Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment

Report 1: Conceptual Framework

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Staff Report 93-SR 65
October 1993

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This report was prepared for Agriculture Canada under a contract with the Resource and Environmental Policy Division, CARD.

This report was prepared using WorkPerfect 5.1 and Harvard Graphics. Production typing and final formatting Mary Shearer.

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ABSTRACT

The trade-off between agricultural production stability and environmental sustainability is a growing concern. The two major Canadian farm income stabilization programs of 1991, GRIP (Gross Revenue Insurance Plan) and NISA (Net Income Stabilization Account), are being considered for their resource neutrality impacts.

This report presents a conceptual framework designed to evaluate the environmental impacts of GRIP and NISA, focusing on land use, technology, and soil degradation shifts. The approach involves a multidisciplinary effort to create a system that permits evaluation of important relationships between policy, agricultural production, and the environment. The focus is on development of an integrated agro-ecological economic system built around Agriculture Canada's Regional Agricultural Model (CRAM) and the Erosion Productivity Impact Calculator (EPIC) model.

CRAM, a risk-neutral, aggregate resource allocation model, is modified to include a more detailed technology specification and producer risk due to production and net return variability. Environmental impact indicator functions are developed using EPIC simulations based on experimental design and metamodeling techniques. The integrated system will be used to evaluate the economic and environmental impacts of alternative policies.

AGRICULTURAL POLICIES AND SOIL DEGRADATION IN WESTERN CANADA: AN AGRO-ECOLOGICAL ECONOMIC ASSESSMENT

Increasing recognition of interrelationships between environmental stability and agricultural practices is forcing policymakers to reconsider the impacts of agricultural policy. The view that agricultural policies should be evaluated for their impacts on environmental stability is more generally linked to the idea of resource neutrality.

Resource-neutral policies do not distort production decisions, asset values, marketing decisions, or environmental stability. In 1991, under the Farm Income Protection Act (FIPA), two major farm income stabilization programs were introduced in Canada. The first program, the Gross Revenue Insurance Plan (GRIP), was designed as a safety net for eligible producers against production and marketing risks. The second program, the Net Income Stabilization Account (NISA), was aimed at protecting eligible producers against income volatility, particularly during low-income years. Environmental criticisms most frequently directed at GRIP are linked to shifts in land use (Young et al. 1992). There is growing concern that GRIP and NISA are not resource neutral and will influence producers to bring environmentally sensitive land, highly susceptible to erosion and marginally productive, into production. To evaluate the resource neutrality of GRIP and NISA with emphasis on land use and soil degradation, an integrated agro-ecological economic system, built around Agriculture Canada's Regional Agricultural Model (CRAM) (Horner et al. 1992), will be developed for Alberta, Saskatchewan, and Manitoba in western Canada.

The approach involves a multidisciplinary effort to create a system that permits evaluation of important interrelationships among the environment, agriculture, and policy. This work builds on the lessons learned in a successful effort to build a similar system, labeled CEEPES (Comprehensive Economic Environmental Policy Evaluation System), for the corn and sorghum producing areas of the United States (Johnson et al. 1990; Bouzaher and Shogren 1992).

GRIP was designed to support farmers' income based on an annual targeted gross revenue per seeded acre (Furtan 1992a). GRIP was integrated with crop insurance and replaced the former Western Grain Stabilization Program (WGSA) in providing market protection. The rules and provisions of GRIP vary by province. NISA provides incentives to farmers to smooth their consumption. Under NISA, farmers are encouraged to save during high-income years and to draw

upon those savings during low-income years. Producers make annual contributions to an interest bearing account, not to exceed 2 percent of their net eligible sales, which is matched by the government. The program is uniform across all of the western provinces.

The first objective of this study is to develop the conceptual framework to better understand the relationship between agricultural policies and the environment in Canada. The integrated agro-ecological economic system will be constructed to conform with the conceptual framework. The second objective is to use the integrated system to estimate the economic and environmental implications related to GRIP and NISA in western Canada. The use of resources by alternative crop production patterns will be a major focus. Evaluation of alternative policies will increase Agriculture Canada's understanding of the interrelationship between agricultural practices and the environment. The main indicator of environmental sustainability is soil erosion relating to both water and wind. Other environmental impacts will be assessed qualitatively through changes in crop mix, tillage practices, use of agricultural chemicals, and crop intensification and specialization.

