A Strategy for the Development of Sustainable Agricultural Systems

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Introduction

There is a linkage of environmental problems to a dichotomy between the structure of natural systems and the structure of our society's political boundaries (Chambers 1979). On the other hand, the greatest challenge to modern agriculture is to create sustainable agricultural systems by taking maximum advantage of ecological processes to retain and recycle nutrients, enhance pest control, and create microclimates favourable for crop growth. Because these ecological processes function in part at the landscape level (Zonneveld 1988), the creation of sustainable agricultural systems requires an understanding of landscape ecology (Barrett et al. 1990).

This need to reconcile landscapes and political boundaries and to take maximum advantage of ecological processes within a given landscape can be addressed by landscape ecology (Naveh and Lieberman 1984), ecological land classification (Rubec et al. 1988), and agroecological land classification (Agriculture Canada 1989). Strategically, the Sustainable Agriculture Division of PFRA proposes that this can be done by integrating environmental constraints and socio-economic goals and objectives through the application of multiobjective programming (Figure 1). This simultaneous and orchestrated accounting of agroecologically defined environmental constraints and socio-economic objectives and goals should promote the advent of sustainable agriculture through greater regional integrity and diversity of agricultural systems (Kochurov 1991), as well as coincide with the Green Plan's definition of sustainable agriculture (Figure 2). Similar approaches proposed by Smit et al. (1984) (Figure 3) and Park and Shabman (1982). The latter is especially interesting since it incorporates most of the components of the proposed strategy, ie. - i) ecological zonation of the land, in this case watersheds, ii) the setting of environmental quality goals for these zones, iii) the tradeoff procedure needed when multiple-objectives in these zones must be reconciled and iv) the use of fiscal measures to collect inducements ($) for the implementation of Best Management Practices (BMP) allowing for these environmental quality goals to be attained. Thus the proposed strategy will also involve four distinct activites.

The first activity (Section 1) must define the regional settings particular agricultural systems must operate in. Failure to adapt particular agricultural systems to their respective regional settings could mean that there is a lack of synchrony between the two. The proposed settings are the Agroecological Resource Areas (ARA) and Regions (ARR).

The second activity (Section 2) must lead to the proper diversification of agroecosystems as dictated by socio-economic considerations and influenced by some basic principles of ecology. The stability that arises from the synergistic interactions between the components of an optimally diversified agroecosystem will make this system sustainable.

The third activity (Section 3) will consider the integration of the agroecologically defined environmental constraints (Section 1), socio-economic objectives and goals (Section 2). These constraints, goals and objectives must be expressed numerically and, preferably in a linear arithmetic form, incorporated into a MOP model, and integrated so as to yield the socio-economically, and environmentally noninferior feasible solution.

The fourth activity (Section 4) will argue that proper environmental policy, in particular fiscal measures such as subsidies and fees on environmentally damage can be used as means of attaining this optimum solution.

Section 1: Accounting for Environmental Constraints of the Landscape

Agroecological Land Classification as a Means to Regionally Integrated Agricultural Systems

The benefits of regionally integrated agricultural systems, and in particular their ability to sustain agricultural output, is based on the theory of landscape ecology (Zonneveld 1988), ecological land classification (Rubec et al. 1988), and agroecological land classification (Agriculture Canada 1989).

Landscape Ecology

The basic assumption of landscape ecology is the that a specific tract of land, including all of its heterogeneous components, is a holistic entity, ie. a landscape (Zonneveld 1988, Figure 4). Managing this landscape will require that all these components be integrated into a final decision making process, that is multiobjective programming process (see Section 3). This holistic view of landscape also warrants a basic attitude: that reality consists of wholes in a *hierarchal structure* (Smuts 1926).

Ecological Land Classification

The rational behind ecological land classification is that landscapes can only be surveyed and described systematically as a whole because of the inherent complexity resulting from a hierarchal organization of their many components (Wiken 1980). In the UK, Bunce et al. (1981) established 32 ITE (Institute of Terrestrial Ecology) land classes. Recognising that populations of plants and animals are usually influence by the interaction of various factors, they developed a classification scheme based on combinations of physical variable such as climate, geology, and altitude. Placing soil and land survey samples in each of the 32 classes ensures that the different types of landscapes in Great Britain are represented. In denmark, Primdahl (1991) argued that a form of ecological land classification based on combined physio-graphic and socio-economic criteria could improve conservation strategies and reduce the discrepancy between centralized decisions and local landscape development. Conservationists have also recognized that conservation and diversification is not a universal remedy to ecosystem instability, and that they need to be performed according to the environmental constraints of the regional landscapes (Western 1989; Green 1989).

Agroecological Land Classification (AECL)

"Farming by soils" (Nolan et al. 1990; Roberts 1991) and Best Management Practices (BMPs) (Roberts 1991) aim to adapt farm practices, and in particular crop fertilization and conservation tillage to distinct soil types. AELC is similar to farming by soils and BMP except that it is wider in scope and attempts to account not only for soil types but soil development, topography and agro-climatic zoning as well. AECL is a particular case of ecological land classification.

A relevant AELC scheme is "agroecological resource areas" (ARA) and "regions" (ARR) (Agriculture Canada 1989; Pettapiece and Hiley 1991). The working definition of an ARA is: A natural landscape area which is more or less uniform in terms of agro-climate, landform, soils and general agricultural potential (Agriculture Canada 1989). Broad areas of generally similar agricultural potential and management were separated with an emphasis on natural characteristics. The boundaries were based on eco-climatic zonation, physiographic subdivisions and general soil characteristics. For example, prairie was separated for parkland and forest, hilly uplands from undulating plains, sands from clays and Solonetzic soils from Chernozemic and Luvisolic soils. These were broad areas based on general dominance or consistent mixes of characteristics (Pettapiece and Hiley 1991).

Agroecological resource areas, as a particular form of ecological land classification, account for the hierarchal complexity of landscapes by integrating many biophysical attributes into a single mapping unit. Because of the distinctiveness of these areas, a certain degree of homogeneity can be expected in regards to their agricultural potential. This homogeneity should facilitate program development and resource targeting.

Development of the ARA/ARR classification. The US had been using a "major land resource areas" (Austin 1965) concept to integrate land use into an environmental setting. Areas were briefly described in term of land use, climate, elevation and topography, water soils and crops. Another very similar concept was that of Agroecological Zone as used by FAO (FAO 1978a; 1978b). This involved an ecological framework, with a strong emphasis on agro-climatic parameters. These two concepts became the basis for the development of the agroecological resource area (ARA) concept (Pettapiece and Hiley 1991). The identification and compilation of the necessary resource information included; a) ecological regions, b) climatic parameters, c) physiographic areas, d) soil information and, e) a group of people for consultation and direction.

The project design resulted in the following basic assumptions; a) the resource base is described by agro-climate, soil development, texture and landform, b) the smallest areas to be recognized should be 100 000 ha, c) the areas should be easily identifiable in a physical or visual sense.

Specific map compilation activities were then conducted to delineate areas with the greatest possible degree of homogeneity. Broadly similar areas were identified within a general priority framework of: climate > texture > soil development = landform. Where possible the nearest major physiographic boundary was used to approximate climate and ARA boundaries. This related the areas to visible surface features such as uplands or plains. Finally, given the general nature of the objectives, it was decided that about five categories would be appropriate for each of the characteristics and the following legend was developed;

* Landform which reflects broad slope and shape features;
* Four textural categories of particle size distribution;
* Soil development categories to the Order of Great Group;
* The general provincial agro-climatic classification;

Final map preparation included the aggregation of the areas into larger units (ARR), the assignment of names to the regions and areas, and the compilation of a short descriptive legend using the component categories and design convention.

<u>Description of the ARA/ARR Classification</u>. If ARA and ARR are to become a recognized scheme for development, implementation and targeting of programs they will have to be described in terms of soils, habitat, rural water supply and diversification opportunities. An initial attempt at this was done for four landscape regions, in western Canada (PFRA 1990; Figure 5). Eventually, a description of the biophysical attributes of all landscape regions will have to be completed. Program development to promote agricultural and environmental sustainability must recognize these differences to make appropriate use of resources both now and for future generations.

