WORKING PAPER

A FRAMEWORK FOR EVALUATING TRADE-OFFS BETWEEN AGRICULTURAL DRAINAGE AND WETLAND CONSERVATION

Hamid Jorjani
Peter Duinker

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FOREWORD

Hamid Jorjani was a 1987 YSSPer who collaborated with Peter Duinker (Biosphere Project) on the important issue of wetland conservation versus agricultural drainage. This paper presents the results of their study. The framework developed and the elaboration of environmental consideration will be very helpful to those involved in environmental impact assessments of proposals to drain wetlands, either at specific locations or as class actions.

I would like to thank Floor Brouwer and Robert Munn for comments on the manuscript.

Bo R. Döös
Environment Program Leader

ABSTRACT

Wetlands in Canada and Europe have in recent decades been subject to extensive drainage and reclamation programs, particularly for agricultural purposes. As a result, a host of important wetland habitats have been lost, along with the various benefits that individuals and society at large gain from the existence of wetlands, e.g., wild life, and recreation. To prevent further, usually regrettable losses of wetlands to agricultural drainage, we believe that a more systematic evaluation system is required for comprehensive weighing of benefits of drainage versus benefits of wetlands. In this paper we develop a set of system indicators as part of a comprehensive framework for evaluating the expected performance of agricultural drainage programs. First, we examine both drainage and wetland conservation, in turn, from farmers' and societal perspectives. Then we describe the structure of the framework, and present a set of indicators encompassing both agricultural and conservation point of view. In addition, we propose methods whereby the monetary equivalents of each indicator's performance might be estimated. Finally, we suggest case study applications in Canada and Europe. The framework should be easily modified for applications in other regions as well.

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Hamid Jorjani and Peter Duinker

1. INTRODUCTION

> "As habitat continues to be destroyed or modified, various resource sectors are beginning to recognize the need to identify all social and economic wildlife costs and benefits in quantitative terms. This would facilitate the evaluation of land-use proposals and the justification of habitat requirements in less biased and adversarial ways than those used in the past by regulatory agencies and by the proponents of development." (WHC 1986a).

Today the politics of allocating natural resources to their best use is a crucial component in the complex relationship among agriculturists and environmentalists/naturalists. The limited land base has created a conflict among these groups. On one hand, there is a strong lobby for intensive use of farm drainage, more subsidies to farmers for reclaiming marginal lands to increase farm productivity, and provision of better flood and erosion control. On the other hand, naturalists and environmentalists emphasize the important roles of wetlands in maintaining wildlife populations, regulating stream flow, and abating pollution, among other things.

Unfortunately, on many occasions planners have apparently shown insufficient concern for maintaining natural systems and environmental quality. This lack of concern is not entirely due to the unwillingness of planners to recognize the intricate relationships between economic activity and nature conservation. On the contrary, it is often their lack of attention to developing and applying a framework where a sufficiently broad array of alternatives is evaluated across a consistent set of system indicators.

Wetlands in Canada have been subject to extensive drainage and reclamation programs, particularly during the last few decades. We believe that the reasons for this evident lack of interest in wetland conservation is twofold: (a) agriculturists fear unabated urban and industrial expansion on Canada's prime agricultural lands (AIC, 1987) and the attendant possible food shortages or increased cost of food production due to soil degradation (Girt, 1986); thus, subsurface drainage has remained an important investment to increase agricultural productivity and counterbalance the loss of agricultural land; and (b) the information needed for a balanced land-allocation process is insufficient. Existing information at both the micro- and macro-levels has not been robust enough to permit comprehensive evaluation of all benefits and costs of drainage programs.

Despite the historic importance of agricultural drainage, particularly in its role in the rise and fall of a number of ancient civilizations, its interactive role in our socio-economic and environmental system has not been fully recognized (Adams, 1962; Pearce, 1987; Rangeley, 1987). However, economic valuation of drainage programs has recently received increased attention from agricultural economists, environmentalists, and land-use planners. The few studies that have evaluated drainage benefits for agriculture have not been well received because they are said to be too limited in scope. For example, the incremental crop yield due to drainage is difficult to ascertain. Some studies (e.g. Cecile et al., 1985) have used data from experimental plots, but the use of these data has been criticized because they did not represent average conditions on a farm, but rather the special conditions on experimental plots. Further, most previous economic studies of agricultural drainage have concentrated on individual farmers abstracting from environmental considerations. Studies of individual cases without any consideration of their ecological impacts are increasingly inadequate for policy-makers. Lack of an integrated approach to this problem has caused some irreversible damages to a number of wetlands of high ecological value in several countries including Canada. To create a sufficient level of awareness of the extent and impact of agricultural drainage programs in Canada, further investigations are urgently required (WHC, 1986a). Economic development is only likely to be sustainable when environmental considerations are adequately taken into account at the outset. Agricultural development can indeed take place without a detrimental effect on environment. At this time of excess agricultural productivity, both farmers and the community as a whole must be informed about the importance of preserving valuable ecosystems and their important role as stabilizers in the biosphere. Farmers must also be informed about the potential economic benefits of preserving such lands of high ecological values. What is needed is an interdisciplinary approach that accounts for temporal and spatial variations in a systematic evaluation of drainage benefits relative to wetland conservation.

The general objective of this paper is to develop a comprehensive framework for evaluating the expected performance of regional agricultural drainage programs. First, we examine both drainage and wetland conservation, in turn, from farmers' and societal perspectives. Then we describe the structure of the framework, and present a set of indicators encompassing both agricultural and conservation points of view. In addition, we propose methods whereby the monetary equivalents of each indicator's performance might be estimated. Finally, we suggest case- study applications in Canada and Europe.

2. AGRICULTURAL PERSPECTIVES ON DRAINAGE

2.1 Background

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.

Drainage influences the biological and chemical characteristics of wetlands and surrounding areas drastically. It is known that removal of the surface and gravitational water from the soil enhances certain chemical and microbial reactions. For example, removal of water and entry of oxygen in reclaimed peatlands cause oxidation of peat and humus. Further, draining some wetlands that have accumulated iron pyrite (FeS_2) under waterlogged conditions causes FeS_2 to be oxidized to soluble iron and sulfuric acid:

$$2FeS_2 + 7O_2 + 2H_2O <-------> 2FeSO_4 + 2H_2SO_4 \quad (1)$$

Iron usually gets deposited as colloidal iron hydroxide (ochre) in drainage effluent and sometimes blocks subsurface drain 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 soil's acidity (Troeh et al., 1980; Bradshaw and Chadwick, 1980). Moreover, concentration of these soluble chemicals can also affect water quality downstream. It is plausible that the increased acidity in some of Ontario's lakes has been due to this process. Increased acidity in rivers and lakes on account of drainage can have an impact on fauna and floral population of a region and hence reduces recreational, educational, and heritage values of wetland and its surroundings. Gosling and Baker (1980) reported incidents of fish kills in the Norfolk boards (U.K.) on account of acid drainage water.

The importance of agricultural drainage should be examined from two sets of perspectives: those of farmers and those of society at large.

2.2 Farmers' Perspectives

Farmers are assumed to be economically rational decision-makers who normally allocate scarce resources to alternative uses in such a way that their revenue exceeds their production cost by the largest amount possible. This process of decision-making is more prevalent in developed, capital-intensive, and highly technological agricultural systems where farmers have adequate means to apply various technological inputs to maximize their welfare. Whatever their agricultural system may be, farmers invest in agricultural drainage systems to increase their net benefits. Mathematically, this can be expressed as:

$$NB = [(Y = f\,(L, K, l, m, Xi....Xn)\ *\ PY) - C] \tag{2}$$

where:

NB = net benefit,
Y = production,
L = land,
K = capital,
l = labour,
m = management,
X = variable inputs,
PY = price of output, and
C = costs of production.

Farmers can increase their net benefit by manipulating either Y or C. Agricultural drainage is an input that can help increase a farmer's benefits through the following means.

2.2.1 Physical Production

Agricultural drainage will improve the yield of existing crops, particularly moisture-sensitive crops such as corn which reacts negatively, in terms of yield, to excess soil moisture during crucial stages of its growth (Jorjani, 1982). The removal of groundwater improves soil aeration and increases soil temperature. The increased soil aeration and temperature has a direct influence on biological activities in the soil. One of the most important benefits of the improved biological activities in crop production is that it enhances the process of nitrogen minerilization. This means a better crop yield with smaller amounts of nitrogen fertilizer. Crop production under waterlogged conditions requires additional doses of nitrogen fertilizers to offset the harmful effect of poor drainage (Van Hoorn, 1958). Van Vuuren and Jorjani (1984) estimated the increased value of corn yields resulting from subsurface drainage on test plots at the Elora Research Station in

Ontario, Canada, to be CDN[1] /ha annually. The average yield difference between drained and undrained fields was 770 Kg/ha annually.