The integrated systems approach underlying the proposed analytical framework is followed by a review of the major rules and provisions of GRIP and NISA that will be explicitly modeled. We describe the methodology for modifying CRAM and then present the environmental component that will be linked to CRAM to evaluate soil erosion impacts of the programs. The final section describes economic and environmental model linkages, and concludes with proposed policy runs.

Integrated Systems Approach

Nonpoint source pollution problems are typically multidimensional because the relevant phenomena are studied and evaluated by different disciplines, such as economics, ecology, physical and natural sciences, and sociopolitical sciences. Therefore, an integrated modeling framework that embraces all the disciplines is needed for a comprehensive treatment. Furthermore, a holistic approach is becoming a key to understanding the interactions between the agricultural and environmental factors in determining the nature and intensity of environmental impacts and the policy implications for economic efficiency and environmental quality. The policy implications are, in turn, vital to the design of regulations and institutions for environmental protection. In recent years, more attention has been given to the development of integrated models for economic-environmental policy assessment both at the farm level (Cole and English 1990; Taylor 1990; Wossink et al. 1990) and at the watershed level (Milon 1987; Bouzaher et al. 1990; Lakshminarayan et al. 1991). At the regional level, Bouzaher and Shogren (1992) and Setia and Piper (1992) are notable empirical studies

employing the most comprehensive modeling systems approach to date. The use of integrated environmental models in other areas is surveyed in Brower (1987) and related policy issues are discussed in Nijkamp (1980).

In order to analyze the impact of the GRIP and NISA programs, the integrated system in Figure 1 is proposed. The conceptualized integrated system consists of an agricultural decision component (CRAM), an input substitution component, a policy component, an ecological component, and a trade-off analysis component. The conceptual framework represented in Figure 1 uses the integrated philosophy and a similar approach to modeling structure as in CEEPES. The agricultural decision, policy, and input substitution components are integrated into a new CRAM (RS-CRAM, for resource-sensitive CRAM) and linked to an environmental block made up of a set of metamodels and associated data. The environmental metamodels (summary response functions) will be constructed with the Erosion Productivity Impact Calculator (EPIC) (Williams et al. 1984), which was developed by the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) to estimate the long-term impacts of erosion on soil productivity. Note that the key linkages between RS-CRAM and the ecological block are policy, crop and management practice, input use, and location. Every time a policy scenario is evaluated, the economic model simulates the behavioral responses to the policy and passes its production results to the ecological block for generating environmental indicators; a trade-off analysis is then performed. An integrated systems approach requires a careful definition of the policies to be analyzed before the actual system is built, so it is important to understand the policy space for this study.

GRIP and NISA Policies: Overview of Major Rules and Provisions

GRIP

GRIP currently has two components: crop insurance and revenue insurance. The crop insurance component is designed for crop yield protection, while the revenue insurance component is designed for price protection. Producers may enroll in either component or in both. Individual crops may be enrolled in the crop insurance component, but producers who enroll in the revenue protection component must enroll all eligible crops.

Entry and exit from the GRIP program is restricted. Producers may use an opt-out option by giving written notice three years before quitting the program, and after quitting must wait two years before reentering the program. Upon reentering the program the producer is limited to 50 percent of GRIP benefits in the first year, 75 percent of GRIP benefits in the second year, and GRIP benefits

return to 100 percent in the third year. Instead of the opt-out option, the producer may choose a buyout option by paying back all GRIP benefits received in the last five fiscal years above his/her premium level. The reentry restrictions for this option are the same as for the opt-out option (Furtan 1992b).

Premiums for the two components are shared among producers, provincial governments, and the federal government. The details of the GRIP program vary from province to province.

The basic design in Alberta and Manitoba includes a number of components (Furtan 1992a). Payments for the crop insurance component are triggered when the annual crop yield is less than the long-term average yield multiplied by the coverage level. For most provinces the coverage level is 70 percent. The crop insurance payment (CI) is calculated as:

[(long-term average yield × coverage level) — annual crop yield]
× crop insurance price × acres.

Payments for the revenue insurance component are triggered when the sum of the market revenue and the maximum crop insurance payment for a crop is less than the target revenue for that crop. The target revenue (TR) is calculated as:

Coverage level × long-term average yield × indexed moving
average price × acres.

The revenue component payment (RIP) is then:

TR — (maximum crop insurance + market revenue)

where market revenue (MR) is

Market price × annual yield.