PFRA and Agroecological Land Classification

PFRA's Sustainable Agriculture Division is presently leading a pilot project aimed at the integration various Rural Water Development Program (RWDP) databases and the ARA/ARR classification. The rationale for this integration is that the reporting of surface and groundwater on an ARA/ARR basis rather than on an RM, Twp or even drainage basin basis may lead to decision making that is less likely to disregard the environmental constraints of the landscape. This is well exemplified in a report by Omernik and Griffith (1991) where "ecoregions" proved to be more uniform in terms of certain biophysical attributes than the traditional hydrologic units. Uniformity in these cases should dictate congruent programming and policy directed at these biophysical traits. However, hydrogeological considerations need not be reflected by AELC. This is partly due to the fact that aquifers sources are largely the result of geological phenomena (Driscoll 1986), whereas ARR/ARA are mainly a reflection of surface characteristics. This does not mean that ARA/ARR need be irrelevant to groundwater, but rather that this relevance is not apparent. Certain surface characteristics reflected in the ARA/ARR could in fact influence the exploitation of the underlying aquifers. This is why an important component of the above pilot study will involve existing groundwater investigations in the south-east of Saskatchewan (SWC 1991) and the Stettler region of Alberta (Alberta Environment 1991).

Section 2. Accounting for Socio-Economic Goals and Objectives

When a suitable agroecological landscape classification has been established and described it will facilitate the promotion of sustainable agriculture. Doing so will involve two activities. First a goal or objective must be set. It must be sufficiently discrete so as to focus attention on its achievement. Undiscrete goals and objectives such as sustainable agriculture or rural development often generate more rhetoric and polemic than concrete action. In this case socio-economic goals and objectives will be set by applying some basic environmental economics methods thus generating socio-economically desirable levels of primary agricultural production (P_s) and environmental quality (EQ_s). Secondly, means of attaining P_s and EQ_s on and agroecological regiona basis will have to be developed. These means can be described as best management practices (BMPs), sustainable land management practices (SLMP).

Environmental Economics and Externalities

Benefit-cost analysis used for the measure of the worth of agricultural projects and programs (Gittinger 1982) does not fully account for all costs and benefits. Many costs associated with the damages to air, water, soil, and existing cultural values are not presently accounted for in BCA. These are commonly referred to as shadow costs, intangibles, or externalities. Environmental economics tries to effectively account for these externalities.

Theory of Environmental Economics

Economics is concerned with efficiency of resource use. The most simple case in which such efficiency, or pareto optimum, can be attained is when, all markets are competitive, all markets participants are fully informed and when all valuable assets can be individually owned. Environmental economics is concerned with the limitations to this market theory as they pertain to the inefficient use of common, public, and private property. These inefficiencies, such as pollution and land degradation, arise because traditional welfare economics fails to account for the externalities that arise when at least one of the above market characteristics is not warranted (Kneese 1977) and market failure is said to have occurred because the private and social costs of providing welfare do not equate. The proponents of environmental economics will argue that this disparity is caused by the limited role economics theory plays in the efficient allocation of all resources used for the production of goods and services. Environmental problems, in this sense, are not caused by economic theory, but rather of its limited scope and application. In other words; environmental degradation is the result of inefficient and thus uneconomical use of natural resources.

With this in mind it is now important to understand that the role of governmental environmental policy is to extend the role of the pricing system.

Environmental economics is involved primarily with the pricing of externalities to economic activity. This should make the marginal private costs (MPC) of production of a firm or industry equate to the marginal social costs (MSC) of production (Figure 6). Depending of the elasticity of demand, and assuming that the costs of these externalities will be transferred to the consumer, the level of production will shift from P_p to P_s. This is perhaps the most widely feature of environmental degradation. This externality aspect may arise because of the inputs used or because the act of consumption itself is a nuisance. In either case an adjustment in the mix of inputs and outputs must be made to allow for this shift. This is achieved when proper diversification is attained through input substitution and the optimization of their efficient use.

MCC = MDC: Substitution, Optimum Diversity and Synergism

The task of environmental economics is to maximize the efficiency in the use of all natural resources use in the production of goods and services. This will occur at some level of production P_s (Figure 6). At P_s, resources will be used-up and effluents will be discarded into the landscape environment at a level which is socio-economically acceptable. In other words the firm will be using natural resources efficiently and will generate only an optimum amount of pollution (Pearce 1976). Practically, the firm must evaluate the marginal costs of controlling (MCC) environmental damage versus the marginal costs of environmental damage (MDC) (Figure 6a). Where MCC = MDC, the total cost of damage to the environment is minimized. Alternatively, the firm can evaluate the marginal benefit of control (MBC) versus the MCC (Figure 6b). Again, where MCC=MBC, the degree of environmental quality is optimum considering the socio-economic need of producing P_s. The proper mix of inputs to attain socially and economically desirable agricultural output will also occur where MCC = MBC.

The task at hand is thus to substitute alternative inputs and outputs so that MCC = MDC and TDC is minimal (Figure 6). Minimal of tolerable soil loss (Crosson 1983; Johnson 1987; Mannering 1981) for example could reflect minimal TDC. In fact, substitution is one of the key concept in resource economics (Dasgupta 1989; Goeller and Weinberg 1976; Goeller 1979; Hartwick and Olewieler 1986). A simple case of resource substitution can be illustrated using production functions (Figure 7). A production function illustrates the trade off between different inputs at given level of production. If this level of production has been previously identified as being P_s, governmental authorities can then promote a an environmentally desirable input/output resource mix by influencing the prices of different alternative inputs (Pearce 1976).

Optimum Diversity of Agricultural Systems and Synergism. The productivity of diversified agricultural systems can be greater than the sum of the products of individual system components. This phenomena is called synergism (McNaughton 1988). Specialized agricultural systems sacrifice the potential gains from synergistic interactions among the various components of diversified systems (Ikerd 1990). The benefits of diversifying cropping systems can be measured easily. Cereal-legume intercrops are one such example (Vandermeer 1989;

Ofori and Stern 1987; Willey 1979). However, the benefits of diversification on the productivity of agricultural systems as a whole have not been documented as extensively. An obvious example of such synergism resulting from the interactions between two agricultural systems is the interaction between livestock and legume forage crops (Ikerd 1990). An illustration of the negative impacts of decreased diversity on the input/output ratio, an index of productivity, of agricultural systems is exemplified by Barret et al. (1990). As the crop diversity in this region of Ohio decreased, the yield of corn, soybean, wheat and oats were increased bu over 100%. However, at the same time, the quantity of plant nutrient needed to produce this increased yields had increased by more than 1000%. Also, the profitability of integrated [read diversified] agricultural systems has been reported to be comparable to that of less integrated, less diversified systems (Stanhill 1990; Vereijecken 1990; Titi & Landes 1990).

Edwards (1990) and Edwards (1987) insist on the importance of integration and how this concept can be used to bring about diversification and lower input sustainable agriculture (LISA). The integration of various components in a particular agroecosystem should allow for ecological interactions. The positive aspects of this interaction contribute to what is called synergy, and subsequently to a reduction in the need for external inputs to that agroecosystem (Edwards 1990). This reduction precludes needlessly high levels of inputs as a result of little or no synergism.

Application of Environmental Economics

Proper levels of on-farm, or regional diversity in resource mix must be promoted so as to generate synergism and a reduction in the needless high level of external inputs. This means that MDC and MCC functions must be generated so as to identify P_s where MCC = MDC. The MCC curve can be inferred from the financial aspects of conservation planning, whereas the MDC curve will require the metering of soil productivity losses and nonpoint source pollution. The MBC functions, for its part, can be inferred from hedonistic analysis, that is; the quantification of people's willingness to pay for the enjoyment of environmental quality (Bockstael & Kling 1988).

Best Land Management Practices as a Means to P_s and EQ_s

Having set P_s and EQ_s, means of attaining these goals and objectives must be developed. In a broad sense, such development falls under the heading of land evaluation. The ideal outcome of land evaluation is meant to be a series of Best Management Practices (BMPs) aimed at protecting water quality, and Sustainable Land Management Practices (SLMP) aimed at protecting soil quality. This separation between BMPs and SLMPs is known to be an artifact of the unnecessary split between soil and water conservation disciplines. Ideally the outcome of land evaluation and regional land use planning (RLP) will resemble more a best land, or landscape, management practices (BLMP).