2.2.2 Cropping Patterns

In wet zones, agricultural 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 a better crop-rotation patterns (Briggs and Courtney, 1985).

2.2.3 Timeliness of Planting and Harvesting

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 systems (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 get into the field earlier, and 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 sowing or harvesting periods, is prevented due to a high water table.

2.2.4 Indirect Costs

Drainage lowers the water table which in turn alters the physical conditions of soil. By lowering the water table, more pore space becomes available and consequently the net soil-water storage capacity increases. Increased net storage capacity enhances the infiltration of water into the soil and as a result surface runoff is reduced. Reductions in surface runoff decrease the chances of flooding and erosion. 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 water systems. Thus, by reducing surface runoff from agricultural land, drainage can reduce sediment transport and consequently non-point pollution of water bodies.

Drainage becomes a crucial factor particularly in irrigated farmlands (mostly in arid zones) where poor natural drainage systems might fail to remove accumulating salts. Moreover, in these areas drainage can also bring the water table into a dynamic equilibrium with the irrigation system.

2.2.5 Efficient Machinery Use

Farming in wet zones, characterized mostly by heavier soils, necessitates the use of powerful and consequently expensive farm machinery. Under these circumstances, drainage can reduce specific machinery costs by providing a better trafficability and/or traction on the farmland. With improved trafficability, smaller tractors can accomplish the same job at a

[1] All monetary units reported in this paper reflect the actual values given in the original documents cited, and are in US dollars unless otherwise stated.

lower cost (Trafford, 1970), and could prevent or reduce other kinds of soil degradation such as compaction.

2.2.6 Indirect Economic Benefits

Tax regulations in many countries (e.g., Canada, U.S., and various European countries) have a profound effect on the profitability of drainage investments (Van Vuuren and Jorjani, 1986). The tax benefits of drainage investments include mainly investment tax credits and various forms of depreciation write-offs and expense deductions. However, these benefits may vary among income brackets. Furthermore, there are also some other economic and policy factors such as export subsidies and drainage subsidies that influence the tax benefits of agricultural drainage.

2.3 Societal Perspectives

The general societal objectives of drainage programs or projects are either to maximize economic efficiency in terms of higher productivity, or to strive for self-sufficiency in food and other agricultural products. Undoubtedly, both these objectives can influence the general state of the economy through the multiplier effect (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). There are several forces that produce intertemporal variations in regional and national economic states during and after implementation of regional drainage programs and 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). The following discussions of the economic performance of the agricultural sector delineate the importance of agriculture (with drainage as an endogenous factor) in the economy.

2.3.1 Productivity and Economic Efficiency

Higher economic efficiency and economic growth imply sustained increases in societal welfare derived from conventional goods and services, the production of which often require natural resources such as prime agricultural land. As the world's population and standard of living increase, demands for agricultural products increases. These increases in demand necessitate the expansion of farming. Expansions are, however, only possible through either extension of agriculture onto previously virgin lands such as grasslands, wetlands, and marginal farmlands, or through the increased use of capital-intensive inputs like fertilizers and more powerful farm machinery. Since the latter is a more expensive option, most farmers opt for the former, improving drainage conditions on poorly drained lands and creating better environmental conditions for higher production levels. In this process of draining previously uncultivated land, farmers, with the help of modern mechanical diggers, and often with the encouragement of financial assistance by governments, have greatly expanded the land base for agricultural development. In addition to Europe and North America, other regions such as the Soviet Union, China, the Near East, and North Africa have also benefited from extensive drainage programs.

Table 1. High agricultural productivity due to land drainage in the Ijsselmeerpolders, the Netherlands

Crop	Average Yields (T/ha)	
	Ijsselmeerpolders	Netherlands
Sugar beets	57.0	47.5
Potatoes: feed	50.2	38.5
seed	31.0	25.0
Onions	40.0	36.5
Winter Wheat	5.9	5.4
Spring Barley	4.3	4.2
Oats	5.5	4.4

Source: Bradshaw and Chadwick, 1980

The agricultural sector in the Ijsselmeerpolders of Holland is beyond doubt a classic example of high productivity and economic efficiency due to agricultural drainage (Table 1). The high productivity undoubtedly benefited every level of the Dutch economy including employment, wages, services, industry, marketing, research and development, and the general well-being of society. A simplified demonstration of this macro-economic phenomenon can be expressed in the following example. A farm community (say a district or a township) consists of k farms, subset of the N farm communities which comprise the agricultural sector of the country or region as a whole. These k farmers sell their output (Yki) to each other or to a group of proprietors (Pki) that include brokers, agro-food processing industries, wholesalers, distributors and retailers. The proprietors then distribute farm products either as raw materials or processed foods. However, to produce those primary farm products, k farmers require a number of inputs that range from basic necessities in their households to a number of complex goods and services produced by a multitude of primary and specialized firms. This dynamic economic system (at k level) is influenced by a number of factors such as farmers' production levels and efficiency, among other things. Because agricultural drainage can improve farmers' production functions and net benefits (Equation 1), it can have a positive impact on this dynamic macro-economic system. To demonstrate these chain effects, let us use a simplified macro system which is comprised of a market with two players only (Figure 1), that is, the kth farmer who produces the ith agricultural commodity, and the jth consumer who demands the same ith commodity. Analyzing this simplified model, it can be observed how a farmer's decision concerning drainage and its impact on the production of agricultural commodities (Yki) supplied to the market can affect agricultural commodity prices and the players' income levels through revenues (farmer's) and expenditures (consumer's). The fluctuations in the income levels not only influence the consumer's demand for farm products, but they also affect the farmer's ability to purchase the required inputs for production of the ith good. Extending this model to a larger sector of the economy which includes more than two players and a market would produce a complex macro-economic model. Assuming this macro- economic system includes three markets (namely, goods and services, money, and production and labour) and three sectors (namely, households,

