968	-144.94	2355.01	1552.51	1705.40	3096.14	3705.29
1969	2810.51	2639.07	1293.01	1735.17	1515.47	593.00
1970	1439.11	1910.20	3053.20	9235.84	10519.20	10003.00
1971	1660.57	1036.11	867.32	533.76	1245.78	1067.23
1972	-2482.80	4516.71	-2827.50	2709.70	3233.29	3368.10
1973	1261.83	266.88	976.84	517.21	37.60	1061.41
1974	-1285.80	6974.16	4593.75	4410.30	3065.36	2821.76
1975	-2671.40	1212.06	-7188.30	1041.00	629.76	-1315.60
1976	-637.41	-5512.70	-7906.80	1278.05	-1967.40	-2178.10
1977	-24.90	-6234.50	-8479.50	-1685.10	660.90	-2857.30
1978	-1432.70	-65.01	-1722.90	-484.40	-558.33	-721.50
1979	699.10	3964.82	-3701.60	56.20	62.70	218.10
1980	-892.75	2935.72	-93.06	646.92	-709.91	1549.04
1981	-179.41	1129.02	-1408.20	1534.48	1488.22	1242.90

Values representing 1981 are calculated averages over 14 years.

8.4 Summary and conclusion

Testing the relative impact of several pricing procedures the study primarily aimed to achieve a better understanding of the complex interaction between drainage, nitrogen fertilizer application, total production, and the quality of apples produced. Results of these analyses revealed that yield and quality of Cox's responded more strongly to nitrogen fertilizer application. However, this response became negative when higher doses of nitrogen fertilizer were applied. In the case of Golden apples it was found that while this cultivar responded to drainage improvements, its interaction with nitrogen fertilizer treatments was not as clear as in the case of Cox's particularly, when quality aspects were taken into consideration. In all the test procedures Golden demonstrated IRR percentages that were much higher than the real interest rate. Furthermore, using after-storage prices, the incremental benefits of drainage were found to be much higher in the case of Golden apples. This was primarily due to two reasons: a) the overall higher yields of Golden apples on all plots as compared with that of Cox's apples, and b) the poor performance of Cox's apples on the poorly drained plots, particularly on (0N) and (2N) subplots.

With regard to cox's, the results emerging from these analyses suggest that production of this cultivar on drained marine clay soils will be most profitable if farmers apply the normal rates of nitrogen fertilizer. However, in the case of Golden apples while results of these series of analysis revealed that this cultivar responds positively to drainage, no clear understanding emerged with respect to its response to application of nitrogen fertilizer. On one hand, the quality analysis suggests higher levels of return on the (0N) subplots, and on the other hand, it seems that profitability is considerably high on the (1N) and (2N) subplots when quality aspects are not considered.

However, in the final analysis regarding choosing the most profitable apple cultivar for fruit production on marine clay soils, farmers must also consider ceratin other aspects such as the availability of imported apples in the domestic market. Equally important is the export potentials of certain apple cultivars. For this analysis it was assumed that prices chosen would reflect some of these aspects. For example, during this investigation it was noted that prices of Cox's apples were much higher than that of Golden apples. This was the main reason why despite of lower yields of Cox's its revenues and the resulting IRR were reasonably high. Witness the IRR of Cox's on the (1N) subplot in Table 8.2.

One of the major limitations of this investigation is that due to dearth of quality data (which was only limited to 5 years) the actual quality measures over the entire planning horizon could not be tested. Because although yields of both cultivars were relatively higher after 1973 period, it was not clear how much of those yields were class 1 apples. As discussed in section 8.1 records of quality classes represented a five year period during 1969-1973 inclusive.

CHAPTER 9

PHYSICAL AND ECONOMIC BENEFITS OF SUBSURFACE DRAINAGE BY SOIL TYPE IN EASTERN ONTARIO

9.1 Introduction

Artificial drainage of soils which are poorly and imperfectly drained naturally, can produce important positive impacts on agricultural productivity. Despite the undeniable gains, a comprehensive approach to quantify the physical and economic benefits of artificial drainage is virtually nonexistent in Ontario. The approaches that are extant result in wide discrepancies among on-farm benefit evaluation hampering private decision-making regarding drainage investment as well as public involvement in facilitating such investment. Many drainage projects, particularly outlet drains, are controversial not only because of possible negative off-farm effects, but because so little clarity exists relative to on-farm benefits.

The controversy in benefit calculations centers on three problem areas:

1. The most important is the stochastic nature of annual yield increases resulting from drainage. These yield increases differ annually because of variations in annual climatic conditions, mainly precipitation. Most evaluations have been carried out on the basis of a fixed yield increase, obtained by comparing yields on drained as opposed to undrained land over a relatively short time period, usually one or a few successive years (e.g. Brooks, 1971; Galloway and Johnston, 1982; Leitch and Kerestes, 1981). The ensuing average does not truly represent the average annual yield increase. Furthermore, some of these evaluations do not take the relationship among yield, drainage and precipitation into account.

2. Most studies do not distinguish drainage benefits among soil types, but either represent one specific soil or lump together all or several soil types (e.g. Brooks, 1971; Cecile et al., 1985; Galloway and Johnston, 1982; Van Vuuren and McCaw, 1987).

3. Yield response may be obtained from test plots or from actual farm observations. Using test plot data provides the advantage of being able to control other variables affecting yield. These variables can then be kept at the same level between drained and undrained land. On the other hand, studies using experimental plot data are usually criticized because plot yields do not represent average farm yields. Although farm observations provide actual yield figures, there are also disadvantages in using these data. It becomes difficult, costly, and often impossible to obtain information on all variables affecting yield. Since the magnitude of these variables differs among farms, these variables should be incorporated in the model, but are often excluded because they are not available.

This study concentrates on on-farm benefit evaluation of subsurface drainage in eastern Ontario, Canada. It excludes any off-farm effects and is entirely based on secondary data which have been compiled by various provincial agencies (e.g. OMAF). Eastern Ontario was chosen because a substantial amount of undrained land remains there. The availability of undrained land is important because the yield on artificially drained land must be compared to that of undrained land. This study uses farm rather than experimental plot data, although management data, which are important in determining yield, could not be obtained. The main purpose of this investigation is to find out whether or not secondary farm records can be used for economic valuation of subsurface drainage on the farm level. For this economic valuation the emphasis will be on the interrelationship among yield, natural soil drainage classes, precipitation levels, and soil types. Such interrelationship is lacking in most drainage evaluation studies.

Benefits from artificial drainage are twofold; (a) drainage increases yield when compared to that from undrained land, and (b) it allows change in cropping patterns from low- to high-value crops where high-value crops cannot be grown economically on undrained land. This study concentrates on both kinds of benefits. It investigates the magnitude of the physical increase in corn yield emanating from artificial drainage on various soil types under various natural soil drainage classes. Corn was chosen because it is an important cash crop in most parts of Ontario where corn heat units are adequate and because corn is sensitive to moisture stress. In addition to ascertaining the physical yield increase, the economic benefits of subsurface drainage resulting in increased corn yield are examined. The study also examines the economic benefits resulting from a switch in cropping pattern on naturally poorly drained soils from oats to corn.