Direct and Indirect Land Evaluation (LE)

Land may be evaluated directly, by trial. Direct land evaluation is of limited value unless the evaluator has resources to collect a large amount of data. However, most land evaluation is done indirectly. It assumes that certain soil and site properties influence the success of particular land use in a reasonably predictable manner (MacRae and Burnham 1981, pp.2)

Stages in Indirect Land Evaluation. Indirect land evaluation can be divided into six steps, representing successive interpretive stages (Figure 8). In the figure characteristics means land properties that are likely to be relevant and can be assessed without excessive effort, whereas land qualities are complex attributes relevant to use which are determined by a set of interacting single land characteristics. Suitability refers to one tightly defined use of practice, whereas land capability refers to a range of uses, eg. - forestry, agriculture or recreation. Land capability is more difficult to assess than suitability since priorities must be established between uses. Finally, the concept of value involves a monetary or similar basis, whereas optimum land use, or sustainability, should be the outcome of land evaluation.

The FAO Land Evaluation Framework

Since its inception the FAO framework for land evaluation has been used as a blue print for the development of other land evaluation schemes (Van Diepen et al. 1991). The framework as such does not constitute an evaluation system but is designed to provide tools for the construction of evaluation systems in support of rural land use planning (Van Diepen et al. 1991).

Principles and Basic Concepts as applied to BMP and SLMP Development. The framework essentially involves the matching of land units (LU) described in terms of rated land qualities and land utilization types (LUT) described in terms of minimum required land quality (Figure 9). This will also be the process by which Agroecological Resource Areas (ARA) and Regions (ARR) described in terms of their biophysical attributes and land use potential will be matched to management practices described in terms of minimum required biophysical attributes. A proper match will allow for the recommendation of the best land management practice for particular ARA-ARR. Because land use potential will have to respect P_s and EQ_s, such management practices will promote the advent of sustainable agriculture.

Best land management practices are meant to be an integral of BMP and SLMP. Traditionally, BMPs were directed at water quality conservation (Clausen and Meals 1989; Park and Shabman 1990) whereas SLMP were directed at soil quality conservation. the concept of landscape and the theory of landscape ecology (Forman and Gordon 1986) do not promote such a dichotomy between soil and water. Best land management practices are an attempt at abolishing this dichotomy.

Section 3. Multiobjective Programming Methods

Introduction

Environmental-socio-economic integration pivotal to sustainable agriculture is a multiobjective programming (MOP) problem (Figure 1). Goicoechea et al. (1982), Cohon (1978), Hill (1973), Ignizio (1982), Stansbury et al. (1991) and Cornett and Williams (1991) have all reported on the use of MOP techniques for solving land, water and other natural resource use conflicts. Because this type of arbitration is in the realm of public decision making and public interest, Cohon (1978) sees MOP as an essential tool for the analyst reporting to the public decision maker. In doing so, he identified problem areas that must be addressed. These problems can be addressed by a variety of MOP methods. These all have one cardinal requirement however: the generation of *noninferior* solutions. Noninferiority is the major new concept of MOP. Noninferiority in the context of MOP can be defined in the following way (Cohon 1978);

> *A feasible solution to a MOP problem is noninferior if there exists no other feasible solution that will yield an improvement in one objective (Z_n) without causing a degradation in at least one other objective.*

Cohon (1978) refers to this definition as the northeast rule; when all objectives Z_n are to maximized, a feasible solution is noninferior if there are no feasible solution lying to the northeast." (see N_o in Figure 11).

Classification of MOP Methods

Cohon (1978) classifies MOP methods according to the decision making context (single versus multiple decision makers), and on the basis of information flow (bottom-up, top-down) (Figure 10).

Generating Techniques

These emphasize the development of information about a MOP problem this is presented to a decision maker in a manner that allows the range of choice and the tradeoffs among objectives to be will understood. Thus, the analytical goal is not political analysis or prediction, but the generation and evaluation of alternatives in terms of several objectives. The information flow is of the bottom-up variety. Analysts apply a generating technique to find an exact representation of an approximation of the noninferior set (F_o) in objective and decision spaces. This MOP technique will describe the tradeoff between two or more objectives (Z_n) when various weights (w) are ascribed to each objective. Weights here are not to be interpreted as preferences but rather as arbitrary nominal values orderly arrayed for the sake of generating many alternative noninferior solutions to the tradeoff problem between Z_n and Z_{n-1} (Z_1 and Z_2 in Figure 11a, Cohon (1978)). The importance one attributes to objective Z_1 and Z_2 for instance will determine the slope of the line tangential to N_o, and thus the trade-off between Z_1 and Z_2 at that point.

Techniques That Incorporate Preferences

These share the analytical goal of the generation methods: analysis of a MOP problem without explicit consideration of the political dynamics of the problem. Unlike the implicit treatment of preferences by the generating methods, preference-oriented techniques require that decision makers articulate their preferences and pass that information on to the analyst. This MOP method has been influence by the theory of *multi-attribute utility functions* (Bentham 1948). These functions (u_n) are mathematical statements that indicate the utility of all combinations of values (weights) for the various attributes or objectives (Z_n) that are under consideration (Figure 11b, Cohon (1978)). The best compromise solution is where the utility function is tangent to a noninferior set (N_o) of feasible solutions (F_d). In a sense, these techniques are a subset of the set of generating techniques where the weights (w) and thus the slope of the line tangential to N_o (1/w) are set by the utility function. Agronomically, these functions could be replaced by agricultural production functions (Figure 9).

Multiple Decision Maker (MDM) Methods

Multiple-decision-maker methods are directed at the resolution of conflict among many interest groups or decision makers. The involvement of many decision makers with distinct preferences and utility functions (Figure 11c) in the planning of a public resource such as land is substantially motivated by the existence of the *paradox of majority voting* (Arrow 1951). This paradox is possible whenever there are more than two voters and alternatives and results in intransitive orderings of social states (Tables 1 and 2, Cohon (1978)). In such a case, transitivity can be obtained only by imposing an ordering on at least one individual or by allowing one individual to dictate what the social ordering should be. The implication is that a suitable best-compromise can only be attained when all, or at least as many as possible, of the stakeholders are involved in the decision making process, ie. - multi-disciplinary teams.

Multi-disciplinarity as a Means to LEAS. Land evaluation for agricultural sustainability (LEAS) in Europe, North America and Australia have in the past made use of multi-disciplinary teams. Bunce et al. (1986) reported on an ecological classification of land and its application to land use planning in the highland region of Scotland. The classification scheme was meant to generate an inventory of all, regional statistics, give an indication of the broad regional distribution of resources, and to assess land use potential. In Australia, Hobbs and Saunders (1991) proposed a multi-disciplinary framework for the reintegration of fragmented landscapes.

FAO's (FAO 1978a; 1978b) framework is an early attempt at achieving multi-disciplinarity. It involves the execution and interpretation of basic surveys of climate, soils, vegetation and other aspects of land. Canada, however, is just beginning to develop multi-sectorial responses to land-use issues (Manning 1986). For instance, the Soil Quality Evaluation Project (SQEP) (Acton 1989) will attempt the integration of a number of studies pertaining to wind and water erosion, organic matter loss and salinization. Smit and Brklacich (1985) have reported on the feasibility of construction a multi-sector land evaluation system for New-Brunswick. Petch (1985) has also reported on the use of Integrated Resource Management (IRM) in Alberta. The philosophy of IRM in Alberta is founded upon some basic principles (Petch 1985), including the use of a team approach by experts.

The appreciable benefit of another multiple-decision maker technique, the Goal Achievement Matrix (Hill 1973), is that it caters to some extent to qualitative and non-parametric information. For instance, the costs of soil degradation sill need to be properly determined (Crosson 1985), whereas socio-economic goals and objectives are still to a large extent qualitative. In such cases Hill (1973) recommends the use of an *ordinal scale* which ranks entities (goals) by ascribing weights to them (Table 3, op. cit., pp. 39).