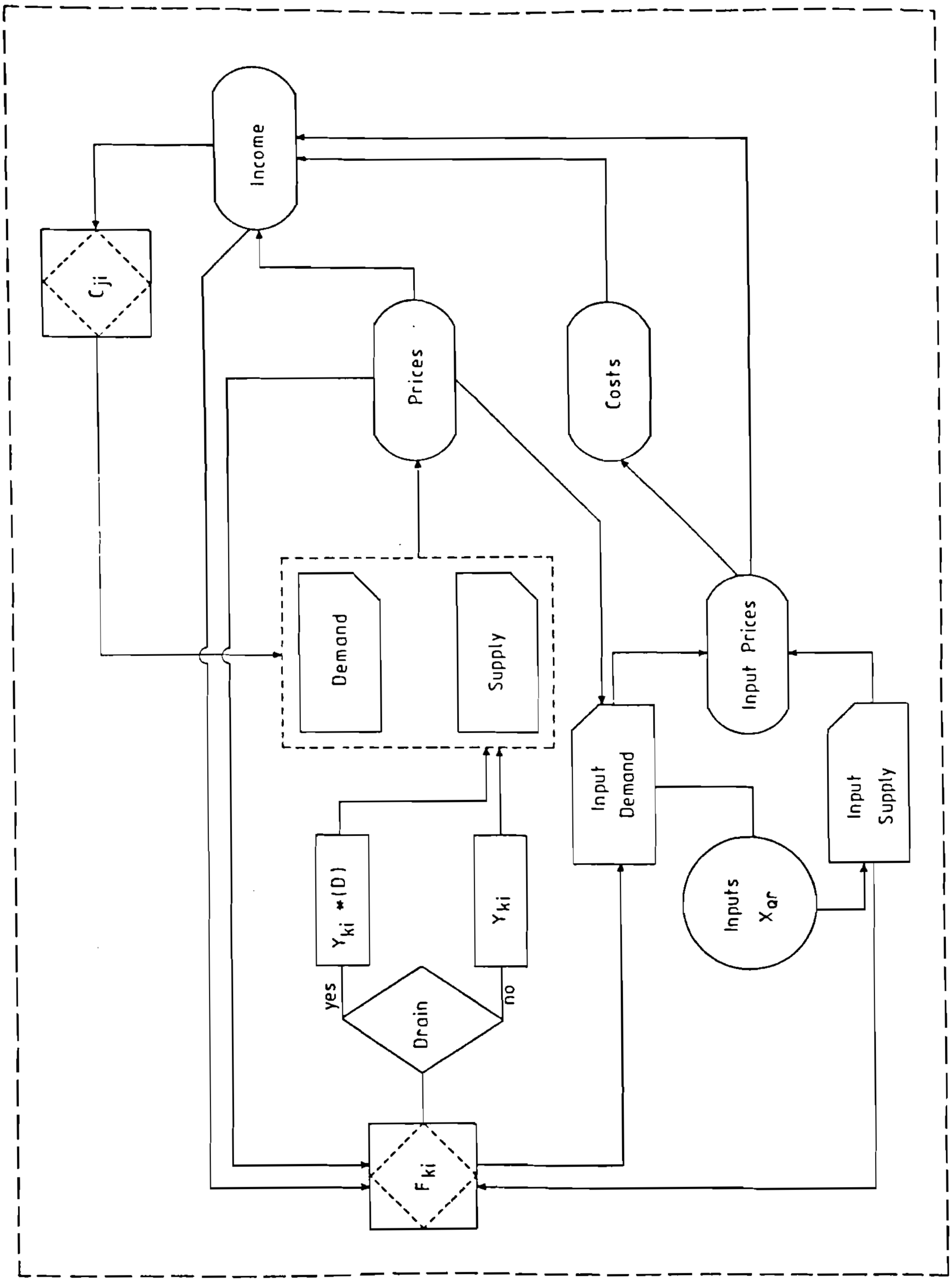

Figure 1. A simplified macro-system representing a market with two players.

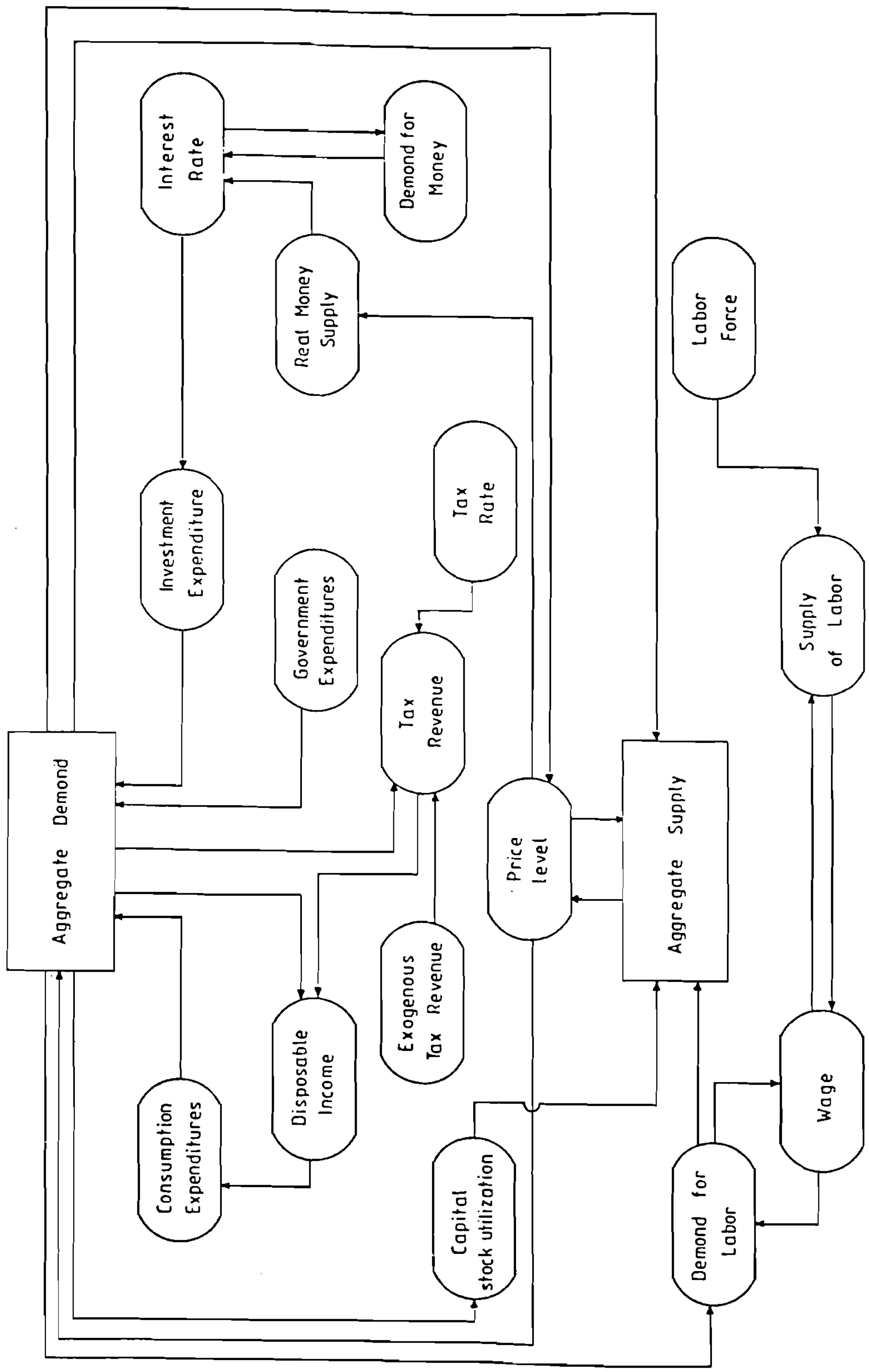

Figure 2. A macro system illustrating the impact of aggregate supply of agricultural commodities on prices, employment, balance of payments, government budget, consumers' disposable income and the aggregate demand.

business, and government), 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). Using such a model (Figure 2), one can analyze the impact of drainage programs on the aggregate supply of agricultural commodities and its further effects on items such as prices, employment, balance of payments, government budget, consumers' disposable income, and finally the aggregate demand. This model can also be extended (with modifications) further by including additional sectors of the national economy.

2.3.2 Employment

Drainage investments affects employment in the following ways.

2.3.2.1 Primary Source of Employment

Primary-employment groups include both private and public organizations that are directly involved in (a) planning, administration and management, (b) materials and machinery manufacturing and handling, and (c) implementation of drainage projects. This includes all the specialized consulting firms, drainage contractors, manufacturers, distributors, and public offices at various municipality, county, provincial and federal levels.

2.3.2.2 Secondary Source of Employment

A more general category includes all the additional manpower required in a region after drainage projects are completed, that is, both the manpower required for management of the projects as well as the additional manpower needed as a result of the higher productivity and economic efficiency. For example, the Eastern Ontario Drainage Program in Canada (Cecile et al., 1985) not only enabled some of the low-income farmers of the region to increase their productivity (through better soil-water conditions), but it also expanded economic activities in that region. This expansion provided more employment opportunities for the local population. The Ijsselmeerpolders in Holland are another example of how a major drainage and reclamation project can generate employment opportunities at the regional and national level. Whether a major regional or a limited farm- level drainage project, the cumulative impact of such projects on employment is undoubtedly positive.

2.3.3 Reclamation and Augmentation of Land

Drainage and reclamation have been important societal goals in the low countries of Europe since the Middle Ages. To augment the land base for agricultural and non-agricultural uses, the Dutch used earth embankments (dikes) to enclose shallow coastlands of the North Sea. With windmills they pumped water from the enclosed area and drainage channels to facilitate the reclamation process through shrinkage, crack formation, and finally soil ripening (Schultz, 1982). Thousands of hectares of prime agricultural land in Holland originated this way (Veen, 1982). Currently, a complex network of drainage systems is being used in the newly reclaimed Dutch polders to control the water-table level and seepage (Kienhuis, 1982).

Bradshaw and Chadwick (1980) noted that reclamation of coastal salt marshes has been carried out in eastern England over many centuries. After enclosure with dikes, the areas were left for a few years to allow rain water to leach out salts through drainage ditches. This process permitted many communities in eastern England to augment their arable land base.

In addition to coastal lowlands, many inland wetlands have been reclaimed for agricultural as well as non-agricultural uses. At present, part of Haarlemmermeerpolder is being used by the Schiphol development project (the Schiphol International Airport). The Holland Marsh, north of Toronto, Ontario, Canada, can be cited as another example. This lowland was previously a large marsh that, because of its location and agricultural potentials, was reclaimed and eventually became one of the major vegetable-producing areas in Ontario. There are numerous other locations around the world that have benefited from agricultural drainage and reclamation. Framji et al. (1981) reported the drained areas in the world as 158.4 million ha, while in a report by Rangeley (1987) the gross drained and flood-protected areas is recorded as 144 million ha. Both these studies have indicated North America, Asia, and Europe as the major drainage areas. Recent increases in the amount of drained land could be due partly to the abrupt increase in oil prices and its impact on commodity prices in early 1970s on one hand, and the Green Revolution during the 1960s on the other. Both these phenomena favoured production of high-yielding varieties that require intensive use of inputs along with effective soil-water management including drainage.