The total GRIP payout is the sum of the crop insurance payment and the revenue insurance payment.

Saskatchewan shared the basic GRIP design in 1991 but made some major modifications for the 1992 program. Crop insurance was made available to farmers as it was before 1991. Producers can choose coverage levels of 50, 60, 70, or 80 percent of crop yield. They can also choose from three price options: a low price, a high price, or a market price. Individual crops may be enrolled in the crop insurance program, and producers make a new enrollment decision each year without restriction. Crop insurance (CI) payments in Saskatchewan are calculated as

[(risk area average yield × soil productivity index × coverage level)
— annual crop yield] × crop insurance price × acres.

Revenue insurance payments are calculated for each risk area, of which there are 23 in Saskatchewan. These payments are the same for all crops within an area. This average payout (AP) per hectare is given by:

$$\frac{\sum_{i=1}^{n} (guaranteed\ price_i - market\ price_i) \times (acres_i \times long\text{-}term\ average\ yield_i)}{\sum_{i=1}^{n} acres_i}$$

where n is the number of crops grown in the risk area. The farmer's individual payment (RI) is calculated for each crop as:

AP x (individual $yield_i$/area average $yield_i$).

NISA

Under NISA, producers are given an incentive to stabilize income by making contributions to individual accounts in good years and withdrawing from these accounts in bad years. The producer can deposit up to 2 percent of eligible net sales annually in an individual NISA account that is matched by a joint contribution from the federal and provincial governments. The producer can deposit up to 20 percent of eligible net sales in the account, but only the first 2 percent is matched. Government contributions earn interest at a rate of 90 percent of the monthly average of the weekly three-month Treasury bill tender rates while producer contributions earn 3 percent above this rate. Government contributions and any interest earned are not taxed until they are withdrawn from the NISA account. If the account balance reaches the account limit, which is the lesser of $375,000 or 1.5 times average eligible net sales, no further contributions are allowed until the account balance falls below this limit. Average eligible net sales are calculated using the most recent five years of eligible net sales.

For purposes of the NISA program, eligible net sales are defined as gross sales less total purchases of all agricultural commodities. Crops eligible for NISA include wheat, barley, flax, canola, soybeans, and corn. Gross sales include market receipts from commodity sales, GRIP and other government payments associated with agricultural commodities, and the estimated value of farm fed grain. The maximum amount of annual eligible net sales per individual is $250,000.

NISA payments can be triggered in two ways. If a participant's income falls below a set minimum, the Minimum Income Trigger, a payment is triggered equal to the size of the shortfall plus

any contributions made to the account in that tax year. If a farm unit's gross margin falls below the previous five-year average, the Stabilization Trigger, a payment is triggered equal to the difference between the current year's gross margin and the average gross margin.[1] The farmer may withdraw the larger of the two triggered amounts, but the withdrawal cannot exceed the account balance. If the account balance is less than the account limit, the farmer can refuse a withdrawal at any time. If the account balance is above the account limit, the farmer can only refuse a withdrawal once every five years. Withdrawals are taken from government contributions and earned interest before they are taken from the producer portion. If an individual wishes to close an account, the entire account balance is paid out over five years.

For the purposes of calculating NISA payments, net income is the farmer's individual net income from all sources. A farm unit's gross margin is calculated as eligible net sales less eligible expenses. Eligible expenses include all operating expenses except land rent, property taxes, interest, capital charges or depreciation, and salaries paid to family members.

Potential Impacts of GRIP and NISA

The potential impacts of GRIP include changes in land use, input use, and production practices. Possible changes in land use due to GRIP include an increase in the use of marginal lands for crop production, changes in crop mix, changes in input use, decreases in summer fallow acres, and shifts from forage production to production of GRIP commodities. The risk-reducing effect of GRIP may lead to a reduction in crop diversification, reducing the use of crop rotations and possibly increasing the use of inputs. However, the crop insurance component may lead to moral hazard, which tends to decrease input use. Moral hazard occurs when insurance coverage provides an incentive for the economic agent to reduce the use of profitable inputs. It is also likely that GRIP will affect the use of different tillage systems.