Applicability of MOP Methods to the SA Strategy

All three classes of MOP methods are applicable to the SA strategy. The ideal method, socio-economically and environmentally speaking is the generating technique one. The alternative solutions in this case would be solely base on landscape ecology and environmental economics and would best reflect the integration of environmental constraints and socio-economic goals and objectives (Figure 11a). However, institutional mandates will dictate preferable outcomes at the expense of socio-economic and environmental considerations. MOP techniques that incorporate preferences are recommended where institutional mandates prevail (Figure 11b). Where institution mandates and interest groups are involved, multiple-decision maker MOP methods can be used (Figure 11c) though in this case the analytical task is muddied and noninferiority is threatened.

Application of MOP Techniques

In order to make best use of MOP techniques those techniques should implemented that incorporate the preferences of individual decision makers, and or those of MDM. Under some circumstances the more objective but less practical generating techniques could be used when environmental constraints are discrete. This is the case with tolerable soil loss ("T") or percentage remaining critical wildlife habitat. A combination of all tree classes of methods can also be used: a generating technique including a discrete environmental constraint can also accommodate a single utility function reflecting the interests of a number of decision makers.

Section 4. Environmental Policy as a Means to Sustainable Agriculture

Introduction

Once the optima in regional diversity, ie. - the preferred resource mix has been identified through the solution of the MOP model, environmental policy will be used to orient the choices of the various stake-holders in accordance with this mix. To do so, proper environmental policy must be designed. It will be argued that fiscal measures, and in particular fees on any other environmentally damaging activity are possibly the best option.

Environmental Policy

Markets and the pricing system have failed to allocate all natural resources efficiently. Seneca and Taussig (1974) call this market failure. The role of environmental economics is to determine P_s where such market failure does not occur. The role of environmental policy is to use moral suasion, direct control and/or fiscal measures to bring about P_s and minimal TDC (Figure 6) through a substitution of inputs (Figure 7).

Environmental policy must not only aim at efficient resource use but must also allow for equity. Income distribution is generally recognized as socially desirable by most economists. Income distribution comparisons of alternative government programs to enhance environmental quality must thus stand on equal footing with benefit-cost tests of relative resource-use efficiency (Seneca and Taussig 1974). Environmental policy as influenced by environmental economics is thus truly socio-economic in scope and consistent with the definition of sustainable agriculture (Figure 2).

Alternative Solutions to Environmental Problems

Collective action towards environmental degradation can be taken through a diversity of vehicles (Seneca and Taussig 1974; Baumol and Oates 1979). The common law alternative is usually ineffective since emitters and receivers of non-point source pollution are usually numerous which makes the identification of the claimant and defendant quasi impossible. Creating a free-market for environmental quality is also probably ineffective since potential users cannot be excluded from using the service for free. Even if such was the case, such exclusion would lack equity. In fact, both solutions, common law and market solutions to environmental problems founder on the same circumstance: the diffuse and pervasive nature of production externalities.

This partial failure of the legal and market approach to environmental problems legitimizes the use of environmental policy (Baumol and Oates 1975; 1979). Environmental policy is in fact the "market solution imposed" (Seneca and Taussig 1974) by the government through regulation and fiscal measures. However, it too has limitations: metering, establishing proper discounting rates, policing, pricing, corporate and environmentalist opposition, and bureaucratic inefficiencies.

The Range of Environmental Policy Instruments

In Table 4 (Baumol and Oates 1979) the policy instruments that can be used for the preservation of environmental quality are classified into four broad categories. The first three are techniques to influence the polluter's behaviour; moral suasion, direct control and market processes. The fourth approach involves direct government expenditures, largely for the construction and operation of projects that improve the environment. PFRA, Agriculture Canada and Environment Canada have been involved to some extent in all of the above.

Subsidies. These are appropriate when no alternative fiscal approach is politically feasible or where fees on environmentally damaging activities have a very undesirable and inequitable pattern of incidence on different groups. These are usually not too politically volatile since they involve a transfer of public money to the primary agricultural sector. Traditionally tax payers have not been overly critical of this kind of transfer. The recent GATT negotiations have however made the public aware of the actual societal support to this sector.

Fees on Environmentally Damaging Activities. These are part of a basic approach for the regulation of polluting behaviour where metering of individual emitters is feasible. Though these are generally recognized as an ideal fiscal measure, their application to primary agricultural production is severely limited by the technical problems involved in metering individual emitters of non-point source agricultural pollution. This limitation will be addressed shortly.

Auctioning of Pollution Permits. This is an alternative to fees where metering of individual emitters is feasible. However, though it does eliminate the uncertainty associated with the polluters response to fees and is not subject to erosion by inflation or growth, it is politically volatile. This alternative has previously been coined the "right to farm" concept and is in a way analogous to cross compliance.

Deposit by Potential Polluters. This is attractive where direct observation and monitoring difficult but the burden of proof can be shifted to potential generator of damage. It is obvious that this can not apply to traditionally privately owned agricultural land. It could always apply to special short term grazing leases and feedlots.

The complex systematic nature of environmental problems and the legitimate sense of urgency that these problems create make direct controls and market processes the most rational immediate choice (Baumol and Oates 1975; 1979; Seneca and Taussig 1974; Kneese 1977; Pearce 1976). However, market processes imposed by environmental policy are seen as preferable to extended direct controls. There again, environmental policy aimed at extending the role of the market to all natural resources involved in the production of particular goods and services has been plagued by opposition from business and environmentalists, as well as by technical problems such as metering, policing and discount rates.

Direct Controls or Fiscal Measures?

The failure of markets and government in improving environmental quality is caused by an over reliance on moral suasion and voluntarism on one hand, and often inapplicable direct controls on the other (Baumol and Oates 1975; 1979). Economists have advocated the use of pricing measures which they believe to be more efficient, more permanent, and more desirable for a number of reasons. They base their pretensions on the following criteria for the evaluation of environmental policy (Baumol and Oates 1979);

Dependability. How reliable is the approach in achieving its objective? Are its workings certain and automatic or does it depend on a number of unpredictable elements?

Permanence. Is the program likely to be effective only so long as it captures public interest, or can it be expected to endure even when other issues have seized the attention of the media and the public?

Adaptability to Economic Growth. Is the program flexible enough to adapt to expansion in economic activities and population growth, both of which tend to accentuate problems of environmental damage?

Equity. Does the program divide its financial burdens among individuals and enterprises fairly?

Incentives for Maximum Effort. Does the program offer inducements to individuals or enterprises to minimize environmental damage, or does it encourage no more than barely acceptable behaviour?

Economy. Does the program achieve its results at relatively low cost to society, or does it waste resources?

Political Attractiveness. Is the method likely to recommend itself to legislators and to voters?

Minimal Interference with Private Decisions. Does the method tell the individual or the businessman what to do, or does it offer the broadest scope of choices consistent with protection of the environment?

The consensus seems to be that fiscal measures, and in particular effluent charges, are preferable to moral suasion and direct measures (Baumol and Oates 1975; 1979). Table 5 summarizes the appropriate use of the various instruments of environmental policy. This appropriate use is a function of the above eight criteria. In general it can be said that direct control and moral suasion should have preference over fiscal measures only in cases where; 1) metering and policing is impossible or costly, 2) adverse environmental effects prevail, 3) hazardous pollutants are involved.

The Supply and Demand of Soil and Water and it's Effect on Their Conservation

The *tragedy of the commons* concept (Hardin 1968) states that resources that are not privately owned will be subjected to over exploitation since no one has any vested interest in their conservation. This concept has had far reaching implications in the realm of public policy. In particular it has been used by some to call for an outright "privatization" of most natural resources in an effort to breed some responsibility into their use (Block 1985). Responsibility is meant to be a function of market processes; if private resources are willingly supplied, a certain willingness to pay should prevent an excessive and irresponsible use of this private resource. Thus, in economic terms conservation is only possible if the willingness to supply is kept under control by a willingness to pay. Conservation is an alternative to exploitation when the costs of development do not generate and acceptable rate of return to the supplier.