2.3.4 Balance of Payments

The increased economic activities associated with higher export earnings have a significant impact on public and private economies. Export earnings have a special significance in the balance of payments as they generate foreign exchange to offset deficits created by imports. In some regions agricultural products are among the major export items, particularly in North America and Europe. A series of events in the early 1970s (mainly rising income in certain countries such as OPEC member countries, devaluation of the U.S. dollar, poor weather conditions in specific grain-producing countries, and increased subsidies to farmers) caused farming in North America and Europe to expand rapidly to meet the increasing demand for food products. This expansion took place in two ways: first, by extension of croplands through forest clearing and drainage, among other things; and second, by intensification of farming through intensive use of fertilizers and pesticides (UNEP, 1987). In Canada, the increasing trend in crop land was nearly 5% during the period 1971-1976; the same trend in Ontario was 15% (Hansen, 1981; Statistics Canada, 1981). With these expansions, Canadian farmers were able not only to provide enough food for the growing domestic consumption, but made major contributions to Canada's balance of payments. During 1985 Canadian farmers earned nearly $20 billion. In the same period Canada's total agricultural products exports amounted to CDN $700 million (FAO, 1985).

In addition to increasing export earnings from surplus agricultural production, drainage can also improve a country's balance of payments through import replacement. For example, considering the agro-climatic conditions of Canada, vegetable growing is one of the important sub- sectors of the Canadian economy because of its import-replacement potentials. The delta areas of British Columbia, and the marshland areas of Montreal, and Central and Southwestern Ontario are the dominant vegetable-producing centres of Canada. Some of these areas, such as the Holland Marsh in Ontario, could not have been developed without drainage. During 1984, Canadian vegetable growers received over 523 million dollars in farm cash receipts. In the same period, Canada imported over 500 million dollars of fresh vegetables (Statistics Canada, 1987). Thus, had these resources for producing vegetables in various parts of Canada not been developed, Canadian consumers would have had to spend an additional 500 million dollars on imports of fresh vegetables, or reduce their consumption of these foods.

3. ENVIRONMENTAL PERSPECTIVES ON WETLANDS

3.1 Background

> "Since the days of earliest settlement, more than 65 percent of Maritime salt marshes, 70 percent of Southern Ontario and St. Lawrence Valley wetlands, 40 percent of Prairie wetlands and up to 70 percent of Pacific estuary wetlands have been converted to other uses mainly for agricultural and urban expansion." (WHC, 1986a).

During the past few years, concerns over the loss of wetlands of high ecological value in Canada has stimulated numerous professional gatherings, research, and governmental as well as non-governmental actions (Kreutzwiser and Pietraszko, 1986). Some of Canada's most unique wetland ecosystems are believed to be under imminent threat of drainage for agricultural purposes. Wetlands in Canada have until now been vulnerable to such development for, too often, they have been reclaimed without adequate consideration for the social costs of such actions.

Under the Ramsar Convention, wetlands are defined as areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 metres. 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 a farm field. In this paper we are mostly concerned with permanent wetlands that are important habitats for terrestrial wildlife and breeding areas for many commercially important fish and crustaceans (WHC, 1986b). 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 Canada'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. The prairie potholes of central and southern Alberta, Saskatchewan, and Manitoba, together with areas in northwestern and eastern Ontario, provide some of the prime duck-producing areas of the North-American continent (Hammack et al., 1974).

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 in some detail at the major components of farmers' and societal perspectives on wetland conservation.

3.2 Farmers' Perspectives

3.2.1 Income generation

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).

Whatever the type of wetland may be, a farmer's perspective may be mathematically expressed as follows:

$$NB = [(vw = f\,(R,\,P,\,H,\,E,\,S,\,I)\;^*\,F) - C] \qquad (3)$$

where:

NB = farmer's net benefit,
vw = value of the wetland (income-generating potential per unit),
R = recreational services,
P = pollution-abatement services,
H = flood-control services,
E = scientific and research services,
S = scenic vistas,
I = institutional benefits,
F = fees or prices, and
C = total costs.

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

Equation (3) suggests how a farmer can increase his net benefit (NB) 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 he may not be willing to manipulate his costs further. Instead, he will try to maintain and prolong the availability of these services. The income-generating services of wetland from the farmer's point of view are outlined below.

3.2.1.1 Recreation

Some wetlands, particularly those which are located close to open water, can provide excellent opportunities for sports (e.g. fishing, hunting, trapping) and camping activities. This function, however, largely depends on the type of wildlife habitat of the wetland, its accessability throughout the year, as well as its proximity to major transportation networks and population centres (Raphael and Jaworski, 1979).

3.2.1.2 Waste Assimilation and Pollution Abatement

Wetlands are known for their capacity to serve as biological and chemical oxidation basins (Abdalla and Libby, 1982). Some wetlands are used as natural filters for removing nutrients and biochemical oxygen demand from sewage wastes which have already received secondary treatment. This process involves applying waste water from a secondary treatment plant to wetlands where the vegetation and underlying soils remove nutrients and other contaminants. Wetlands with peats at the surface are known to be excellent natural filters for absorbing heavy metals, organic pesticides and other pollutants (Thibodeau and Ostro, 1981). Drainage for agricultural purposes of a wetland used for pollutant filtering would not be advisable.

3.2.1.3 Flood Control

Wetlands can perform significant hydrologic functions that include flood control, water storage, and storm protection. The magnitude of these functions, however, varies according to water absorption capacity of a specific wetland and its location. In Ontario, some wetlands store water during spring melt and seasonal storms, and gradually release the stored water into waterways. This process prevents flooding and damages to stream banks. Wetlands affect groundwater flow and in some situations can recharge aquifers. In addition, some marshlands can diminish the effect of storms due to frictional effects. The magnitude of these effects depends on the hydrology and terrain of a specific area (Farber and Costanza, 1987).

3.2.1.4 Research

"Not only are wetlands interesting places for elementary and undergraduate students to visit, but they are also of significant value in basic and applied scientific research" (Reimold et al., 1980). The education and research values of wetlands could be important income generating-potentials from farmers' point of view. Unique wetlands are often of special scientific interest and are used as field sites for research and education. Under special arrangements, farmers can provide access to these wetlands under either a user-fee or a long-term rental arrangement.

3.2.1.5 Scenic Vistas

Scenic vistas are benefits that derive from direct contact with a wetland. These benefits are sometimes referred to as non-consumptive uses of wetlands (Reimold et al., 1980). Some of these uses include canoeing or kayaking through marshes, smelling the fresh air, being engulfed by fog while hearing some rare birds, watching a child smile when it sees a turtle in its natural environment. These uses are valued by many individuals who are willing to pay a fee for being able to enjoy them. Farmers might consider the income-generating potentials of such services.

3.2.1.6 Institutional Benefits

Some of the government and non-government actions such as management agreements for habitat protection and conservation can also be considered as sources of direct or indirect income for farmers. Through these programs, regional or national conservation agencies and private landowners negotiate either small-scale purchases of critical lands (from a nature-conservation point of view) or long-term habitat protection and management programs. For the last few years, Wildlife Habitat Canada has approved a number of "cooperative habitat projects" in different regions of Canada to protect and manage rare ecosystems (WHC, 1986b). 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, 1986b).

These programs are also being carried out elsewhere. In the U.K. for instance, 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. In the U.S., the Fish and Wildlife Service has paid considerable amounts of money to landowners to protect wetlands (Danielson and Leitch, 1986).

3.2.2 Non-income Perspectives

Sometimes a farm family derives satisfaction from either direct access to wetlands or from their vicarious values (i.e., knowing that wetlands can be enjoyed by future generations as well). The common potholes and ponds in farms in Southwestern Ontario, along with the surrounding wetlands, provide special ecosystems which are often appreciated by rural families.

3.3 Societal Perspectives

Unlike those for drainage and reclamation, societal perspectives on wetlands have been rather narrow. A survey in Ontario, Canada, designed to evaluate wetland values and landowners' 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.