9.2 Methods and Material

Production Function

The quantitative impact of variables affecting crop yield is estimated from a production function. This function is a mathematical expression relating crop yield to all variables impacting on that yield. These variables can be divided into two groups: first, those under the farmer's control, such as the amount of labor and capital applied and the timing of their application and second, those beyond the farmer's control, such as weather conditions and soil type. The capital input includes all nonland and nonlabor inputs, such as fertilizer, seed, pesticides machinery use, etc. The production function is mathematically expressed as:

$$Y_c = f(L, C \mid W, S, N) \qquad 9.1$$

Where:

Y_c=corn yield; L=labor; C=capital; W=weather conditions; S=soil type; N=natural soil drainage classes.

The variables to the left of the vertical bar are those under the control of the farmer, while those to the right of the bar are not. Inputs under the control of the farmer can be categorized as management (denoted by M). In most estimation procedures variables not under the control of the farmer are excluded from the equation. It is assumed that they are either fixed among farms or years or, if varied, that they have a zero mean, a constant variance, and zero covariance with variables under the control of the farmer.

Preferably all non-constant variables affecting corn yield should be included in a regression equation in order to estimate that yield. Due to privacy protection legislation, which forbids the release of names and addresses of farmers from whom the government records crop yields, these farmers could not be contacted. Consequently, no management input data could be collected. This precludes the inclusion of relevant management data. However, information is available on the drainage condition of parcels. Exclusion of management data results in a low R^2. The effect of management is captured in the constant term of the equation. The estimation is based on the assumption that the management variable has a zero mean, a constant variance, and zero covariance with variables not under the control of the farmer.

The production function for this study concentrates on factors beyond the control of the farmer. It includes three major factors: soil type (here the term soil type and soil texture will be used as synonyms), natural soil drainage condition, and monthly precipitation levels during the first four months of the growing season. Mathematically it is expressed as:

$$Y_c=f(S, N, W \mid M) \qquad 9.2$$

This equation estimates corn yield per acre from the three variables to the left of the vertical bar, but excludes management. The original yield data are stated in bushels per acre. The production function is measured in these units. They will later be converted into kg. or tonnes per hectare.

The study area represents seven soil types. These include: sands, sandy loam, loam, silt loam, clay loam, clay and heavy clay. These soil types were determined with respect to the relative proportions of the various soil separates in a soil as described by the classes of soil texture given by Agriculture Canada (1978). The description of these classes are given in Table 9.1. Depending on topographic conditions and characteristics of the subsoil layers in the study area these seven soil types have been grouped under three natural soil drainage classes. Natural drainage classes are defined on the basis of field moisture capacity and length of period during which excess moisture is present in the soil. Three classes used in this analysis are: naturally well drained, imperfectly drained, and poorly drained soils. Naturally well drained land is defined as land where due to the inherent characteristics of the soil (e.g. texture) water leaves the soil rapidly. Land is considered naturally imperfectly drained if water leaves the soil slowly enough in relation to supply of water so that the soil remains wet for a medium length of time during the growing season. This situation usually occurs in stratified soils (Foth and Turk, 1972). Land is considered naturally poorly drained if water leaves the soil so slowly in relation to the supply of water that the soil remains wet for a comparatively large part of the growing season. This situation occurs either in fine textured soils or in low-lying areas and places where water movement in the soil profile is restricted due to the presence of an impervious layer in the subsoil.

Precipitation is expressed in terms of monthly levels of rainfall in mm. in May, June, July, and August. Based on earlier investigations (e.g. Upfold and Morris, 1987) it was found that in Ontario a harmful effect of climate on corn yield is most likely to occur during the first four months of corn growth and development. This critical time period begins right after planting and ends when grain filling gets underway.

Table 9.1. THE NAMES OF SOIL TEXTURAL CLASSES USED IN THIS INVESTIGATION WITH RESPECT TO THEIR CLAY CONTENTS.

SOIL TEXTURAL CLASSES	CLAY CONTENTS IN %
Sands	not > 15.0
Sandy loams	not > 20.0
Loams	7-27.0
Silt loams	12-27.0
Clay loams	27-40.0
Clays	≥ 40.0
Heavy clays	> 60.0

Soil type and natural soil drainage class are expressed as dummy variables in the model. These are qualitative variables difficult to quantify. A statistically significant regression coefficient for dummy variables signifies a change in intercept. It is assumed that precipitation has the same yield effect on all soil types and natural soil drainage classes, but that total yields per acre differ among soil types and natural drainage classes.

Two regression equations representing the production functions are estimated, one for artificially drained land and the other for land without artificial drainage. The observations are per farm. Precipitation is not measured per farm. Instead, precipitation levels at the nearest weather station are used.

The functional form of the regression equation conforms to a priori expectations. Moisture stress can result from too little or too much moisture. It is therefore expected that yield is negatively affected by very low levels of moisture. Yield is expected to increase by increasing moisture till it reaches an optimum level. Beyond that level, additional moisture is expected to decrease yield. This kind of response curve can be obtained by using a quadratic or a square root function. The quadratic form is adopted for this analysis since it gives better statistical results than the square root function.

Estimating incremental crop yield

According to the production function specified above, yields will differ annually because of annual variations in monthly precipitation levels. Since precipitation is a stochastic variable, the actual annual value of monthly precipitation levels over the lifetime of the drain is unknown. Over a long time period, however, monthly precipitation is normally distributed. The expected value of this distribution is a good estimate of the average annual monthly precipitation level over the lifetime of the drain. Expected values of monthly precipitation levels differ somewhat among the various weather stations in the region. Consequently estimated incremental crop yields will also differ among soils of the same type and natural soil drainage class, according to where those parcels are located. Differences in expected values of monthly precipitation levels among weather stations are partly the result of differences in length of time over which these expected values are calculated. The longer the time period over which records are available, the more accurate expected values of monthly precipitation levels will be relative to the true averages. The Ottawa CDA (the abbreviation is a reference to one of the three weather stations in Ottawa) weather station commenced its records in 1890. Since this station has the longest track record over time in the area, monthly precipitation levels from 1890 to 1986 from the Ottawa CDA weather station were used to calculate their expected values. The benefit analysis for this study is thus based on the precipitation regimen prevailing around the Ottawa CDA weather station. For another precipitation regimen the benefits will be different. However, for small regions such as the one under consideration for this study in eastern Ontario, these differences are usually small.

The above computed expected values of monthly precipitation levels are substituted in the production functions giving the estimated average (here the term average is used as synonym for sample mean) annual corn yield on drained and on undrained land. Deducting corn yield on undrained from that on drained land provides the estimated average annual increase in crop yield per acre due to subsurface drainage.

Economic evaluation

Two economic evaluations are performed, one for the incremental crop yield of corn, and the other for a change in cropping pattern from oats to corn. The incremental crop yield must be converted into an average annual net revenue. This is done by multiplying the additional average annual corn yield by its average net price (net of trucking and insurance) and deducting the annual maintenance cost of the drain. Other pertinent information includes the initial investment cost of the subsurface drain and the going interest rate. The criterion used for the evaluation is the internal rate of return (IRR). This is defined as the discount rate which makes the net present value of the investment equal to zero. Mathematically it is expressed as:

$$I_o = \Sigma N_R/(1+i)^t \qquad 9.3$$

Where:

I_o=initial investment cost per hectare; N_R=average annual net revenue per hectare; i=internal rate of return (IRR); T=time span during which the investment lasts.