Does soil conservation as it is implemented by governmental agencies such as PFRA make economic sense? In primary agricultural production, the demander of the soil organic nitrogen, for instance, is not distinct from the supplier. Therefore, there cannot be a willingness to pay since the demander already owns the resource. This implies that in economic terms, soil organic nitrogen conservation can never become an alternative to soil organic nitrogen extraction because we cannot ascribe a price or cost to it since there is no willingness to pay. This could explain why the economics of soil conservation, which to a large extent involves the conservation of soil organic nitrogen, is nonsensical as long as the supplier and user or the resource are indistinguishable. This also explains why, in the necessary absence of economic incentive, governmental financial incentives have been used extensively in the past. However, it is generally well recognized that such financial incentives are not meant to be permeant, unlike soil organic matter conservation. In view of the fact that economic incentives cannot exist and that financial incentives cannot be permeant, alternatives must be found.

Financial Incentives Revisited: This is presently the mainstay of soil conservation. The question is the asked; should present incentive programs be continued, and for how long? If so, should cross compliance be installed? The present review of the GATT has also lead to the categorization of these programs as "red", "yellow" or "green". Education and awareness in this context is meant to inform the landowners of financial incentives, of lack of disincentives, when opting for soil and water conservation.

Moral, Ethics and Regulation: Beyond financial and economic incentives, soil and water conservation can be installed through a politico-moral ethic comparable to that of human rights. This is a far reaching paradigm shift which involves a reconsideration of man's domination over nature (Serres 1990; Liess 1972) and the establishment of and "environmental bill of rights". Though this is environmentally the best solution, it does contradict in essence the workings of the market economy, and is thus infeasible at the time.

Economic Terms Revisited: It is now apparent that because of the private ownership[1], and because of the hegemony of the free market ideology, governmental financial incentives on one hand, and an environmental bill of rights on the other, are presently inadequate. The alternative to such financial and ethical measures is economic, that is the creation of a willingness to pay. Since the soil resource, for instance, is privately owned (supplied) and utilized (demanded) this is impossible. The private user of the soil will however be willing to pay for the disposal of externalities generated when exploiting his/her privately held resource if he/she is **obliged to do so**. Presently such an obligation does not exist since externalities can be disposed of at no costs. This would thus explain why governmental incentives are presently used extensively. The alternative is thus to set fees (Pigou 1932) on the disposal of soil, nutrient and chemicals removed from private land when the soil resource on these private lands is being exploited. This would create an obligation and a willingness to pay and would thus keep the demand for such disposal sites under control. That is, soil, nutrients and chemicals would not be disposed of, but rather, because of an economic incentive to do so, kept where they are the most economically productive; ie.: on the farm.

Fees could be implemented by the metering of agriculture's contribution to the effluent load of a stream or river on basis of existing legal boundaries ("locality") (Foran et al. 1991). The effluent load contributed by the locality is equal to the difference between the effluent load entering and the effluent load leaving a stream or river crossing that locality. Assuming the effluents discharged by the industrial firms is measurable (Baumol and

[1] ie. The private use of a private resource makes conservation uneconomical.

Oates 1975; 1979), it need only be subtracted form the locality's overall effluent load to obtain the farm contribution. Otherwise, it would be very difficult to meter directly the chemical and sediment effluent discharged from each farm. The locality could then be given taxation powers to collect a fraction of the effluent fee from individual farm operators on the basis of their production and conservation practices, and if possible on the basis of the actual soil loss and nutrient and pesticide leaving the farm to the common environment. We have already seen in Section 2 how soil conservation planning tools could be used to measure this contribution to the pollution of the commons.

Interpretive Summary

Implementation of this strategy will permit the integration of agroecologically defined environmental constraints, and socio-economic objectives and goals. Agricultural systems will thus be of greater integrity and sufficiently diverse so as to insure the stability of the agroecosystem they comprise. It is this insured stability that makes these agricultural systems less likely to stop producing the required food and fibre over prolonged periods of time. This is what we chose to call sustainability. The implementation of the proposed strategy will involve;

1. The adoption of *agroecological land classification* as a means of identifying environmental constraints to primary agricultural production;

2. *Establishing the MDC (Marginal Damage Cost) or MBC (Marginal Benefit Cost) curves* related to soil degradation. The MCC (Marginal Control Cost) curve for its part can be inferred from the financial aspect of soil conservation. The socially desirable level of primary agricultural production (P_s) occurs where MDC (or MBC) = MCC.

3. The adoption of *MOP techniques* especially those that incorporate individual preferences and MDM techniques as a means of integrating the agroecological environmental constraints and the socio-economically desirable level of primary agricultural production.

4. *Externalities generated by the private use of private resources need be accounted for* in economic terms when attempting to generate economic incentives for soil (organic nitrogen) conservation.

Agroecological land classification is presently being evaluated internally by PFRA. It involves applications to the Rural Water Development Program and possibly soil conservation activities. Technically the applications consist of database management attempting the link between soil landscape and agroecological landscape polygons and legal coordinates such as RMs, Twps, sections and quarter sections of land. This will permit the reporting of environmental, engineering and socio-economic data presently available on an agroecological basis.

Establishing fees for the movement of resources traditionally external to the benefit cost analysis of primary agricultural production would contribute to a more economical and thus efficient use of all resources involved in agriculture. Past experience and theoretical applications with effluents to air and water from industries other than agriculture demonstrate that is likely so. In those cases, the flow of materials from private to public property could be relatively easily identified . Such is not the case with primary agricultural production. For fiscal measures to be applicable to primary agricultural production the metering of effluents from individual farm enterprises will have to be possible, or the private ownership of land will have to be either constrained, or extended to air, surface and groundwater. In a way, the challenge is to extend the use of effluent fees and taxes to nonpoint source primary agricultural pollution. Metering of this type of pollution is a technical problem. However, these fees are unlikely to be acceptable to the farming community at this time.

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Figure 1. The relationship between the various components of the proposed Sustainable Agriculture (SA) Strategy.

Notes:

1. Environmental constraints are particular to the Agroecological Resource Regions).
2. These are determined through the application of environmental economics theory and should identify the socio-economically desirable level of primary agricultural production at which all social, environmental and economic costs of production are accounted for.
3. These can be expressed as individual preferences of the decision maker and/or through the involvement of numerous decision makers (ie. - interest groups).
4. Multiobjective Programming
5. Environmental policy alternatives include;
   * moral suasion,
   * direct governmental control (regulation),
   * fiscal measures,
   * government investments.

Figure 2. The integration of socio-economic and environmental considerations when designing sustainabnle agricultural systems and policy. (Adapted from the Green Plan, Environment Canada).

Figure 3. Integral land evaluation (ILE) as an extension of physical land evaluation (PLE). (Adapted from Smit et al. 1984).

Figure 4. Landscape as an ecosystem. (Adapted from Zonneveld 1988).

Figure 5. Landscape regions (Agroecological Resource Regions) in the Prairie Provinces.

Figure 6. An illustration of how P_s, a socio-economically desirable level of production, can be determined theoretically from marginal social (MSC) and private (MPC) costs, industrially from total control (TCC) and damage (TDC) costs (TC = TCC + TDC), and practically, at the farm level, from marginal control (MCC) and damage (MDC) costs. (Adapted from Baumol and Oates 1979).

Figure 7. Agricultural production functions representingthe alternative input substitutions that allow for equivalent outputs of corn. (Adapted from Baumol and Oates 1979).

Figure 8. Stages in indirect land evaluation (MacRae and Burnham 1981).

Figure 9. FAO procedure for the assessment of the suitability of land utilization (FAO 1976).

Figure 10 Relationships amoung the categories of multiobjective programming (MOP) methods. (From Cohon 1978).

Figure 11. Graphical illustration of three MOP techniques. Z_1 and Z_2 are the objectives, F_0 is the set of feasible solutions, whereas N_0 is the set of noninferior (nondominated) feasible solutions. Because of the nature of environmental protection, Z_1 was established as a discrete constraints. Tolerable soil loss (T) is an example of such a constraint.

Tables 1 and 2. An illustration of the "paradox of majority voting" (Arrow 1963). The majority vote in Table 2 does not reflect the aggregation of individual choices expressed in Table 1. If it did, A > C would in fact be dictated by only a minority of individuals (ie. - one of three). The involvement of a multitude of stakeholders in the decision making process rather than majority voting through referendum on a series of issues is thus more democratic.