Although the aggregate conventional economic value of wetlands was enumerated at least as early as the 1920s (Viosca, 1928), an international convention concerning wetlands was drawn up only in 1971 in Ramsar, Iran (Pain, 1987). The 45 member-countries recently met in Regina, Canada, to safeguard the Ramsar Convention. Currently, this convention has listed only 357 sites that together cover an area the size of Wales (about two million ha) (Pain, 1987). This apparently limited societal concern for wetlands is partly due to the fact that, for a long time, economic decisions concerning wetland exploitation were made within a pricing system where subsidies favoured agricultural productivity more than environmental quality. Some of the agricultural policies of the EEC are known for this built-in bias in favour of agricultural development (Black and Bowers, 1981; Turner et al, 1983; Bowers and Cheshire, 1983; Nature Conservancy Council, 1984; Bowers, 1985; Barnaby, 1986). Besides the narrow development objectives of the post-war years that gave decision-making a decidedly economic bias, the passive view that "environmental services do not lend themselves to economic analysis" (Martin, 1985) seemed to be partly responsible for this perspective on wetlands. In response, some environmentalists and 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 was hoped that this monetization would enable society to evaluate the expected performance of wetlands better. The following section illustrates some of the important societal values of wetlands, particularly those that have been monetized in published studies. The enumeration of these values will demonstrate the serious gaps in our knowledge concerning wetlands.

3.3.1 Biological

3.3.1.1 Biotic Communities

The biotic communities of wetlands, including both flora and fauna, vary according to the geographic and natural composition of a specific wetland. For example, the cypress wetlands of Florida, U.S., support a different fauna and flora than the wetlands of northern Scotland. On a smaller scale, the biotic communities of wetlands in Ontario, Canada, are different from those in the prairie potholes of the neighbouring province of Manitoba. Furthermore, it is not uncommon to observe distinct variations in either flora or fauna within a specific type of wetland in a small region. The rolling peaty moors of Scotland are sometimes dominated by heather and sometimes by cotton grasses (Lindsay, 1987). Thus, wetlands provide a wide variety of flora and fauna that can range from deep-rooted trees to insectivorous plants such as bladderwort, and from insects to birds and deer (Viosca, 1928; Clark, 1978; Crow and Macdonald, 1978; Weller, 1981; Thompson, 1987).

Stewart and Lance (1983) reported several changes in the floral and faunal 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 these 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 waterfowls. In their (Briggs and Courtney, 1985) account, drainage of wetlands generally causes a serious decline in the numbers of some mammal species in Europe. Their list of endangered mammals include: the Pyrenean desman (Gatemys pyranaicus), the southern water shrew (Neomys anomalus), 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. 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 good wintering areas for deer. Other animals are also known to benefit from wetlands as a cover area. It is also important to stress that changes in 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.

One of the earliest attempts to demonstrate some of these values in monetary terms was that of Viosca (1928). In this work, the value of some of the natural resources derived from Louisiana wetlands, U.S., was estimated to be US $20,500,000 (Table 2).

Table 2. Monetary value of natural resources derived form Louisiana wetlands.

Economic Item	Value in million US$
Game	1.0
Commerical fresh-water fish	2.5
Fresh-water game fish	1.0
Frogs, turtles, fresh-water shrimps, and mussels	1.0
Salt-water fish, crabs, terrapins	2.0
Salt-water shrimps	3.5
Salt-water game fish, crabs and shrimp caught by anglers or consumed by fisherman etc.	1.0
Oysters	2.0
Fur and alligator hides	6.5
Total	20.5

Source: Viosca (1928)

3.3.1.2 Rare or Endangered Species

It has been estimated that currently one species per day goes extinct (Myers, 1985). If not arrested, this unprecedented rate will eventually cause the disappearance of at least one third of the planetary complement of species (Myers, 1979). Wetlands comprise a major pool of the genetic variability in the biosphere (Viosca, 1928; Thompson, 1987). Drainage, reclamation and cultivation of wetlands have already caused irreversible changes by damaging wildlife habitats. Due to lack of sufficient knowledge concerning biotic communities it is not known precisely how much biotic depletion has taken place (Myers and Ayensu, 1983). However, it is known that some of the few remaining wetlands are the only habitats left for a wide range of flora and fauna. In Canada, there are a number of such wetlands. For example, the floodplain of the upper St. John River in New Brunswick supports the Furbish's lousewort, an endangered plant species. Similarly, the Akudlik Marsh in Manitoba is a breeding ground for a number of rare waterfowl species such as Ross' gull and little gull (WHC, 1986a). In Europe, 74 species of birds have been listed as endangered. Some of these rare birds such as swans, geese, ducks, rails, waders, and warblers, are wetland species (Nature Conservancy Council, 1982). Within the European Community, 465 wetlands are considered as important bird- breeding areas (ICBP, 1981). One of the rare natural resources of the U.K. is the blanket bogs of the northern highlands of Scotland. These unique treeless ecosystems cover an area of 400,000 ha and provide an important habitat for a number of highly specialized flora that have adapted to the wet, acidic conditions. For example, sundew and bladderwort are insectivorous plants and depend on small animals (mainly insects) as a nutrient source. Furthermore, these bogs are also a very important habitat for 70% of U.K.'s population of greenshank, 25% of its dunlin (red-backed sand-piper), and some nesting golden plover, Arctic skua and merlin (Thompson, 1987).

Some scientists have tried to quantify the economic value of these rare wetland flora and fauna. For example, the "option" (i.e., the assurance of future uses) and "existence" (i.e., the benefits from simply knowing that something exists) values of the endangered whooping crane were estimated to be US $573 million annually (Stoll and Johnson, 1984).

We must be aware that drainage of wetlands, or land reclamation from the sea, can provide habitat for other kinds of wildlife. In the Oostvaardersplassen area of the Netherlands, parts of the new polder are very important bird sanctuaries.

3.3.1.3 Biochemical Processes

Wetlands provide habitat for a number of anaerobic organisms which are responsible for several important biochemical processes. If these species can be correctly identified, and their important functions measured, it should be possible to modify specific economic techniques to estimate their monetary value to society. For example, Farber and Costanza (1987) used the "gross primary production" (GPP) method to calculate the total annual equivalent dollar value of Louisiana wetland and marine habitats to be US $2,442/acre/year.

3.3.1.4 Adsorption and Assimilation

Most wetlands are known to be characterized by biological uptake and adsorption of pollutants and nutrients. These phenomena have recently received much attention, particularly from the point of view of non-point sources of pollution. Hey et al. (1982) noted that because traditional wastewater-treatment systems can not treat non-point source pollution, wetlands can be considered as cost-effective alternatives. Fritz et al. (1986) carried out an analysis to determine cost-effectiveness of Cypress wetlands in Waldo, Florida, U.S. They found that, given certain site- specific variables, Cypress wetlands are the most cost-effective tertiary treatment alternative. This is primarily due to the adsorption and assimilation capacity of Cypress wetlands, permitting biological treatment while the wastewater flows over its surface. In a related study based on seven criteria, Fritz and Helle (1986) found that Cypress-wetland tertiary treatment may be a feasible alternative for approximately 35% of the wastewater treated in Florida. The criteria included: treatment result, cost, energy requirements, effect on environment, reliability, acceptance by regulatory agencies, and availability. In an attempt to quantify the pollution-reduction value of wetlands, Thibodeau and Ostro (1981) estimated that an acre of marsh substitutes for plant cost of $85 and annual operation and maintenance costs of $1,475. The total cost of such a plant was estimated to be $16,960.

3.3.2 Hydrological

3.3.2.1 Water storage

Due to their specific physical characteristics, wetlands are important in water storage, and can influence groundwater flow and sometimes recharge aquifers (Thibodeau and Ostro, 1981). Thus, water wells that are located in or adjacent to a wetland can be replenished as long as the wetland is functional. The water-supply value (WSV) of wetlands has been calculated as the difference between the cost of wetland wells (CWW), and the cost of providing water from the next best source (CNBS) (Gupta, 1973). According to Gupta's (1973) calculations, an average wetland can supply 100,000 gal/day at a cost of $7.44. The same quantity of water from the next best source would cost $24.00. Therefore, the WSV of an average wetland, should these quantities of water be sought, is $16.56 per day, or $6,044 per year. Capitalized at 6%, this is $100,730 per acre (Thibodeau and Ostro, 1981).

3.3.2.2 Flood and Storm Control

Another important wetland function is flood control (Abdalla and Libby, 1981). Because of their organic soils and generally flat topography, wetlands can absorb large volumes of water. A study conducted in the floodplain swamps of the Ipswich River, U.S., suggested that due to the large temporary water-holding capacity of these wetlands in spring, flood peaks downstream were reduced (Sammel et al., 1966).