The IRR must be compared to the going interest rate r. If IRR > r then investment is economically beneficial. If IRR < r the investment is not profitable. In this analysis IRR should be compared with the real interest rate since the analysis is performed in deflated dollars. Over the long run the real interest rate is around 4%.

For the change in cropping pattern the average annual net revenue is obtained from the following equation:

$$N_R = [Y_cP_c - i_c] - [Y_oP_o - i_o] \qquad 9.4$$

Where:

Y_c=total corn yield in tonnes per hectare from drained land; P_c=average corn price per tonne; i_c=production cost of corn per hectare excluding the cost of land; Y_o=total oats yield in tonnes per hectare on undrained land; P_o=average price of oats per tonne; i_o=production cost of oats per hectare excluding the cost of land.

Data used

Since 1979 the Crop Insurance and Stabilization Branch (CIS) of the Ontario Ministry of Agriculture and Food (OMAF) has been collecting farm records including crop yields and information concerning the drainage condition of the fields. For this analysis these data from five counties in eastern Ontario were used covering eight years, 1979-1986.

The annual aggregate monthly precipitation levels for the climatic stations in the study area were obtained from Environment Canada in Toronto.

Information concerning soil types and natural drainage classes were obtained from the Soil and Water Management Section (SWM) of OMAF. The SWM data were compiled from Ontario soil maps and represent those farms that were recorded in the CIS crop yield records. However, these recorded soil types of individual farms may not be entirely accurate because of the scale of the soil maps. Moreover, over time natural soil drainage classes may change because of human activity affecting ground water levels, for example, the digging of outlet drains and wells. Since the soil information is based on maps that are

Table 9.2. NUMBER OF OBSERVATIONS AND SAMPLE MEAN CORN YIELDS (bushels/acre) BY NATURAL DRAINAGE CLASSES AND SOIL TYPES ON ARTIFICIALLY DRAINED FIELDS.

	NATURAL AND ARTIFICIAL DRAINAGE CONDITIONS					
	POOR		IMPERFECT		WELL	
	N	Y	N	Y	N	Y
SOIL TYPES						
Sands	32	101.8	40	76.2	37	92.2
Sandy loams	47	97.2	49	99.1	10	108.4
Loams	7	87.3	12	86.6	70	58.8
Silt loams	139	99.4	2	78.5	-	-
Clay loams	86	98.6	31	94.2	2	95.9
Clays	84	86.4	-	-	-	-
Heavy clays	216	98.6	-	-	-	-

N=number of observations, Y=sample mean yields.

around 40 years old, the natural soil drainage classes used may not be entirely accurate at present.

The distribution of sample mean crop yields according to soil types, natural drainage classes, and artificial drainage condition of the field are given in Tables 9.2, and 9.3.

For several soil types there were no observations for certain natural drainage classes. For the purpose of this analysis the yield records were pooled together for all artificially drained fields and also for all fields without artificial drainage. In order to separate the soil types and natural drainage classes dummy variables were used. An example of the matrix representing all

Table 9.3. NUMBER OF OBSERVATIONS AND SAMPLE MEAN CORN YIELDS (bushels/acre) BY NATURAL DRAINAGE CLASSES AND SOIL TYPES ON FIELDS WITH NO ARTIFICIAL DRAINAGE.

	NATURAL AND ARTIFICIAL DRAINAGE CONDITIONS					
	POOR		IMPERFECT		WELL	
	N	Y	N	Y	N	Y
SOIL TYPES						
Sands	2	76.1	9	43.1	16	71.8
Sandy loams	22	69.8	23	72.1	1	113.6
Loams	2	78.1	8	58.5	27	78.7
Silt loams	41	88.6	1	84.0	-	-
Clay loams	31	75.9	5	44.1	-	-
Clays	17	59.7	9	69.9	-	-
Heavy clays	86	69.2	-	-	-	-

N=number of observations, Y=sample mean yields.

the dummy variables is provided in table 9.4. However, in accordance with statistical principle governing the use of dummy variables, sandy soil and naturally well drained class were used as two separate bases in the analysis. The effect of these statistical bases will be captured in the constant term.

9.3 Results and discussion

Production function estimates

Table 9.5 shows the regression coefficients of the production functions estimating corn yield on artificially drained as well as on undrained land. It also

Table 9.4. A MATRIX OF TWO SETS OF DUMMY VARIABLES REPRESENTING NATURAL DRAINAGE CONDITIONS AND THE SOIL TYPES FOR ARTIFICIALLY DRAINED CONDITION.

		Dummy variable									
		Natural drainage			Soil types						
NATURAL DRAINAGE	SOIL TYPES	SND^1	SND^2	SND^3	SD^1	SD^2	SD^3	SD^4	SD^5	SD^6	SD^7
Poor	Sands	1	0	0	1	0	0	0	0	0	0
Imperfect	sands	0	1	0	1	0	0	0	0	0	0
Rapid	Sands	0	0	1	1	0	0	0	0	0	0
Poor	Sandy loams	1	0	0	0	1	0	0	0	0	0
Imperfect	Sandy loams	0	1	0	0	1	0	0	0	0	0
Rapid	Sandy loams	0	0	1	0	1	0	0	0	0	0
Poor	Loams	1	0	0	0	0	1	0	0	0	0
Imperfect	Loams	0	1	0	0	0	1	0	0	0	0
Rapid		0	0	1	0	0	1	0	0	0	0
Poor	Silt loams	1	0	0	0	0	0	1	0	0	0
Imperfect	Silt loams	0	1	0	0	0	0	1	0	0	0
Rapid	Silt loams	0	0	1	0	0	0	1	0	0	0
Poor	Clay loams	1	0	0	0	0	0	0	1	0	0
Imperfect	Clay loams	0	1	0	0	0	0	0	1	0	0
Rapid	Clay loams	0	0	1	0	0	0	0	1	0	0
Poor	Clays	1	0	0	0	0	0	0	0	1	0
Imperfect	Clays	0	1	0	0	0	0	0	0	1	0
Rapid	Clays	0	0	1	0	0	0	0	0	1	0
Poor	Heavy clays	1	0	0	0	0	0	0	0	0	1
Imperfect	Heavy clays	0	1	0	0	0	0	0	0	0	1
Rapid	Heavy clays	0	0	1	0	0	0	0	0	0	1

SND^1=naturally poorly drained; SND^2=naturally imperfectly drained; SND^3=naturally well drained; SD^1=sands; SD^2=sand loams; SD^3=loams; SD^4=silt loams; SD^5=clay loams; SD^6=clays; SD^7=heavy clays.

shows their level of significance. The coefficients found are the best estimates given the limited amount of data.

Almost all coefficients of the soil variables are significant, except those for loams and clays on undrained land. Almost all coefficients of the soil variables are significant, except those for loams and clays on undrained land. The coefficients must be related to the deleted dummy, sandy soil. For example, the yield on sandy loams on artificially drained land is 9.6 bushels/acre higher than on sandy soils. According to Table 9.5 loams and clays give a lower yield than sandy soils on artificially drained land. Why this is so is not entirely clear.