Table 3. A Goal-Achievement Matrix according to Hill (1973).

Table 4. Approaches to environmental policy according to Baumol and Oates 1979.

Table 5. Summary of the appropriate uses of various instruments of environmental policy according to Baumol and Oates 1979.

Figure 1

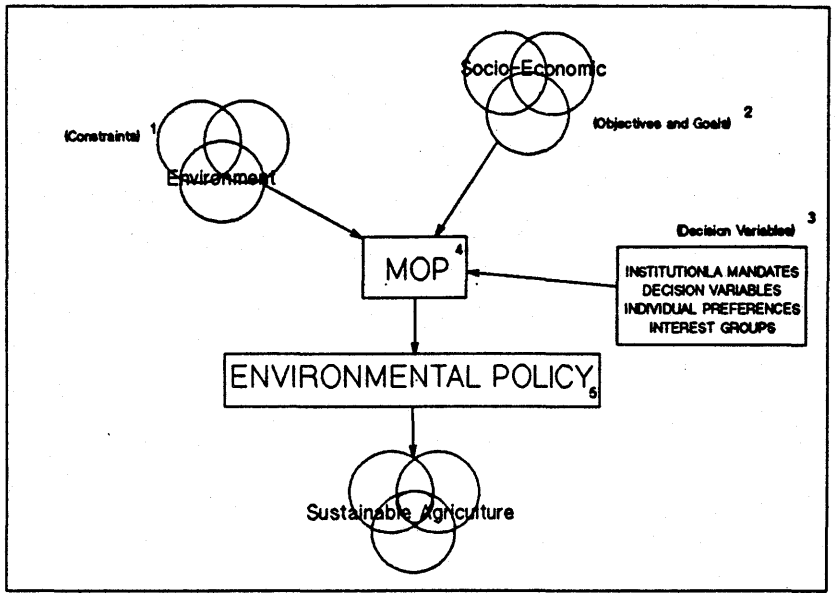
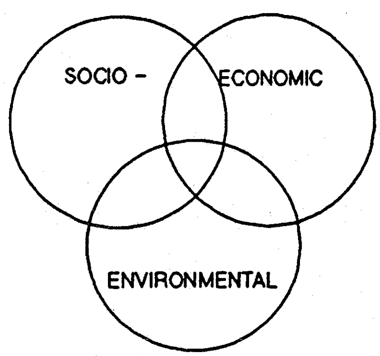
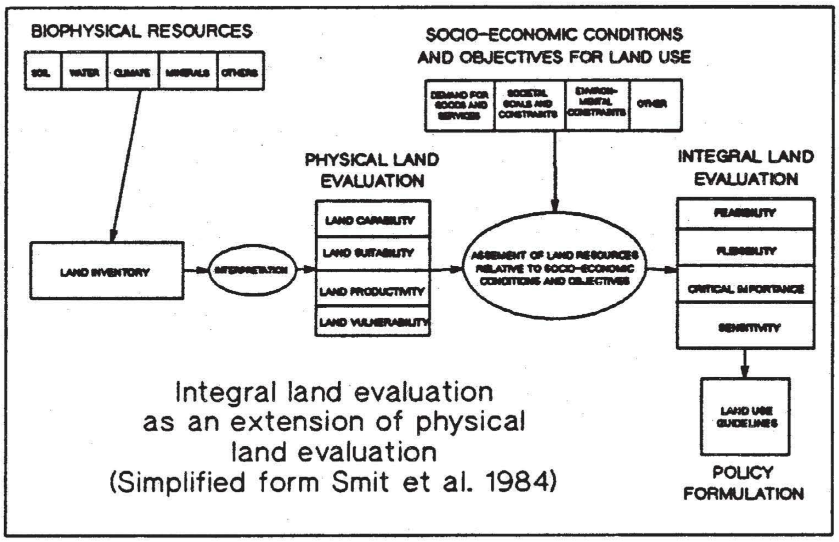


Figure 2



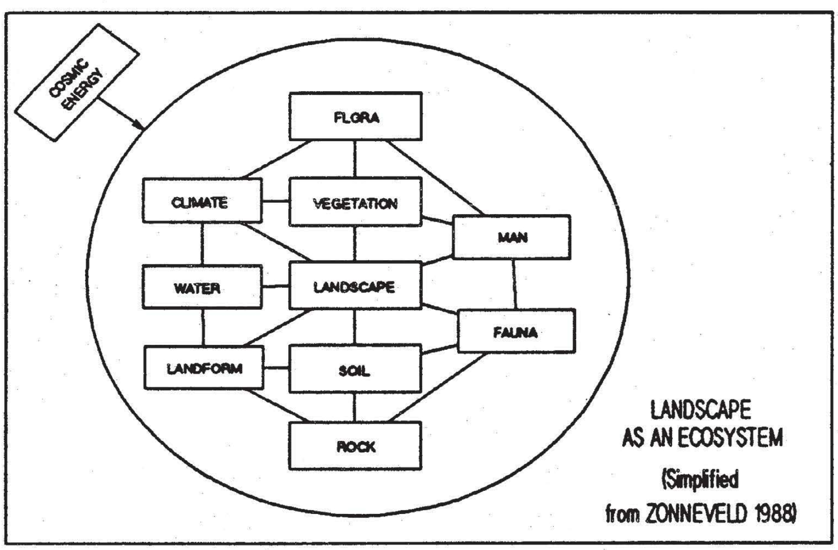
The integration of socio-economic and environmental considerations when designing sustainable agricultural systems and policy (Adapted from Sadler 1989)

Figure 3



Integral land evaluation
as an extension of physical
land evaluation
(Simplified form Smit et al. 1984)

Figure 4



LANDSCAPE
AS AN ECOSYSTEM
(Simplified
from ZONNEVELD 1988)