Farber (1986) developed a method to estimate the value of wetlands in reducing property damage from hurricane winds. Essentially, this method is a wind-damage distance-decay function which diminishes wind damage as the distance from landfall increases. Using historical storm-probability data and official damage estimates, the present value of storm control of Louisiana coastal wetlands was estimated as $7.48 per acre (Farber and Costanza, 1987). In a study conducted by the U.S. Army Corps of Engineers (1976), the annual monetary loss at various amounts of reduction in wetlands storage was estimated. Extrapolating from those estimates, Thibodeau and Ostro (1981) quantified the average loss prevented due to flood damage as $2,000 per acre of wetland.

3.3.3 Recreational

3.3.3.1 Wildlife

Wetlands support a wide range of flora and fauna that many people deem to be very important (Thibodeau and Ostro, 1981). Wetlands provide habitat for a great variety of mammals, game birds, and vegetation. Some of the fauna include bear, deer, squirrels, marsh rabbits, geese, ducks, coots, rails, snipers, fish, frogs, turtles, shrimps, crayfish, freshwater mussels, and reptiles. Floral populations of wetlands are also very diverse and range from magnificent Cypress and Tupelo in wooded alluvial swamps to round-leaved sundew insectivorous plants of blanket bogs (Viosca, 1928; Thompson, 1987).

The open space and the colourful wildlife associated with wetlands attract many people from crowded urban settings. Some wetlands possess a wealth of birds, fish, wild fruits and exotic crops (wild rice), trees, flowers, and other plants that can be valued at equivalent market prices. Wetlands can also provide a venue for research which may not be possible or would be more expensive if sites and their unique wildlife were not available (Morris, 1987). Monetary perspectives on some of these services have been outlined by Raphael and Jaworski (1979). For example, the annual value of fish, frogs, and bait in Michigan has been estimated to be equivalent to $286 per acre. These monetary values are commonly calculated on the basis of an economic concept known as "the willingness to pay". Brookshire et al. (1983) need this technique to determine the monetary value of wilderness, so it should be possible to apply it to determine the monetary value of some wetlands.

3.3.3.2 Sports

The sports services of wetlands are among the oldest functions, dating back to the early hunter societies. Today, sport values of wetlands are mostly limited to hunting and angling. Based on the annual expenditures by recreational participants and standard values of recreational days, along with estimated sport and commercial harvests, Raphael and Jaworski (1979) calculated recreation and sports value of Michigan's coastal wetlands. They estimated the average return value for sport fishing, waterfowl hunting, and commercial fishing at $286, $31.23, and $3.78 respectively per acre of wetland per year.

Using the principle of willingness to pay, Farber and Costanza (1987) calculated the annual value of commercial fishing and trapping in wetlands of south Louisiana. The economic value of willingness to pay for an acre of wetland, by commercial fishing and trapping, in 1983 dollars, was estimated as $37.46. The apparent discrepancies among some of the above values are mostly due to either different methods or site-specific values for economic variables.

3.3.4 Heritage

3.3.4.1 Landscape Aesthetics

Today people increasingly turn to nature to nourish their minds and find inspiration, interest, creativity, and above all solitude and peace. They are realizing that a clean environment and rare ecosystems are resources which sometimes possess more spiritual and heritage values than the material world. Society is beginning to learn more and more about these resources and their importance in the biosphere. Wetlands, because of their unique features, are among these valuable natural resources. The landscape features of wetlands have awed people for centuries. According to Reimold et al. (1980), "wetlands stimulate the vision, hearing, sense of smell, touch, and taste in ways that have been recorded by painters, musicians, and writers of many ages". For example, Elder (1525-1569) painted a number of wetland scenes, including the "Hunters in the Snow". J.F. Lansdowne (born 1937), a contemporary Canadian painter with a love for birds and their wetland habitat, recently painted a pair of Canvasback ducks that appeared on Canada's 1986 Wildlife Habitat Conservation stamp. Another contemporary artist who has been inspired by wetlands is A. Crider, a composer from Florida, whose songs such as "O Kissimmee River" are melodious descriptions of wetlands and their beauty (Reimold et al., 1980).

Although determining the aesthetic value of wetlands is very difficult, there have been a number of studies with that very objective. Messman et al. (1977) worked out a method that incorporated cultural and aesthetic values of wetlands. Smardon and Fabos (1983) developed a method for rating visual- cultural values of different freshwater wetlands.

3.3.4.2 Conservation

> "A major hindrance to preserving wetlands has been the inability to demonstrate their socio-economic value to wildlife productivity and, therefore, improve their importance as a component in resource allocation decisions" (WHC, 1986a).

Because wetlands have traditionally been considered as obstacles to agricultural development, in certain societies the notion of a wetland as a valuable renewable resource is ludicrous. Drainage of wetlands has had a serious impact on wildlife habitat (WHC, 1986a). The European Common Agricultural Policy is regarded as another culprit (Barnaby, 1986). "The World Wildlife Fund is concerned about the EEC's continuing support for drainage schemes to increase agricultural production despite mounting surpluses of grain" (Pain, 1987). Other countries such as the Soviet Union are no exception. Hill (1976) noted that based on estimates from Averyanov et al. (1971), during the period 1956 to 1965 the area of drained land in the Soviet Union was extended from 8.4 to 10.6 million hectares. Moreover, it is also reported that in the past few decades, major drainage programs on the large marshes bordering the Caspian and Black seas have reduced the wintering area for millions of waterfowl (Osakov et al., 1971).

Nevertheless, despite these drainage programs, conserving the diversity and productive potential of wetlands has become a priority (e.g. the Ramsar Convention). Currently there are a number of other international organizations such as the World Wildlife Fund that have an interest in wetland conservation.

In a large country like Canada, conservation of wetlands is a complicated process that involves many public and private agencies, both at national and provincial levels. At the national level, there are a number of organizations that are involved in habitat development, rehabilitation, and education (Table 3). Some of these organizations are directly or indirectly involved in wetland conservation.

Table 3. Canadian national organizations involved in habitat development, rehabilitation, and education

1. Federal Government, directly via the Canadian Wildlife Service and other agencides managing Federal lands, and indirectly through Federal/Provincial Agreements
2. Ducks Unlimited Canada
3. The Nature Conservancy of Canada
4. Candian National Sportsmen's Shows
5. Canadian Wildlife Federation
6. Wildlife Habitat Canada
7. Canadian Nature Federation
8. Trout Unlimited
9. World Wildlife Fund

Source: Modified from WHC (1986)

3.3.4.3 Vicarious

Vicarious values are commonly regarded as option, existence, and bequest values (Loomis and Walsh, 1986). These values are measured in terms of willingness of people to pay some premium over and above their expected recreation benefits to maintain the option of possibly visiting a natural area in the future (Weisbrod, 1964). They are also sometimes measured in terms of satisfaction of an individual for knowing that an important natural ecosystem is protected even though the individual may never visit or see that ecosystem. Economically, the individual is willing to pay (say to the World Wildlife Fund) to protect a unique wetland in a foreign country. As an example, the U.S. Audubon Society was able to raise $696,000 from all over the country to preserve 2,680 acres of marsh in Florida (Ingle, 1974; Thibodeau and Ostro, 1981).

4. THE FRAMEWORK

4.1 Introduction

Decisions are choices among futures 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. 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, the subject of this paper, 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. And from a broad societal perspective, there are cogent arguments for and against both drainage and wetland conservation.

In terms of the framework sketched herein, it is straightforward to characterize the nature of many of the conflicts over natural-resources development and environmental quality:

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 interests are willing to explore system performance to any but single alternatives predetermined to be preferable. 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 resources and environment problems. For example, the process of evaluation in decision-making requires implicit or explicit weighting of the indicators by which system response to action alternatives is gauged. We do not deal here with considerations of quantification of relative weightings (arguably unnecessary) and use of different (implicit) weightings among conflicting parties (arguably ever present). Neither do we deal with considerations of the processes whereby decision-makers are advised, interested parties are consulted or ignored, and decisions are made. We wish simply 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.

4.2. System Performance Indicators

In considering agricultural drainage vs wetland conservation, we suggest that alternative actions need to be evaluated in terms of a range of biophysical, social, and economic indicators (Figure 3). These indicators involve several hydrological, biochemical, ecological, and financial factors both at the farm and societal levels. Some of these factors are readily quantified and easily monetized. On the other hand, because a number of conservation benefits (e.g. biophysical indicators) are not marketable in the conventional sense, it is difficult to monetize them. Consequently, monetary values of certain biological factors are expressed in terms of shadow prices. An example of a shadow price of a biophysical indicator is the cost of producing a sewage- treatment plant or a flood-control structure by the best means possible, assuming such a good can be produced (Fritz and Helle, 1986; Fritz et al., 1986).