TABLE 9.5

RESULTS OF THE MODEL RELATING CORN YIELDS TO MONTHLY LEVELS OF PRECIPITATION, ARTIFICIAL DRAINAGE, SOIL TYPES, AND NATURAL SOIL DRAINAGE CLASSES IN EASTERN ONTARIO, 1979-1987

Parameters	Estimates	
	With artificial drainage	Without artificial drainage
Intercept	64.61	1.65
Sandy loams	8.60****	14.86****
Loams	-7.12***	5.03
Clay loams	5.66***	17.66****
Clays	-8.77****	6.24
Heavy clays	4.25*	10.75*
Silt loams	4.72*	29.25****
Naturally poorly drained soils	1.05	-14.60***
Naturally imperfectly drained soils	-7.30****	-19.25****
Precipitation level in May	0.047	0.79****
Precipitation level in June	0.125	0.28*
Precipitation level in July	0.42****	0.71***
Precipitation level in August	0.21***	0.38*
Precipitation level in May (squared)	-0.0007	-0.0058****
Precipitation level in June (squared)	-0.0005	-0.00132**
Precipitation level in July (squared)	-0.0027****	-0.00407***
Precipitation level in August (squared)	-0.00088**	-0.00197*
Number of observations	863	300
R2	0.10	0.23

**** significance level at 95% or higher
*** significance level at <95% but at or above 90%
** significance level at <90% but at or above 85%
* significance level at <85% but at or above 79%

The natural soil drainage classes show significant coefficients except for naturally poorly drained soils which are artificially drained. These coefficients must be compared with corn yield on naturally well drained soils. One expects a descending order in yield on undrained land, the highest on naturally well drained and the lowest on naturally poorly drained land. The order in yield between the naturally poorly and imperfectly drained land does not occur as expected. This could be caused by inaccurate soil type as well as inaccurate soil drainage class information alluded to earlier. On artificially drained land yield differences among natural soil drainage classes may disappear. This is apparently so for naturally poorly but not for naturally imperfectly drained soils.

As expected, corn yields are more sensitive to precipitation on undrained than on artificially drained land. Precipitation in May has a particularly significant effect on corn yield on undrained land. This signifies the sensitivity of corn yield to insufficient and to excess moisture. The latter results in a delayed planting date and lower soil temperature at planting and seed germination time. On artificially drained land, on the other hand, excess moisture does not have a detrimental effect on crop growth. This is due to a lower ground water table and consequently higher soil temperature during germination and leaf development. Precipitation in July and August appears to be important on artificially drained land. The lower ground water table due to subsurface drainage may cause moisture stress during the flowering stage (July and August) when the atmospheric demand on the crop is relatively high. Increased moisture will increase yield. However, beyond a certain moisture level in July and August, even on artificially drained land, yields will decrease.

Difference in corn yield between subsurface drained and undrained land

Using the coefficients given in Table 9.5 and the expected precipitation value for the relevant months derived from the 1890-1986 precipitation data at the Ottawa CDA weather station, the average annual corn yields on artificially drained and on undrained land and their differences are calculated for different soil types and natural drainage conditions. These values are presented in Table 9.6. As expected, yield differences are largest on naturally poorly drained soils. However, caution must be exercised in interpreting some of these findings particulary in cases where the coefficients are based on a very limited variation in the actual data. It will be noted that when comparing soil types, yield differences are larger on the lighter soils. This phenomenon can be due to a number of factors. Firstly, on sand plains drainage is poor due to the closeness of the water table to surface (OMAF and OMNR, 1982). Secondly, most sandy soils in this region occur on layers of clay (e.g. Richards et al., 1949; Matthews and Richards, 1952; Matthews and Richards, 1954). Under these conditions subsurface drainage by improving drainage conditions of the soil enhances crop

TABLE 9.6

EXPECTED AVERAGE ANNUAL CORN YIELD ON ARTIFICIALLY DRAINED (SUBSURFACE) AND UNDRAINED LAND FOR POORLY, IMPERFECTLY, AND WELL DRAINED NATURAL SOIL CLASSES BY SOIL TYPE IN EASTERN ONTARIO

	Natural soil drainage classes								
Soil type	Yield poorly drained land			Yield imperfectly drained land			Yield well drained land		
	Drained	Undrained	Difference	Drained	Undrained	Difference	Drained	Undrained	Difference
	tonne/ha	tonne/ha	kg/ha	tonne/ha	tonne/ha	kg/ha	tonne/ha	tonne/ha	kg/ha
Sands	5.81	4.93	880	5.35	4.63	720	5.81	5.83	-20
Sandy loams	6.35	5.85	500	5.90	5.56	340	-	-	-
Loams	5.40	4.92	480	4.91	4.63	280	5.40	5.83	-430
Silt loams	6.11	6.76	-650	-	-	-	-	-	-
Clay loams	6.20	6.03	170	-	-	-	-	-	-
Clays	5.30	4.92	380	-	-	-	-	-	-
Heavy clays	6.10	5.59	510	-	-	-	-	-	-

yields. Moreover, light soils are usually low in cohesive materials such as organic matter or clay. Rainfall, depending on its velocity and duration, causes destruction of soil aggregates of these light soils into original constituents. After separation by water these constituents from a dense structure which becomes either a single grain or a stratified crust at the surface or in the lower layers of the plowing depth. These layers not only hamper root development but also hinder the water and air exchange which in turn causes poor permeability. Improved on-farm drainage enhances water movement in the soil profile and consequently allows excess moisture to drain without causing slaking.

The soils in the tables are listed in order from light to heavy soils. The pattern of yield differences between drained and undrained land among these ordered soils is U-shaped. The largest yield differences are found on both the lightest and the heaviest soils. Why drainage of silt loams has a negative effect on corn yield remains unexplainable.

Average annual net benefits of increased yield

The physical yield differences recorded in Table 9.6 must be converted into an economic value, the average annual net revenues. This is done by multiplying these yield differences in Table 9.6 by net corn prices and deducting the annual maintenance cost of the drain. Net corn prices are obtained by deducting the annual maintenance cost of the drain. Net corn prices are obtained by deducting trucking and insurance cost per tonne from the price of corn per tonne.

Three different gross corn prices are used: an intermediate price of $124/tonne based on the 10-year average corn price 1979-1988, a low price of $88.50/tonne and finally a high price of $157.50/tonne. The use of these various prices shows how sensitive the IRR is to the level of commodity prices. Table 9.7 shows the annual net revenues from additional corn yield exclusive of investment cost on poorly and imperfectly drained land at various corn prices by soil type.

Consistent with the results in table 9.6 the highest average annual net revenues are obtained from sandy soils. Net revenues fall as soils become heavier with lowest returns for silt and clay loams, and rise again for clays and heavy clays.