NISA also has the potential to affect land and input use as well as production practices. Like GRIP, the risk-reducing effect of NISA may reduce crop diversification and increase input use. Also, since the amount a producer can contribute to NISA depends on sales of eligible commodities there may be some incentive to shift production away from non-NISA commodities, such as forages, in order to increase the government contribution to the account and increase the balance earning a tax-sheltered interest premium. Finally, changing a producer's risk exposure will likely have an effect on the tillage systems the producer chooses.

Given the potential negative environmental impacts of GRIP and NISA, the conceptual framework proposed in this study rests on the key idea of establishing a direct link between farmers' responses to these programs and their consequent resource use and degradation.

Economic Modeling

Background for Both Theory and Empirical Applications

CRAM forms the foundation of the integrated agro-ecological economic modeling system. The current version of the model requires several modifications, however, to make it useful for analysis of GRIP and NISA. Both programs fall into the general category of subsidized insurance-like programs. Fundamentally, insurance programs are designed to transfer risk from one party to another. To consider the impact of risk on producer decisions, CRAM must be modified to explicitly handle risk. Furthermore, two problems or phenomena associated with insurance are *moral hazard* and *adverse selection*. Both problems are universally associated with all kind of insurance programs. Significant attention has been paid to both problems in literature on crop insurance. Researchers have handled risk, moral hazard, and adverse selection in a variety of ways.

Moral Hazard and Adverse Selection. The economic relationship between insurer and insured is an example of a principal and agent relationship. Following Arrow (1985), the basic principal and agent relationship involves two individuals. One individual, the agent, chooses an action that, combined with a random element, determines an outcome. This outcome affects the welfare of both the agent and the other individual, the principal. Before the agent chooses the action, the principal determines a payoff rule specifying a fee to be paid by the agent based on the principal's observations of what occurs. For the case of crop insurance, the insurer is the principal and the insured is the agent.

Holmstrom (1979) indicates that moral hazards occur when the payoff rule does not give the agent incentive to take the proper action; that is, when the agent's action is not directly observable by the principal. If only the outcome is observable to the principal, and both the principal and the agent have the same information at the time the agent chooses an action, Holmstrom shows that the agent puts forth too little effort. If the agent has information that the principal does not have, however, the agent may put forth too much effort. For the case of crop insurance, if the insured has more information than the insurer, moral hazard may lead the producer to decrease inputs in some years and increase inputs in others more than he would without insurance.

Adverse selection occurs when there are several heterogeneous agents and the payoff rule does not account for this heterogeneity. For crop insurance, the result is that producers who are more likely to suffer a loss buy more insurance than ones less likely to suffer a loss. In this case, Rothschild and Stiglitz (1976) indicate that the low-risk producers suffer a welfare loss due to the presence of the high-risk producers.

Nelson and Loehman (1987) and Chambers (1989) summarize some elements of insurance contracts that tend to counteract moral hazard. They indicate that contracts should be specified using any prior information about farmers, and that monitoring farming practices tends to reduce moral hazard. They also indicate that repeated contracts can be used to reduce moral hazard. Rubinstein and Yaari (1983) show that inefficiencies due to moral hazard can be counteracted if premiums are adjusted according to the insured's past claims. The idea that information about the agent's actions can reduce moral hazard is supported by several authors including Spence and Zeckhauser (1971), Harris and Raviv (1979), Shavell (1979), and Holmstrom (1979), all of whom indicate that information about the agent's actions ought to be incorporated into the terms of the policy.

Restrictions on entry and exit from GRIP essentially make GRIP a repeated contract that should help to discourage moral hazard. In Alberta and Manitoba, the Jackson Offset and Superior Management Adjustment provisions offer incentives against moral hazard and adverse selection by rewarding producers who achieve high yields. In Saskatchewan, calculating GRIP payments for an entire risk area reduces a producer's ability to manipulate program payments by engaging in moral hazard. Since GRIP has several features to provide incentives against moral hazard and adverse selection and since CRAM is a static regional model that is not well-suited to modeling phenomena like moral hazard and adverse selection, we concentrate our modeling effort on capturing the subsidy and risk-reducing effects of GRIP.

Risk in Sector Models. Producer decisions are affected by risk if (1) the outcomes of one or more random variables (e.g., yields or revenues) are unknown at the time production decisions are made; and (2) both the expected outcomes and the variability (or riskiness) of outcomes of the random variables influence the order in which the producer prefers the possible outcomes. Expected utility theory is one approach used to explain preference for risky outcomes given a producer's subjective assessments about expected outcomes as well as their variability. The expected utility hypothesis supposes that the nature of the decision maker can be summarized by a utility function. The preference for various outcomes, then, depends on the relative level of expected utility associated with each.