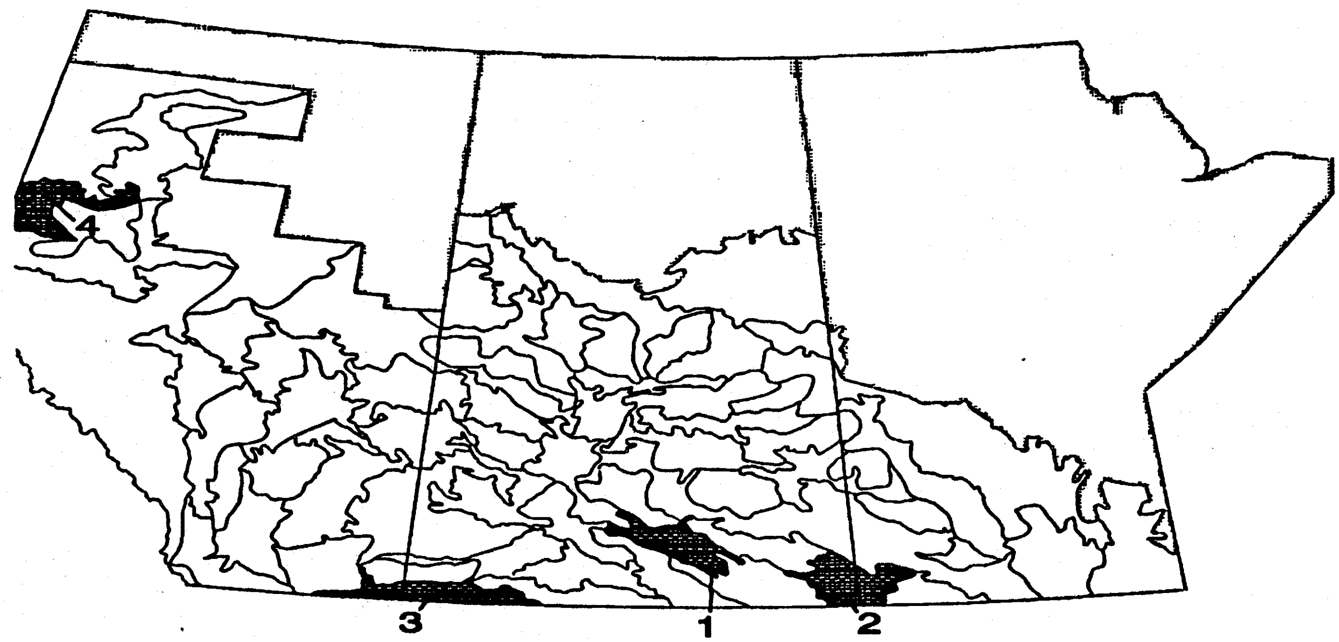
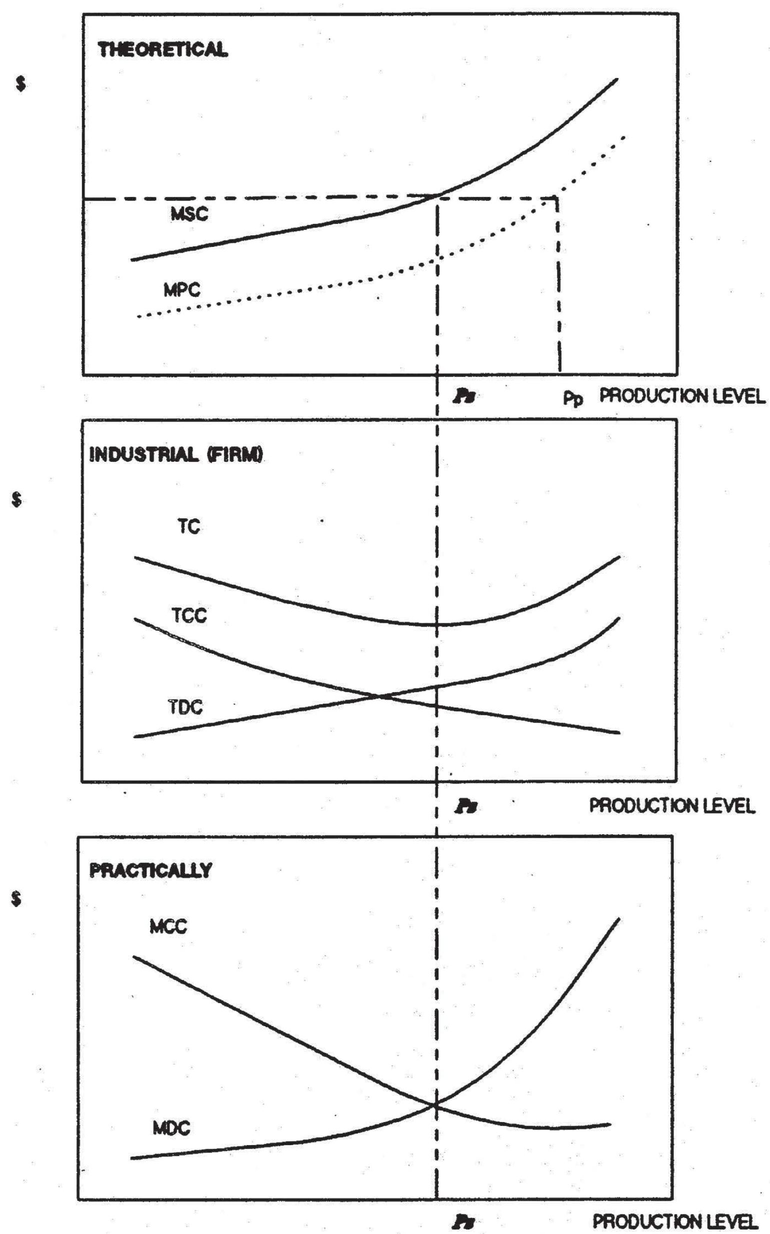


Figure 5: Landscape Regions in the Prairie Provinces

Figure 6


THEORETICAL
$
MSC
MPC
Ps
Pp
PRODUCTION LEVEL
INDUSTRIAL (FIRM)
$
TC
TCC
TDC
Ps
PRODUCTION LEVEL
PRACTICALLY
$
MCC
MDC
Ps
PRODUCTION LEVEL

Determining Optimum Production (Ps)

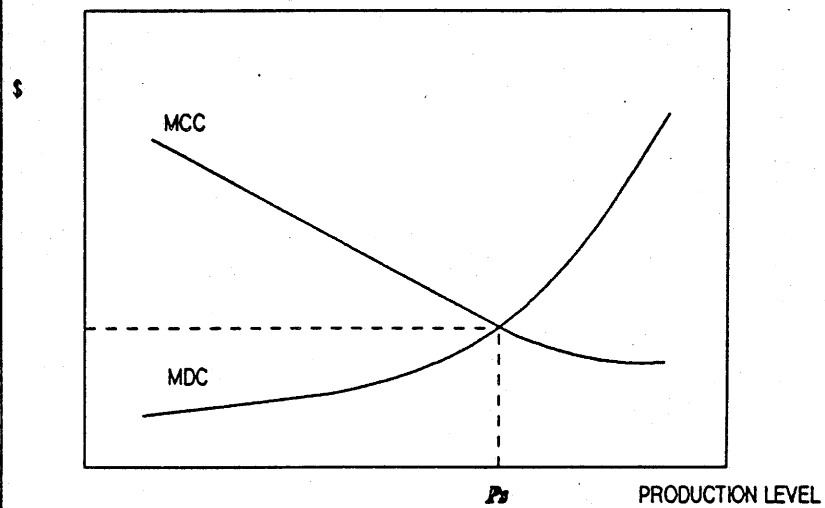


Figure 6a

Determining Optimum Environmental Quality (EQs)

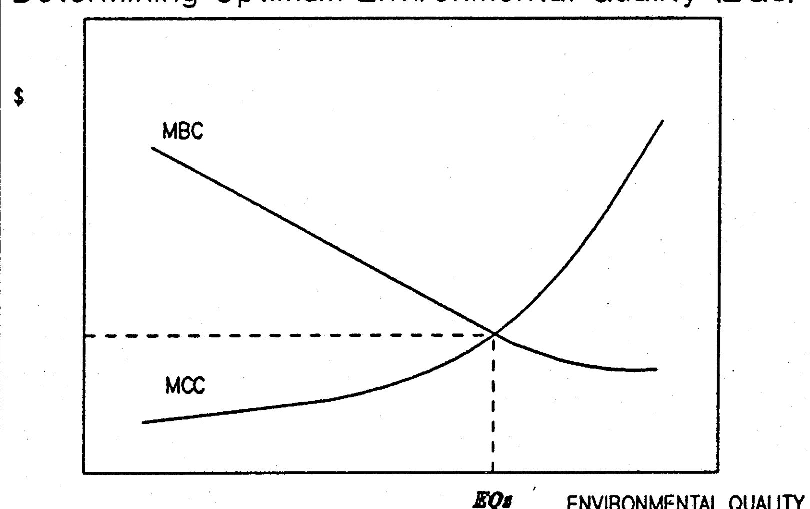
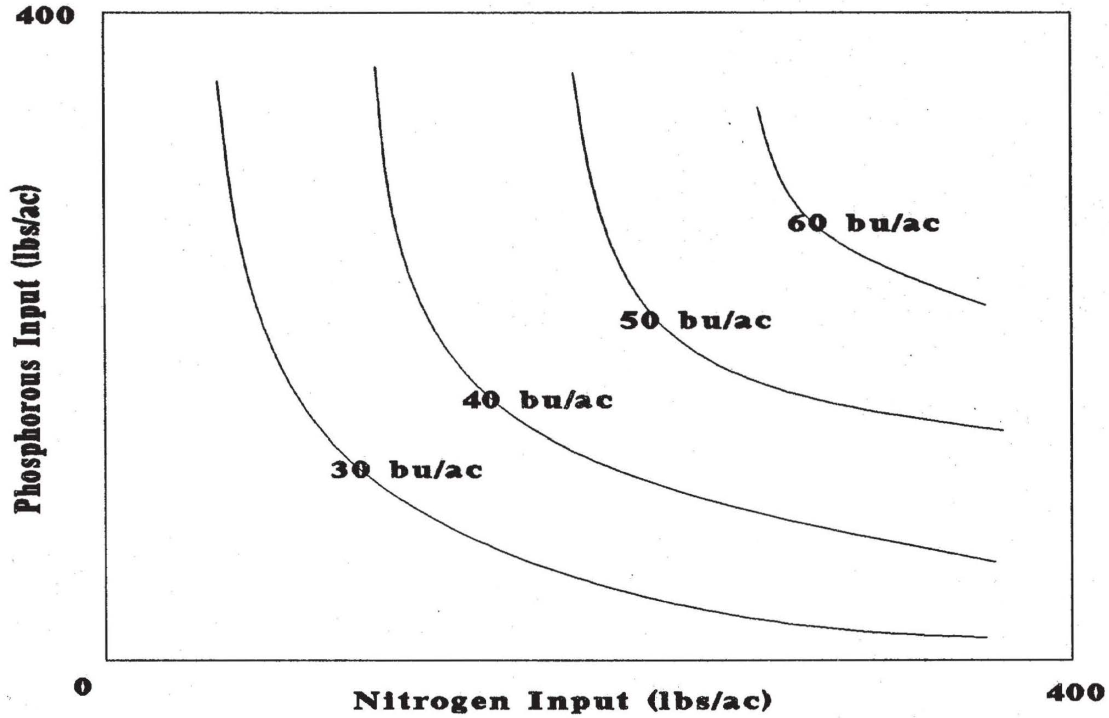
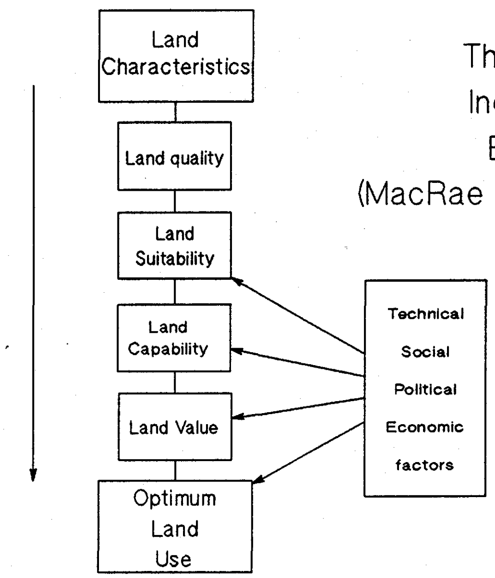