TABLE 9.7

EXPECTED AVERAGE ANNUAL NET BENEFITS (EXCLUSIVE OF INVESTMENT COST) OF ARTIFICIAL (SUBSURFACE) DRAINAGE BASED ON VARIOUS CORN PRICES BY SOIL TYPE FOR EASTERN ONTARIO

Soil type	Annual maintenance cost	Poorly drained: Yield diff.	Poorly drained: Annual net ben. based on corn price/tonne[1] $88.50	$124	$157.50	Imperfectly drained: Yield diff.	Imperfectly drained: Annual net ben. based on corn price/tonne[1] $88.50	$124	$157.50
	$/ha	kg/ha	$/ha	$/ha	$/ha	kg/ha	$/ha	$/ha	$/ha
Sands	3.72	880	69.32	100.65	130.04	720	56.04	81.70	105.72
Sandy loams	3.72	500	37.80	55.60	72.30	340	24.50	36.61	48.00
Loams	4.46	480	35.40	52.47	68.50	280	18.80	28.75	38.10
Silt loams	4.46	-650	-	-	-	-	-	-	-
Clay loams	5.58	170	8.53	14.60	20.26	-	-	-	-
Clays	5.58	380	25.96	39.50	52.20	-	-	-	-
Heavy clays	5.58	510	36.75	55.00	72.00	-	-	-	-

1 Trucking and insurance costs are assumed to be $3.40 and $2.10 per tonne respectively.

Internal rates of return (IRR) of subsurface drainage in relation to increased corn yields

The IRRs of subsurface drainage based on additional corn yields are given in Table 9.8 for naturally poorly and in Table 9.9 for naturally imperfectly drained soils. Although the average annual net revenues exclusive of investment cost are comparable between heavy clays and sandy loams and loams, the IRRS associated with heavy clay are much lower. This is caused by the higher installation cost of subsurface drainage on soils containing clay.

TABLE 9.8

INTERNAL RATES OF RETURN OF SUBSURFACE DRAINAGE INVESTMENT IN NATURALLY POORLY DRAINED SOILS OVER DIFFERENT TIME PERIODS AND AT VARIOUS CORN PRICES BY SOIL TYPE IN EASTERN ONTARIO

Soil type	Drainage installation cost	Internal rate of return: Corn price $88.50/tonne		Corn price $124/tonne		Corn price $157.50/tonne	
		25 years	40 years	25 years	40 years	25 years	40 years
	$/ha	%	%	%	%	%	%
Sands	744.15	7.93	9.02	12.86	13.44	17.14	17.44
Sandy loams	744.15	1.93	4.03	5.52	6.96	8.43	9.45
Loams	892.77	0	2.47	3.21	5.06	5.80	7.20
Silt loams	892.77	-	-	-	-	-	-
Clay loams	1116.22	-10.06	-4.87	-7.29	-2.85	-5.33	-1.47
Clays	1116.22	-3.80	0	0	1.81	1.24	3.49
Heavy clays	1116.22	-1.44	1.41	1.67	3.83	4.72	5.76

At an intermediate corn price it does not pay to drain the heavier soils in the naturally poorly drained soil class for the sole purpose of increasing the yield of corn if this crop is already routinely sown on the undrained land. On naturally imperfectly drained soils subsurface drainage for the purpose of increasing corn yield does not pay off except on sandy soils and on sandy loams if the corn price is high.

The effect of a higher corn price on the IRR is much more pronounced on those soils which show a relatively high IRR at the lowest corn price. The higher the IRR at the lowest corn price, the greater the absolute increase in IRR if the corn price increases. This means that the profitability of subsurface drainage for the sole purpose of producing additional corn per hectare increases more rapidly on lighter than on heavier soils if corn prices go up.

TABLE 9.9

INTERNAL RATES OF RETURN OF SUBSURFACE DRAINAGE INVESTMENT IN NATURALLY IMPERFECTLY DRAINED SOILS OVER DIFFERENT TIME PERIODS AND AT VARIOUS CORN PRICES BY SOIL TYPE IN EASTERN ONTARIO

Soil type	Drainage installation cost	Internal rate of return					
		Corn price $88.50/tonne		Corn price $124/tonne		Corn price $157.50/tonne	
		25 years	40 years	25 years	40 years	25 years	40 years
	$/ha	%	%	%	%	%	%
Sands	744.15	5.60	7.03	9.95	10.80	13.62	14.13
Sandy loams	744.15	-1.44	1.41	1.66	3.82	4.07	5.76
Loams	892.77	-4.42	0	-1.60	1.30	0	2.91

Profitability of subsurface drainage due to switched cropping patterns

The big payoff of subsurface drainage occurs primarily from being able to switch cropping patterns from low- to high-value crops. Table 9.10 lists the average annual net benefits exclusive of investment cost and the IRRs of subsurface drainage on naturally poorly drained soils by a switch from oats to corn made possible by subsurface drainage, assuming that corn cannot be grown economically on this drainage class without artificial drainage. The oats yield used is an average yield from 1979 to 1986 for eastern Ontario obtained from the Agricultural Statistics for Ontario (OMAF Publication 20, various issues). In

TABLE 9.10

AVERAGE ANNUAL NET BENEFITS AND INTERNAL RATES OF RETURN OF SUBSURFACE DRAINAGE INVESTMENT IN NATURALLY POORLY DRAINED SOILS OVER DIFFERENT TIME PERIODS ASSUMING A CHANGE IN CROPPING PATTERN FROM OATS TO CORN DUE TO ARTIFICIAL DRAINAGE BY SOIL TYPE IN EASTERN ONTARIO[1]

Soil type	Drainage installation cost	Average annual net benefits exclusive of investment cost	Internal rate of return	
			25 years	40 years
	$/ha	$/ha	%	%
Sands	744.15	159.30	21.23	21.40
Sandy loams	744.15	231.80	31.11	31.15
Loams	892.77	103.54	10.70	11.44
Silt loams	892.77	198.84	22.12	22.26
Clay loams	1116.22	209.80	18.52	18.77
Clays	1116.22	89.02	6.20	7.53
Heavy clays	1116.22	196.42	17.26	17.57

Based on the following assumptions:
Production costs of corn and oats exclusive of a charge for land are $692/ha and $358/ha respectively.
Prices for corn and oats are $134.21/tonne and $130.30/tonne respectively.
Oat yield is 2.17 tonnes/ha.

this case yield is not calculated from a production function for oats on undrained land. Corn yields, on the other hand, are derived from the production function on artificially drained land.

As Table 9.10 shows, the average annual benefits of this switch are considerable and as a consequence, the IRRs are high. With this switch silt loams provide a very high IRR, while conversely it is unprofitable to drain these soils for the mere purpose of increasing the yield of currently grown corn on those undrained loams.

9.4 Summary and conclusions

To assess the economic value of subsurface drainage on the basis of farm records it is imperative to have access to detailed physical information particularly those pertaining to soil conditions. Soil information extracted from relatively old soil maps may not be entirely accurate. Such information must be verified by either analyzing some field samples collected from each farm or farmer's records and/or his own account of his field's soil condition. Management data is also very crucial for such investigations. Some of the high yields on sandy soils (which are low in organic matter content) may be due to application of fertilizers. Moreover, not all farmers use their production factors efficiently. Hence, some variations in yield are due to farmer's agricultural knowledge and managerial skills. In the absence of this essential information results of an investigation may be too generalized. Therefore, they may not represent the actual farm situation.