There are strong arguments for including risk in CRAM. On theoretical grounds, if producers are risk averse, as a substantial amount of evidence suggests, and risk is ignored in agricultural sector models, overuse of risky enterprises at the expense of those less risky tends to result (Hazell and Norton 1986). Stated differently, if preference for less variable outcomes to more variable ones is ignored, overuse of risky enterprises will result. When either yield or revenue insurance is introduced, as is the case with GRIP, the relative riskiness of the production activities changes, depending upon the rules and provisions of the insurance.

Since Freund (1956) used an expected utility hypothesis to evaluate risky choices, an extensive body of literature on incorporating risk into agricultural programming models has been built. Incorporating yield or revenue risk into agricultural sector models with endogenous output prices is one subset of that work that is relevant to this discussion. So far, there has been a single approach that dominates the literature in this area and is really the only practical method available. It was first used by Hazell and Scandizzo (1974).

In this method using the expected utility hypothesis, researchers have devised decision criteria to facilitate the performance of empirical work. In essence, the decision criteria specify measures for variability of the randomly variable outcomes and a functional form of the expected utility function. An E, V decision criterion uses the variance (V) as the measure of variability and assumes a quadratic utility function for the random variable. Expected utility, and therefore the order in which outcomes are preferred, is linearly related to the expected outcomes (E) and exponentially related to the variance (V) of the outcomes.

The more common approach is to use an E, σ or a modification of that approach developed by Baumol (1963), called the Gain-Confidence Limit Criterion (E, $\phi\sigma$), where ϕ is a risk aversion coefficient and σ is the standard deviation of the random variable. The level of ϕ specifies how important risk is to producers. The underlying behavioral assumption is that farmers maximize expected net income less its standard deviation weighted by ϕ. This is the approach used by Hazell and Scandizzo (1974).

Because quadratic terms are introduced into the objective function of the Hazell and Scandizzo model, and its relatives, quadratic programming is most commonly used to solve such problems. Procedures such as MOTAD (Hazell 1971) have been developed to linearize the objective function, permitting the use of linear programming techniques for optimization. MOTAD is characterized by the use of revenue variance estimates based on the sample Mean Absolute Deviation (MAD). The

reliability of the approach depends on the efficiency of the MAD as a point estimator of the standard deviation. Linearization is particularly advantageous when dealing with large models.[2]

The primary dilemma of researchers attempting to model risk in agricultural sector models has been deciding which measures of revenue expectations and risk to use. McSweeney et al. (1987) offers a good discussion of what must be considered in deciding which measure to use. Using observed postharvest prices and yields, researchers have typically represented producers' expectations by mean values over a short or long period of time. And risk has been represented by the deviations about that mean from a time-series of detrended, and occasionally trended, data. Using such measures assumes that the producer's expected values and the risk associated with them are equal to the historical average and variability about this average. The implicit presumption is that the random variability about the mean represents the risk that producers perceive when making decisions and that the distribution of realized historical values is the same as the distribution anticipated by the producer prior to planting. While most application of sector models with risk have used this approach, others have questioned whether either of these presumptions is an appropriate conceptualization of reality (Young 1980, 1985; Fried 1970).

The conceptual structure of sector models has important implications for estimating σ (Ω is usually used to represent the aggregated counterpart of σ in sector models) (Hazell and Norton 1986). Ideally, sector models should be constructed by linking individual farm models for every farm modeled in the regions. Because this is not feasible, researchers have typically used either a representative farm or an aggregate regional approach. The representative farm approach models representative farms of several homogenous groups of farms within a region. The aggregate regional approach views a homogenous region as a single farm (average or modal) with all of the resources in the region available to it. The appropriate estimates of Ω (an n x n matrix given a model with n risky activities), in either the representative farm or aggregate regional approach, should reflect the aggregate of individual farm covariances that requires viewing the model as a set of individual farms regardless of the structural representation. Covariance relationships between farms should be excluded. For prices there is no aggregation problem since all farmers in a small region face the same prices. If the only available data on yields are aggregate level data this condition will likely not be met since aggregated data tend to smooth over more radical deviations experienced by individual farmers. An alternative is to use yield data collected or generated for a representative farm.