The suite of performance indicators suggested here is classified according to farmers' and societal perspectives. For each indicator, we discuss the means of quantifying its future behaviour as well as means of expressing that behaviour in monetary terms.

4.2.1 Farmers' Perspectives

4.2.1.1 Agricultural Indicators

4.2.1.1.1 Physical Production

Changes in physical production resulting from agricultural actions can be estimated either as the difference in the total physical productivity (TPP) of two production functions (e.g. drainage and no-drainage), or simply as the difference in physical yields (Jorjani, 1982; Jorjani and Irwin, 1983). This change in physical production can be translated into monetary values using specific agricultural commodity prices.

The following is an example of a model for calculating the incremental crop yield due to an agricultural action (drainage) and its monetary value.

$$Y_d = b_{10} + b_{11}S + b_{12}C + b_{13}M + e \tag{4}$$

$$S = b_{20} + b_{21}ST + b_{22}NDC \tag{5}$$

$$C + b_{30} + b_{31}PPT + b_{32}PET \tag{6}$$

$$M = b_{40} + b_{41}FRT + b_{42}PEST + b_{43}MCH \tag{7}$$

$$d = Yield\ Code;\ \text{if}\ d = 01\ then\ Y = drained\ (drn)$$
$$d = 02\ then\ Y = undrained\ (udr)$$

$$Thus,\ I = Y_{drn} - Y_{udr} \tag{8}$$

$$NB = I\ *\ PY - E \tag{9}$$

FARMERS' PERSPECTIVES

Agricultural

- Physical Production
- Cropping Pattern
- Planting and Harvesting
- Scheduling
- Indirect Costs
- Machinery Use
- Indirect Economic Benefits

Environmental

- Income Generation
- Recreation
- Waste Assimilation and Pollution Abatement
- Flood Control
- Research
- Scenic Vistas
- Institutional Benefits
- Non-income Generation

SOCIETAL PERSPECTIVES

Agricultural

- Productivity and Economic Efficiency
- Employment
  - Primary Source
  - Secondary Source
- Augmentation of Land
- Balance of Payments

Environmental

1. Biological
   - Biotic Communities
   - Endangered Species
   - Adsorption and Assimilation
2. Hydrological
   - Water Storage
   - Flood and Storm Control
3. Recreational
   - Wildlife
   - Sports
4. Heritage
   - Landscape Aesthetics
   - Conservation
   - Vicarious

Figure 3. A set of performance indicators for evaluating the expected performance of agricultural drainage programs.

Where:

Y = Crop Yield,
S = Soil Factor,
C = Climatic Factor,
M = Management Factor,
ST = Soil Type,
NDC = Natural Soil Drainage Classes,
PPT = Precipitation Level,
PET = Potential Evapotranspiration,
FRT = Fertilizer Rates,
PEST = Pesticides Rates,
MCH = Machinery Use,
I = Incremental Crop Yield on Account of Drainage,
NB = Net Benefits,
PY = Output Prices, and
E = Total Cost.

4.2.1.1.2 Cropping Patterns

Essentially any change in cropping pattern (e.g. shift from pasture to grain corn) will have a significant impact on a farmer's income. This change in income can easily be estimated through market prices, using a simple accounting procedure.

4.2.1.1.3 Planting and Harvesting Schedule

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 a farmer's income. Therefore, by using changes in the physical yield, one can monetize the impact of land-use actions on timeliness of farm operations.

4.2.1.1.4 Indirect Costs

There are certain costs that are either associated with the loss of top soil (e.g. loss of seeds, fertilizers, and chemical agents) due to surface runoff, and erosion or salt accumulation in irrigated farm-lands on account of 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.

4.2.1.1.5 Machinery use

Land-use actions have a significant impact on the type of farm machinery used, which in turn influences a farmer's total costs. Using conventional market prices, the impact of land-use actions on machinery costs and farmer's total cost can be estimated.

4.2.1.1.6 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).

4.2.1.2 Environmental Indicators

4.2.1.2.1 Income-generating Environmental Indicators

4.2.1.2.1.1 Recreation

The fees that consumers are willing to pay for specific recreational goods and services are determined through the market, for example, a fee for angling in a farm wetland.

4.2.1.2.1.2 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.

4.2.1.2.1.3 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) 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.

4.2.1.2.1.4 Research

Scientific and educational services can be provided for a fee which is determined through either market or shadow prices.

4.2.1.2.1.5 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.

4.2.1.2.1.6 Institutional Benefits

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

4.2.1.2.2 Non-income-generating Environmental Indicators

Non-income-generating benefits are usually expressed either as existence values (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.

4.2.2 Societal Perspectives

4.2.2.1 Agricultural Indicators

4.2.2.1.1 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.

4.2.2.1.2 Employment

4.2.2.1.2.1 Primary Source of Employment

The impact of land-use actions on primary employment can be measured in terms of the cumulative number of employees and/or the wages earned. Statistics on the number and the wages of these groups are readily available.

4.2.2.1.2.2 Secondary Source of Employment

To quantify these 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.

4.2.2.1.3 Augmentation of land

Using market prices of land, one can easily translate the impact of land-use actions on this indicator into monetary terms.

4.2.2.1.4 Balance of Payments

The impact of different land-use actions on a country's balance of payments can 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.

4.2.2.2 Environmental Indicators

4.2.2.2.1 Biological Indicators

4.2.2.2.1.1 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.

4.2.2.2.1.2 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 in economic analyses has become very popular.

4.2.2.2.1.3 Adsorption and Assimilation

The monetization of adsorption and assimilation functions 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.

4.2.2.2.2 Hydrological Indicators

4.2.2.2.2.1 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.

4.2.2.2.2.2 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 (1986). 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.

4.2.2.2.3 Recreational Indicators

4.2.2.2.3.1 Wildlife

The recreational value of wildlife can be monetized using the concept of willingness to pay for calculating the option and existence values of wildlife.

4.2.2.2.3.2 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.

4.2.2.2.4 Heritage Indicators

The heritage aspects of natural resources, described here as (a) aesthetic, (b) conservation, and (c) 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.

4.3 Spatial and Temporal Considerations in the Framework

The underlying economic assumption for this framework is that a drainage improvement or wetland conservation is socially desirable if by the improvement or conservation everyone can be made better off or at least some are made better off while no one is made worse off. The decision for adopting choices concerning drainage improvements or 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. 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). Thus, spatial and temporal factors may 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.

4.3.1 Spatial Considerations

Agricultural characteristics of each region are unique due to interregional variability in agroclimatic and soil conditions. So, each region can only support a specific array of crops and types of tillage. Therefore, potential benefits of drainage improvements will be different from region to region. For example, benefits of drainage improvements in the low-lying clay areas of Southwestern Ontario, Canada (e.g. Kent, Essex, and Lambton counties), would be very 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, that is, 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), Ontario, Canada, could have functions such as secondary sewage treatment, source of water, and natural habitat for several species of water fowl 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 or for that matter wetlands in Europe.

4.3.2 Temporal Considerations

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 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. In the application section, we discuss case-study projects which might allow us to estimate the temporal effects of drainage improvement and conservation in two coastal areas of the North Sea.

4.4.4.4 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.

4.4.1 The Private Level

The private level of planning involves a few basic indicators, and because it is limited to a specific 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 or a wooded wetland 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 4.2.1.1.1 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, 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 externality 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 prairie 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 on a short-term basis.

4.4.2 The Regional Level

Planning at the regional level involves the examination and measurement of several interrelated indicators on a larger 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 being 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 (Jorjani and Groenevelt, 1988).

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 is not 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 over a long period of time as long as societal goals remain unchanged. Currently, societal goals dictate that 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.

4.4.3 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 the 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 valuation of 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 Ijsselmeerpolders 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.

4.5 Input Data

To apply the proposed framework for analyzing agricultural or environmental perspectives of a drainage project, several sets of agricultural and environmental input data are needed. For example, we would require agricultural input data such as crop yield, agroclimatic, soil, financial and management data. In addition, we would also require biological input data concerning the potential income-generating or conservation functions of wetlands. Input data about the agricultural perspectives of the framework are usually available at local agricultural offices. In areas where these types of data are not recorded, survey methods can be used for collecting the required data. For the environmental perspectives and estimation of the income-generating potential of wetlands, we can easily collect implicit values to calculate the opportunity cost of wetlands. This method is a common practice and has been used frequently. While most of the environmental indicators can be quantified using this method, it would be more accurate if we could actually measure the utility of each wetland function.