Despite limitations of this investigation, such as lack of management data and the use of somewhat inaccurate soil and natural soil drainage class information per farm, due to old large scale soil maps, the results obtained are nevertheless consistent with theoretical considerations regarding the soil-water-plant relationship.

The results of this study can be summarized as follows:

1. Precipitation during the first 4 months of the growing season appears to be an important factor influencing corn yield. Where there is a significant relationship, yields will increase initially by increasing moisture level.

2. The increase in physical yield due to subsurface drainage is much higher on naturally poorly than on naturally imperfectly drained soils.

3. The greatest increase in physical yield due to subsurface drainage in the study area is found on lighter soils (as discussed in section 7.3) as well as on heavy clays.

4. Despite relatively great increases in physical yield on heavier soils, the IRRS of subsurface drainage on these soils are relatively low, mainly because of high installation costs of subsurface drainage.

5. Subsurface drainage resulting in a change in cropping patterns from low- to high-value crops shows a high payoff.

6. Given the agroclimatic conditions in eastern Ontario, the economic payoff of subsurface drainage is considerably higher when installation of drainage on the heavier soils of naturally poorly drained land is followed by a shift in cropping pattern. Given some of the findings of this investigation installing subsurface drainage for the sole purpose of increasing corn yield is only justifiable economically for the lighter soils, dependent on the natural drainage condition of the soil and on the price of corn.

Of course these results are based on limited information that represents a small geographic area. While these findings can be used as a general guideline, their use as a specific indicator for productivity of different natural drainage or soil conditions must be avoided. An investigation with more observations and accurate soil and management data may (or may not) provide other results.

CHAPTER 10

EPITOME

10.1 Concept

Land is an important limited natural resource that plays a significant role in our lives. Because of its ecological, economic and aesthetic functions too often conflicts arise between different activities that involve the same land resources.

Hence, every society, particularly those with limited or less suitable land base are faced with the basic problem of allocating limited land resources to many different uses. These different land uses are by no means the ultimate objectives, rather they are the means by which a society can manage its land resources in the pursuit of more fundamental objectives such as overall economic growth and development. Obviously, allocating most land resources to one sector may reduce the availability of land to other sectors of the economy. This may undermine the ability of society to achieve its overall development objectives. Therefore a society's long-term survival will depend on the ways it utilizes its land resources, among other things.

For the last few decades most societies, particularly industrialized countries focussed on one component of growth that is, a rapid economic development without much considerations for the carrying capacity of the environment. For example, in order to increase agricultural production for domestic use and export most industrialized countries favored land use decisions and public policies that encouraged agricultural expansion. Undoubtedly most of these decisions or policies were based on short-term immediate benefits that were seldom compared with their long-term costs. Consequently, the impressive agricultural development of the last few decades in those countries took place at the expense of a tremendous deterioration of the natural environment.

Besides short-term economic policies, there was another reason why the long term costs of rapid agricultural development were not taken into account. With highly uncertain elements such as climatic fluctuations, regional variations, and changes in societal goals, the task of optimum decision making was very difficult especially in the absence of adequate data and decision-making guidelines (frameworks).

One of the areas where these deficiencies were evident was the field of soil-water management. Although the physical aspects of soil-water management (i.e. agro-hydrology) are very advanced, the biophysical frontiers (e.g. enviro-economic aspects) of this field of science remained untouched. For example, the complex linkages among physical, biophysical, ecological and socio-economic factors of soil-water management (drainage) were neither well acknowledged nor were they quantified. Relating these to Figure 4.2, it may be said that in the past most drainage projects were primarily focussed on cause-effects that are presented in boxes 1-7, 13, 16, 34, and ultimately 8-12.

Consequently, numerous agricultural drainage projects were implemented without really going beyond its agricultural perspectives. The environmental perspectives of drainage projects were seldom even qualitatively discussed at the scientific level. Paucity of literature in that area is a witness to this deficiency in understanding the biophysical cause-effect structure of drainage and its impacts.

Today, there is a sufficient body of literature that illustrates the consequences of those short-term decisions on agricultural drainage. For example, it is reported that much of the wetland ecosystems in industrialized countries were lost due to mainly agricultural drainage. In the United States the annual loss of wetlands between the mid-1950s and the mid-1970s was 185000 hectares, with agricultural development accounting for 87 percent of the loss (World Resources 1987). According to Snell (1987) between 1967 and 1982, 57 percent of the modified wetlands in Ontario, Canada were put under crops. There are many other examples some of which have already been cited in earlier chapters of this thesis.

Currently, with the new socio-economic order, a surplus agricultural sector and an over burdened environment in industrialized countries on one hand and the rapid population increase, famine and hunger in non-industrialised countries on the other, sustainable agricultural development is the focus. However, with this new focus most societies are realizing that a long-term agricultural development requires a careful assessment of the complex relationship involved in socio-economic and biological aspects of agriculture, particularly in the area of soil-water management. Why particularly soil-water management? Because in addition to possible climatic changes in the future that will require a better soil-water management system, agricultural drainage as a soil-water management technique is considered to be an important input for sustainable agricultural productivity in both humid and arid regions. In humid regions efficient agricultural production, particularly on naturally poorly drained soils, will not be possible without drainage. Owing to the prevailing climatic and soil conditions in those regions sometimes farmers cannot plant their crops successfully if their fields are too wet. In arid regions agricultural drainage is required to create a dynamic equilibrium between irrigation and ground water table. In the absence of adequate drainage, the irrigation water will increase ground water level to the extent that crops will be negatively affected due to waterlogged and salt poisoned fields. Rise of ground water in arid regions causes salinity in the soil surface.

However, despite these unrefuted benefits of agricultural drainage, and the account of some of its environmental costs in industrialized countries, its interactive role in our socio-economic and environmental systems is not fully understood.

Decisions on drainage projects necessitate access to appropriate frameworks for quantifying the stream of its forthcoming benefits as well as its present and future costs. This implies that the process of evaluation would require an array of performance indicators that would reflect the cause-effect structure of drainage and its impacts.

Once these indicators are weighted in a quantitative terms that are meaningful to decision makers, then a menu of feasible alternatives can be prepared. The list of these feasible alternatives will assist farmers and pubic decision-makers to analyze decisions on agricultural drainage in a manner that maximizes social economic welfare. Social economic welfare can be maximized if the gainers are willing to recognize costs associated with their economic activities and consequently be willing to compensate the losers. Of course to some traditional economists this may appear as an idealistic approach and inapplicable. However, what these economists fail to realize are a) it is becoming increasingly apparent that the previous approach to agricultural development is no more sustainable. At stake are issues of concern to all of us. According to Van den Ban (1987) in Europe the effect of highly productive agricultural practices have caused not only concerns to environmentalists but also to the rural population themselves whose livelihood is dependent on soil, water and the genetic diversity of flora and fauna, and b) because of these issues West European farmers and public decision makers have adopted a new approach to decisions concerning agricultural development that aims to achieve social economic welfare in a balanced way. For example, farmers who are persuaded to forego development will be compensated for loss of profit under a Management Agreement Program (Ministry of Agriculture and Fisheries, 1987). One of the well known examples of such programs is a recent case in England where a farmer in Kent was compensated at the rate of £300,000/annually for 27 years for not draining 700 hectares of land known as Elmley Marshes for growing wheat (anonymous, 1987). The Elmley Marshes are identified under the Ramsar convention as a wetland of international importance. This was, however, a well publicized case because it involved a wetland which under a European directive was already recognized as an area of special scientific interest. Consequently society had already assigned certain values to the region that were equivalent to the amount that was paid to the farmer to forego draining of that environmentally sensitive area. But some of the remaining environmentally sensitive areas may not be as well known as the Elmley Marshes. Witness most wetlands in the United States that are being drained or otherwise destroyed at a rate of nearly 458,000 acres (183,200 ha) per year (Danielson and Leitch, 1986). In order to be able to protect environmentally sensitive areas (for example through management agreements) decision makers require a holistic guideline that will provide them with an array of performance indicators whereby all costs and benefits of agricultural drainage activities are quantitatively expressed. A holistic approach on the biophysical cause-effect structure of drainage and its impacts was virtually non-existent. Consequently, a system of performance indicators for weighing positive and negative aspects of agricultural drainage did not exist either.