For the (E, $\phi\sigma$) specification of the model, the risk aversion parameter, ϕ, must also be estimated. One approach to estimating the parameter is to solicit values from farmers, as done by

Dillon and Scandizzo (1978). The values estimated with this approach are derived from actual decision data and the first-order conditions for maximizing $E - \phi\sigma$ over an estimated production function. Because ϕ is the slope of the indifference curve between E and σ, ϕ is invariant to linear transformations in the underlying utility functions. Therefore, the parameters sampled from individual farmers may be averaged. The major barrier to using this approach is that the necessary data are not readily available.

A second approach that is far more common is to parameterize the model for different values of ϕ and choose the value that provides the best fit between same period survey values of commodity prices or land use and those generated by the model (Hazell et. al. 1983; Simmons and Pomareda 1975; Kutcher and Scandizzo 1981). There are two major problems with estimating ϕ with this approach (Hazell 1982). First, data errors or misspecification of the model will lead to a biased estimate of ϕ. Second, if producers have access to risk sharing institutions, such as crop insurance or futures markets, the observed values of prices and land use from surveys will reflect their availability. Unless these institutions are modeled, ϕ is likely to be lower than the true estimation of risk aversion.[3] A third approach uses the estimated variances and covariances of the production activities, observed production data, and an acceptable probability of a loss. The idea is to use observed behavior regarding production activities and estimates of the variability of those activities to infer something about producers' attitudes toward risk. The methodology was developed by Paris (1979), who derived this equation for estimating ϕ:

$$\phi = -\delta / (X'VX)^{0.5},$$

where δ is a measure related to the acceptable probability of a loss;

X is a vector of observed production practices; and

V is the variance-covariance matrix of returns to the production activity.

The advantages of using this approach are that specifying the probability that producers are willing to accept a loss is much easier than specifying ϕ and the result is more directly interpretable. Furthermore, the disadvantages associated with the first two approaches are overcome.

Modifications to CRAM

A number of changes are envisioned for CRAM that are based on information from the literature as well as from numerous discussions among project team members.

Risk. The existing version of CRAM has positive mathematical programming (PMP) incorporated and it is arguable that the quadratic terms introduced into the objective function with the PMP methodology may capture mean-variance risk costs (Howitt and Mean 1985). But risk is not currently accounted for in a transparent manner. Assuming that producers are risk averse, risk must be accounted for explicitly to have the opportunity to evaluate changes induced by policies affecting the variability of producers' net returns. Furthermore, when historical data are unavailable for the existing policy structure, as is the case here since the GRIP revenue insurance was introduced only recently, it is not possible to capture the costs associated with risk in the PMP coefficients.

Presently the objective function in CRAM is specified as:

$$MAX \quad OBJ = x'y\left[\lambda - \frac{1}{2}\beta xy\right] - c'x - \left[\alpha'x + \frac{1}{2}x'\gamma x\right]$$

where x is a vector of activity levels,

y is a vector of yields per unit of x,

λ is a vector of intercepts of the commodity demand functions,

β is a vector of slopes of the commodity demand functions,

c is a vector of variable costs of production per unit of x,

α is a vector of PMP marginal cost function intercepts, and

γ is a vector of PMP marginal cost function slopes.

The first term in the objective function is the sum of the area under the demand curve. The commodity prices are endogenous and depend upon the shape of the demand curve. The second term is the variable costs of production, assuming Leontief (1951) technology,[4] on purchased inputs. It is also the first term of the cost function. The third term adds curvature to the cost function with respect to land. Inclusion of this term and the methodology used to estimate the parameters falls under the heading of PMP. Estimation of the PMP coefficients is described in Howitt (1991) and Horner et al. (1992). The second and third terms together are the sum of the area under the supply curve. The objective function maximizes consumer plus producer surplus.

The problem then is to incorporate risk into the existing specification of the objective function of CRAM. The methodology devised by Hazell and Scandizzo (1974, 1977) is the most practical method of including price and yield risks in the objective function of a sector model with commodity prices endogenous (Hazell and Norton 1986). There is even a precedent for including risk in this

manner into a sector model with PMP. House (1989) included both features into the USMP regional agricultural model.