Figure 6b

Figure 7



Agriculture production functions representing the alternative input substitutions that allow for equivalent outputs of corn (Adapted from Baumol and Oates 1979).



The Stages in Indirect Land Evaluation (MacRae and Burnham 1981)

Figure 8

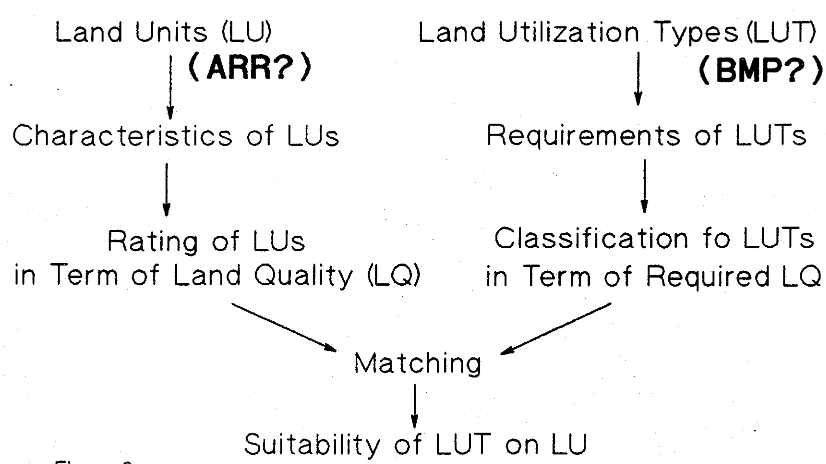
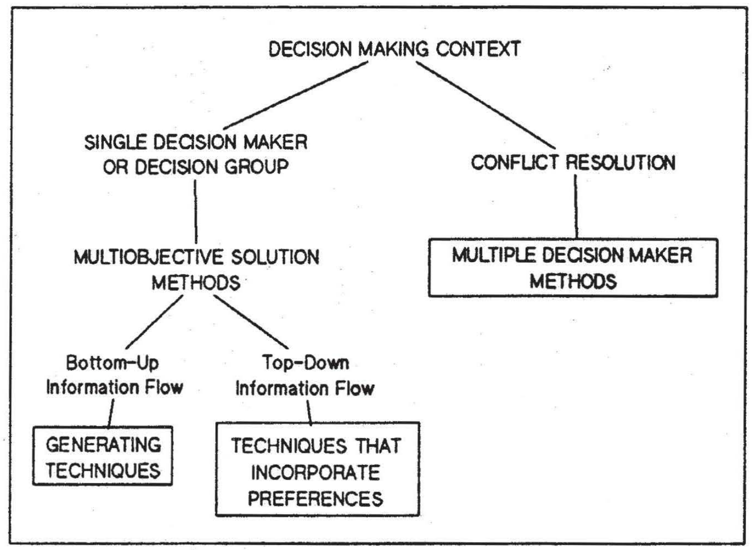


Figure 9

FAO Procedure for the assessment of the suitability of land utilization

Figure 10



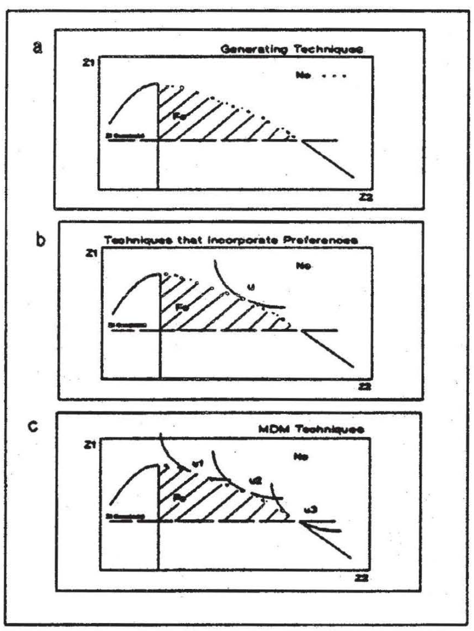


Figure 11

Table 1. Ordering of Three Social States By Three Individuals		
Individual 1	Individual 2	Individual 3
A	B	C
B	C	A
C	A	B

Table 2. Votes on Pairwise Comparisons of Projects, Using the Project Ranking in Table 1		
Pairwise Comparison	Yes	No
A > B	2	1
B > C	2	1
A > C	1	2

Table 3. Goal-Achievement Result By Measurement on Ordinal Scale						
	Weight	Goal 1 Weighted		Weight	Goal 2 Weighted	
Community	2	Plan A	Plan B	1	Plan A	Plan B
Group a	3	+ 6	- 6	3	- 3	0
Group b	1	- 2	+ 2	2	0	- 2
Total		+ 4	- 4		- 3	- 2

Weighted Index of Goal-Achievement for Plan A = (+4) + (-3) = 1
Weighted Index of Goal-Achievment for Plan B = (-4) + (-2) = -6

Table 4. Approaches to Environmental Policy (from Baumol and Oates (1979)).
Moral Suasion(Publicity, social pressure, etc.)
Direct Controls a. Regulations limiting the permissible levels of emissions b. Specification of mandatory processes or equipment
Market Processes (Fiscal Measures) a. Taxation of environmental damage b. Subsidies c. Issue of limited quantities of pollution licenses d. Refundable deposits against environmental damage e. Allocations of private property rights
Government Investment a. Damage prevention facilities b. Regenerative activities c. Dissemination of information d. Research e. Education

Table 5. Summary of Appropriate Uses of Various Instruments of Environmental Policy (from Baumol and Oates (1979))

POLICY INSTRUMENT	APPROPRIATE USE
Moral Suasion	- In breif emergencies - Where metering is impossible - When volunteers are available
Direct Control	- Where metering is impossible - In critical environmental conditions - When dealing with hazardous substances
Fiscal Measures	
- Subsidies	- When fees are inequitable
- Fees	- Where metering is possible
- Permits	- An alternative to fees
- Deposits	- Where metering is difficult
Government Investments	- When private supply of services is undesirable