It was against this background that the present study was undertaken. The study began as a mean not only to test a new joint academic collaboration between two universities, but also to respond to some of those deficiencies in the area of agricultural drainage research.

Hence, in accordance with research objectives the study was formulated to:

1. Provide an understanding of land resources, their uses, and conflicts in uses in the context of land use planning (corresponding with the first objective of the research),

2. Provide an understanding of soil-water management and agricultural drainage, particularly with respect to non-industrialized countries. Currently, most of those countries are in pursuit of agricultural self sufficiency. While it is absolutely essential that they increase productivity in order to provide a

continuous and a cheap source of food material for their inhabitants, it is equally important that they learn from past mistakes of industrialized countries, particularly with regard to drainage and the loss of unique wetlands (corresponding with the first objective of the research),

3. Provide an understanding of agricultural drainage, particularly with respect to its biophysical cause-effect structure and impacts (corresponding with the second objective of the research),

4. Provide a system of performance indicators by endogenizing environmental aspects of agricultural drainage so that it can be used at least for a qualitative examination of drainage costs and benefits. Furthermore, it will also enable future researcher to recognize and identify deficiencies in terms of input data and quantitative means for testing such a system of performance indicators (corresponding with the third objective of the research),

5. Provide a framework that can be used to test at least two system performance indicators from agricultural perspectives (corresponding with both third and fourth objectives of the research),

6. Provide two case-studies that will illustrate whether or not available input data can be used to quantify two agricultural indicators of drainage that reflect farmers' perspective (corresponding with the fourth objective of the research).

10.2 Approach

The thesis is not designed to critically examine the economic theory as it relates to environmental issues, nor does it claim to have found "the answer" to land use conflicts involving agricultural drainage and wetland conservation. It is rather a modest attempt to address the fact that there exist a system of cause-effect structure pertaining to agricultural drainage and its impacts that was not recognized before. Further more, the thesis presents two examples that provide a quantitative expression of two agricultural perspectives of drainage from farmers point of view (i.e. boxes 1-7, 16 and 8 of Figure 4.2).

In an attempt to conceptualize this cause-effect structure the study focussed on land resources (chapter 2) and their characteristics. In this process the study aimed to achieve an understanding of land resources and how conflicts arise when several interest groups compete for the use of limited resources. The study also reviewed aspects involving preservation and enhancement of land resources. By doing this the thesis concentrated on two aspects of land degradation caused by erosion and waterlogging and salinization. In examining these aspects it was recognized that agricultural drainage is considered as an important soil-water management technique for controlling water-caused erosion, and the twin menace of waterlogging and salinity.

Since much of these problems occur in non-industrialized countries where climatic functions are in extreme (i.e. either too wet or dry), most agricultural development projects in those countries involve soil-water management as one of the main factors for increasing agricultural productivity. Therefore, chapter 3 was designed to firstly, review development processes, and secondly, examine land use planning as it relates to agricultural development projects. In this process the study concentrated on rural areas and the important role of agriculture in societies. The study also focussed on the need for agricultural development in non-industrialized countries for achieving self sufficiency in food production and economic growth. However, because of the environmental and socio-economic ramifications of rapid agricultural development during last forty years in industrialized countries, the study emphasized the need for a sustainable approach to agricultural development particularly with regard to agricultural drainage projects. Farmers and rural people of non-industrialized countries who are targets of development projects in non-industrialized countries should particularly be aware of the cause-effect structure of artificial drainage projects and their impacts on the surrounding environment.

In order to elaborated on the cause-effect structure of artificial drainage and its impacts chapter 4 focussed entirely on agricultural drainage as a soil-water management technique. To enhance the understanding of agricultural drainage chapter 4 provided a preliminary review of soil and its hydrological characteristics from agricultural point of view. After this background information chapter 4 presented a holistic view on agricultural drainage. The thrust of this holistic approach was to describe how the lowering of ground water causes several physical, biological, chemical, and ecological changes in the immediate area and its surroundings. These changes are viewed differently by various interest groups. For example, the removal of excess moisture from the soil is viewed as a positive change by farmers because it creates an ideal environment in the soil which enhances crop growth and reduces costs associated with excess moisture in the field. However, environmentalists view these changes as social costs particularly when drainage in the field destroys natural aquatic habitats on the farm and in its surrounding. It is indeed this contrariety in views on the impact of agricultural drainage that causes land use conflicts. Hence it is imperative to examine all positive and negative impacts of drainage in a holistic manner that includes agricultural and environmental perspectives. To this end chapter 4 provided an examination of hydrological, biological, ecological, and economic linkages of the complex biophysical cause-effect structure of drainage and its impact. In this process, these linkages were examined from farmer's and societal perspectives. This approach is crucial if sustainable agricultural development is to be achieved particularly in non-industrialized countries where most farmers and public decision makers may not be aware of the biophysical cause-effect structure of drainage and its impacts.

Chapter 5 was designed to formulate a theoretical framework that can be used as a basis for quantifying some of the above mentioned linkages. To this end an illustrative framework approximating the complex processes of agricultural drainage was developed. The framework was based on a System of Performance Indicators (SPI) that were designed to evaluate trade-offs between agricultural drainage and wetland conservation from farmer's (micro economic) and societal (macro economic) perspectives. In designing SPIs the objective was to develop a simplistic method whereby the monetary equivalent of each indicator's performance could be estimated. It was assumed that these monetary units will allow a relatively less complicated comparison of all costs and benefits of drainage from different perspectives.

In selecting various indicators for this illustrative framework those related to agricultural perspectives, particularly from farmer's point of view, were listed with no difficulty. Most agricultural indicators are readily quantifyable. However, with regard to environmental indicators ceratin assumptions had to be made because not only conservation benefits are difficult to measure in conventional sense, but they also my involve services for which farmers do not posses ownership. For this reason the list of functions and methods to quantify their values were based on a review of several wetland functions and their valuation methods given in the literature. Furthermore, most wetland functions were assumed to be mutually exclusive and to occur in the farm where the farmer can posses ownership.