5. POTENTIAL APPLICATIONS OF THE FRAMEWORK

5.1 Canadian Case Study

A nation's long-term survival depends on the ways it utilizes its natural resources. Therefore, studies on the socio-economic aspects of land-use systems are absolutely essential to help members of a society to better understand the trade-offs among different land uses. Results of these studies can provide decision-makers with the necessary input data that are required for development of new or modified guidelines for land use in Canada. The framework presented in this manuscript is a holistic approach and especially designed to address one of the most important current land issues in Canada. The framework can easily be tested on a regional level. Subsequently, the investigation can be extended to a larger scale that may cover one or two provinces. Results of such an investigation would be very useful to regional offices of Agriculture Canada, Environment Canada, Department of Fisheries and Oceans, as well as provincial authorities. The framework can also be used as an extension tool to assist farmers in their own land-use decision-making.

5.1.1 Major Issues in Canadian Land Use

> "Our appreciation of how agriculture, forest operations, mining and petroleum development, urbanization and industrialization, and water management techniques has increased quite rapidly. At the same time we have now begun to study, to document and to prepare guidelines in an attempt to learn how these important sectors of the Canadian economy can be molded together..... If this continues, it is quite probable that we will have the necessary tools to create a meaningful man/land relationship in Canada." (Cox, 1986).

The short-sighted view of Canada as a vast source of natural endowments is taking its toll. Continuous urbanization and industrialization on farm lands have put a tremendous pressure on Canada's limited prime agricultural land. Only 5% of Canada's land area is free from severe limitations for crop production (AIC, 1987). Wetlands, despite their many benefits, are still being threatened by persistent human encroachment. This unbalanced approach to the use of Canada's national resources has too often been based on short- term benefits that may never outweigh their long-term costs.

Currently, Canadian agriculturalists and environmentalists are concerned with the present threat to viability of the country's agricultural industry due to loss of prime agricultural land and soil degradation on one hand, and the resulting pressure on ecosystems for maintaining farm productivity on the other. It has been estimated that, for every hectare of prime farm land lost to urban uses, two hectares of marginal land are required to maintain agricultural productivity (AIC, 1987). Some of these marginal lands include poorly drained wetlands that play important ecological roles. Hence, there is a common and mutual concern among Canadians that present land-use systems lack appropriate guidelines for sustainability of ecosystems and a viable agricultural system to be achieved in Canada.

5.1.2 Selection of a Site for the Case Study

Southern Ontario, with its high population density and best agricultural land in Canada, provides difficult challenges in terms of drainage vs. wetland conservation. With its rich land resource, the region is currently under intensive land-use pressure. Over time, natural areas of the region, including wetlands, have been subjected to much modification, According to Snell (1987), the extent of wetlands in Southern Ontario used to be as high as 23,800 km2 before settlement by Europeans. By 1982, this had declined to approximately 9,330 km2 of wetlands. Snell (1987) also reported that between 1967 and 1982, 57% of the modified wetlands were put under crops and 24% under low-intensity agricultural uses such as pasture or grazing. During the same period, conversions for construction and recreational uses consumed nearly 7%. While much of these changes occurred in Ontario's southwest, Central and Eastern Ontario also experienced considerable losses of wetlands. Therefore, Southwestern Ontario could be considered as a limited case study. The reason for selecting this region for testing the proposed framework are: (a) it is an important agricultural area in Canada; and (b) its few remaining wetlands, for example the well-known Greenock Swamp, are stressed. Nearly a third of the Greenock Swamp is owned by the Saugeen Valley Conservation Authority, and the rest is in private hands. Nearly one third of the Greenock Swamp is owned by the Saugeen Valley Conservation Authority, and the rest is in private hands. Pressures on the Greenock Swamp are mainly from agricultural clearing and drainage along the margins.

5.2 European Case Study

The complex linkages among physical, biological, and socio-economic factors of agriculture have made the task of optimal decision-making at both micro and macro levels a complicated process. With highly uncertain elements such as climatic fluctuations, regional variations, and changes in societal goals, accurate long-term agricultural planning has become constrained by the virtual absence of relevant decision-making tools. Some of the current agricultural problems of the EEC illustrate the inadequacy of the existing decision-making tools. A successful regional or common agricultural policy requires a careful assessment of the complex relationships involved in socio- economic and biological aspects of agriculture. A better understanding of the interface between man and environment, particularly with respect to agriculture and environment, might provide some of the more urgently needed inputs for accurate long-term planning.

5.2.1 Major Issues in European Land Use

There is no doubt that the impressive agricultural development in Europe took place at the expense of a tremendous deterioration of the natural environment. Because of the agro-climatic conditions of northern Europe in particular, drainage has been used as one of the main inputs for development of agricultural land. As a result of this collective pressure on the European environment, and the present socio-economic order resulting from excess agricultural production, there is an urgency for evaluating questions of long-term environmental sustainability relative to short-term economic gains. Currently, IIASA has an interest in this topic and is supporting a detailed European study that involves conflicts in land use with respect to agricultural sustainability and ecological sustainability as a whole. Therefore, the framework presented here can easily be incorporated in one IIASA's ongoing or future investigations focusing on the impact of land-use changes.

5.2.2 Selection of a Site for a Case Study

A case study could either focus on a specific area, or use the framework to examine the impact of two well-known land-use decisions in England and Holland. Nearly ten years ago in the "Wash" on the eastern coast of England, 340 ha of land were reclaimed from the sea by construction of an earthen flood bank. Ironically, the area had been designated by the Nature Conservancy Council as a site of a special scientific interest on account of its exceptional biological importance as one of UK's most important winter feeding areas for waders and wildfowl. The economic rationale for undertaking the drainage 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.

Around the same time, there were several high-level discussions about a similar project in a coastal area in Holland called "Dollard". However, despite all the pressure from agriculturalists in the region, the authorities decided not to reclaim that coastal land. Currently, this area is protected as a natural habitat and a site for monitoring environmental parameters.

Although these two unique areas are in different countries, they have some common features that would make them an ideal pair of sites for analyzing the biophysical cause-effect structure of drainage and its impacts. The results of such an investigation could provide us with information particularly on the temporal effect of reducing groundwater levels. The information gathered in such an investigation would also allow us to identify the weaknesses of this framework, so it can be modified for future uses with more accuracy.

5.3 Methods, Data, and Resources

5.3.1 Methods

The suggested approach for agricultural perspectives is a rather practical one. Currently this approach is being tested as part of a joint Ph.D. project (for the senior author) between agricultural universities in Guelph (Canada) and Wageningen (the Netherlands). With regard to environmental perspectives, although most of the studies in Canada and the U.S. are based on the principle of willingness to pay, it is possible to apply some new methods and models that are being developed in Europe. The "WAFLO" model is an example of such models. WAFLO allows an analysis of plant-species response to groundwater withdrawal (Fahner and Wiertz, 1987). Essentially, the WAFLO model consists of five sub-models, each of which defines the response of plant species to a different factor related to ground water withdrawal: (a) environmental dynamics, (b) soil nitrogen supply, (c) soil aeration, (d) soil moisture supply, and (e) depth of open water. However, not all WAFLO sub-models are applicable in all situations; in terrestrial environments, the sub-model for depth of open water is not used, but for aquatic systems only sub-models for environmental dynamics and depth of open water are used.

5.3.2 Data

Agricultural input data required for application of the framework in Southern Ontario are available. As mentioned earlier, the agricultural perspectives of the proposed framework are currently being used in a case study in Ontario. The case study is based on records of corn yield, climatic changes, soil types, and management levels of several farms in Southern Ontario. To examine the environmental perspectives of the framework, some biological input data must first be collected.

With regard to the European case study (Wash and Dollard), because the respective authorities in both countries have been monitoring changes in those two areas, their data would be used. However, in case problems arise in this, the agricultural data can be collected directly from the farmers through surveys. Similarly, if adequate biological input data are not found at the office of Dollard conservation authority, some field work would be required.

5.3.3 Resources

The required amount of resources will depend entirely on the type and size of the case study. For example, a complete investigation in Ontario would need at least 2-3 years and perhaps several hundred thousand Canadian dollars. Much of these resources would be required for collecting and analyzing biological input data. For the European case study (Wash and Dollard), the amount of resources required might be much less, mainly because Dutch biologists and environmentalists have been monitoring several factors in the Dollard wetland. Therefore, some of the important biological input data for a European case study may be obtained at a lower cost. However, to carry out a feasibility analysis for these projects 6-8 months and approximately 40-60 thousand Canadian dollars would be required.

6. kEFERENCES

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