With regard to testing this framework the thesis focussed on what was possible to accomplish within its resources. Hence, due to the prohibitive cost of a comprehensive environmental and macro economic analysis the quantitative part was limited to two components of agricultural perspectives from farmer's point of view. These included changes in physical yield and cropping pattern on account of subsurface drainage. With these in mind two different case studies were considered for the empirical analysis (chapter 6). The first case was based on a drainage experiment in IJsselmeerpolders, the Netherlands. This experiment was designed to examine the effect of drainage and nitrogen fertilizer treatments on production of Cox's Orange Pippin (Cox's) and Golden Delicious (Golden) apples on marine clay soils. Hence various observations pertaining to production of Cox's and Golden apples on drained and undrained marine clay soils were available for several years. Some of these records were obtained from the IJsselmeerpolders Development Authority.

The analysis of these data was carried out in two parts. The first section was a statistical analysis that was based on some of the records that were related to apples' vegetative growth and yield (chapter 7.). The main purpose of this analysis was to quantify the overall effect of subsurface drainage, nitrogen fertilizer, and climate on growth and production of apples. This information was needed in order to determine whether or not a model could be developed for estimating the statistically expected incremental apple yields on account of drainage improvements on marine clay soils. The statistical analysis revealed that each apple cultivar responded differently to drainage and nitrogen fertilizer. For example, where as Cox's apple responded more positively to drainage improvements, their influence was found to be more systematic in the case of Golden particularly on fields where no nitrogen fertilizer was applied. With regard to changes in the vegetative growth of apples it was found that while both cultivars responded significantly to drainage improvements, the response of Cox's was more notable than Golden. It was also found that yearly variations had a significant impact on the yield of both apple cultivars.

Based on these statistical relationships and a priori knowledge a production function was tested. The production function chosen for this analysis included several parameters such as levels of nitrogen fertilizer application and climatic changes during crucial stages of apple's growth. The results of this analysis revealed that while production functions (for different drainage classes) could explain 80 to 90 percent of the variation in yield, only a few models indicated significant relationship with nitrogen levels. Consequently, these models could not be used for a comparative analysis of apple yields on account of drainage improvements.

The second component of the IJsselmeerpolders case study involved an economic assessment of subsurface drainage improvements and nitrogen fertilizer treatments for the production of apples (chapter 8). In the absence of a production model to estimate the incremental apple yields on account of drainage improvements and nitrogen fertilizer treatments, this analysis was based on capital budgeting. The purpose of this analysis was to provide an orderly sequence of steps for producing information relevant to drainage investment and nitrogen fertilizer application. Using this approach the study attempted to determine how much of the variation in economic returns of apple production in the study area was due to drainage improvements and nitrogen fertilizer application. The overall conclusion emerging from these economic analyses revealed that Cox's responded more strongly to nitrogen fertilizer application. However, this response became negative when higher doses of nitrogen fertilizer were applied. With regard to Golden apples it was found that while this cultivar responded to drainage improvements, it interaction with nitrogen fertilizer treatment was mixed particularly when the quality of apples was taken into consideration.

The second case study was based on corn yield records representing subsurface drained and undrained farms in eastern Ontario (chapter 9). This case study was designed to assess physical and economic benefits of subsurface drainage by soil type. To achieve this the first part of the analysis involved a production function that estimated incremental crop yield on account of sub-surface drainage with respect to variations in climatic condition and different soil conditions. These estimates revealed that given the agroclimatic conditions of eastern Ontario, incremental crop yields on account of drainage were highest on light as well as heavy soils. Light soils in most parts of eastern Ontario suffer from poor drainage because they either occur on level and depressional topography or in areas with an impervious layer of subsoil. Moreover, slaking is also said to be responsible for poor drainage on such soils.

In measuring the economic benefits of subsurface drainage the study focussed on two aspects (boxes 1-7, 16, and 8 of Figure 4.2). First, benefits due to increases in yields of the existing crop, and second, benefits on account of switching from low- to high-value crops. Results of these economic analyses revealed that when considering increases in yield of the existing crop, economic returns were much higher on the light soils. This was primarily due to the fact that cost of drainage installation on lighter soils was much lower than that on the heavier soils. However, when benefits of a shift in cropping pattern on account of drainage improvements were taken into consideration, it was found that there was a high payoff in drainage investment on all soils. Although it must be noted that benefits of a shift in cropping pattern on account of drainage improvements are only applicable to situations where a farmer is operating on a poorly drained soil where a cash crop such as corn cannot be grown successfully.

10.3 Final remarks

This investigation was an attempt to review, integrate and synthesize ideas that deal with agricultural drainage as a component of agricultural development, and draw attention to its cause-effect structure and impacts from both agricultural and environmental point of view.

A number of conclusions seem warranted on the basis of this wide ranging review of agricultural drainage for land use planning.

1. As we are entering new decade it is becoming increasingly apparent that the previous approach to agricultural development is no more suitable.

2. The most obvious lesson of the current socio-economic order is that we need a rethinking in land use planning and agricultural development.

3. Sustainable agricultural development is creating a new frontiers for the science of land use planning and makes new varied demands of it. Hence land

use planners are expected not only to fully understand the physical aspects of land use planning but also to be attentive to its environmental components and their interaction with physical aspects.

4. Because of the important role of soil-water management techniques in integrated rural development (IRD) projects for achieving agricultural development in non-industrialized countries, there exists a critical link between IRD and land use planning.

5. Farmers and rural people of non-industrialized countries who are targets of IRD projects should be made aware of the cause-effect structure of drainage and its impact on the environment.

6. In order to be able to understand and solve land use conflicts involving agricultural drainage and conservation there is a need for a holistic approach that accounts for hydrological, biological, ecological, and economic linkages of agricultural drainage. This approach is imperative to the ability of private and public decision makers in assessing positive and negative values of agricultural drainage relative to other land use options.

7. Testing the above mentioned linkages with the existing meager input data is cumbersome and may lead to erroneous conclusions.

8. There is need for more studies related to biological and ecological aspects of conservation particularly with respect to wetland values.

9. There is a complex multifactor relationship involved in apple growth and production which is all too easy to be misinterpreted.

10. Not all apple cultivars respond in a similar way to different soil-water management practices.

11. Apples respond differently to climatic factors. For example, where as Cox's yield was quite sensitive to the average temperature in the current spring, Golden showed a significant relationship with the preceding year's value of mean precipitation during month of May.

12. While nitrogen fertilizer alleviated some of the harmful effects of shallow ground water levels, its higher application had an adverse effect on the quality of Cox's apples.

13. In assessing physical and economic benefits of drainage with respect to different soil texture types it was found that benefits of drainage were significantly different on various soil textures.

14. Despite the fact that drainage improvement increased physical yields on heavy soils, economic returns of drainage investment on those soils was found to be very poor mainly due to increased cost of installation.

15. In assessing physical and economic benefits of drainage with respect to different soil textures on a regional level soil maps alone cannot be used for extracting soil information. These information must be verified with additional information obtained from each individual sampled field.

16. The success and accuracy of regional investigations on economics of agricultural drainage is directly proportional to the nature and extent of information and other resources that are made available to its researchers.

17. No sophisticated statistical method can correct deficiencies in an investigation which suffers from insufficient information.

18. This investigation can serve as a bench mark for further studies that deal with subsurface drainage in the context of sustainable land use planning.

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