When an E, V decision criterion is assumed,[5] perfectly competitive levels of outputs and prices in all product markets are attainable. However, several conditions must be stipulated to obtain meaningful economic answers. The conditions are necessary because the nature of the market equilibrium behavior is considerably more complicated under risk compared with the deterministic case. First, the initial source of risk lies in yields and fluctuations in output cause variability in prices. Second, farmers operate in a competitive environment and they maximize expected utility of profit according to the E, V decision criterion. Third, production is lagged and farmers must commit their resources each year before prices and yields are known.

The objective function in CRAM with risk included would be

$$MAXOBJ = x'\hat{y}\left[\lambda - \frac{1}{2}\beta x\hat{y}\right] - c'x - \left[\alpha'x + \frac{1}{2}x'\gamma x\right] - \phi(x'\Omega x)^{1/2}$$

where $\hat{y}$ is a vector of expected yields per unit of x;

ϕ is an absolute risk aversion coefficient; and

Ω is a matrix of variance-covariance coefficients of returns where the ij^{th} element of Ω is $w_{ij} = \text{cov}\,[p_iy_i, p_jy_j]$, where p_iy_i is the returns to crop i, and p_jy_j is the returns to crop j.

Now expected yields replace the deterministic yields and an additional term is added to the cost function to account for risk explicitly. Thus the second, third, and fourth terms together compose the total costs that will sum to the area under the supply curve.

Incorporating Crop Insurance and GRIP Revenue Insurance. Production activities in CRAM are specified to include crop and GRIP revenue insurance. The rules and provisions of both forms of insurance will manifest themselves in the variance-covariance matrix (Ω) and in the variable costs of production (c), since producers are required to pay part of the premiums. Since the program is different in Alberta, Saskatchewan, and Manitoba, the elements of each of these matrices will need to be calculated separately to reflect the differences. To estimate Ω, a time series of yields and commodity prices is needed. The yields will be generated using EPIC, but historical yields will be needed for calibration and estimation of yield coverage levels. Historical prices should be collected at the most disaggregated level and either assigned or weighted to the CRAM regions. Insurance data, including coverage levels and premium rates, also need to be provided for each of the provinces.

For the purpose of deriving the calculations necessary for each coefficient, we can think of production activities being composed of a market component and a program component. The market component represents revenue from selling a crop. The market component contributes to the objective function through yields, prices, and production costs. For each production activity a constant variable cost coefficient is calculated and a series of yields is generated by EPIC. The program component represents the government payments associated with each production activity and the premium paid by the producer to participate in the program.

In Alberta and Manitoba, for production activities that include crop insurance, recall that the crop insurance payment is calculated by

[(long-term average yield × coverage level)—annual crop yield] × crop insurance price × acres.

The coverage level and crop insurance price are constant for a given activity, and EPIC yields are used to calculate long-term average yields and annual crop yields. The resulting series of crop insurance payments are then used to calculate an expected payment and to calculate the variance-covariance matrix of the activities. Similarly, for Saskatchewan, the crop insurance payment is given by

[(risk area average yield × soil productivity index × coverage level)—annual crop yield] × crop insurance price × acres.

Again, the coverage level and crop insurance price are constant for a given activity. The soil productivity index also is assumed to be constant for a given activity. EPIC yields are used to calculate the risk area average yield and the annual crop yield. The resulting series of crop insurance payments are then used to calculate the expected payment and to calculate the variance-covariance matrix.

For production activities that include revenue insurance, recall that for Alberta and Manitoba revenue insurance payments are calculated by

TR — (maximum crop insurance + market revenue)

where

TR = coverage level × long-term average yield × indexed moving average price × acres.

EPIC yields are used to calculate a series of long-term average yields and historical prices can be used to calculate a series of indexed moving average prices. The coverage level is constant for each activity. A series of market revenues will be calculated using historical prices and EPIC yields. A

series of revenue insurance payments will be calculated using this information and using crop insurance payments as calculated before. This series will be used to calculate expected revenue insurance payments and to compute the variance-covariance matrix.[6]

In Saskatchewan, revenue insurance payments per hectare are calculated by

$$AP = \frac{\sum_{i=1}^{n} (guaranteed\ price_i - market\ price_i) \times (acres_i \times long\text{-}term\ average\ yield_i)}{\sum_{i=1}^{n} acres_i} .$$

Historical market prices are used for each crop. A series of guaranteed prices for each crop is calculated as a moving average of the historical market prices. A series of long-term average yields comes from historical yields. The resulting series of revenue insurance payments are used to calculate expected revenue insurance payments in each region and to calculate the variance-covariance matrix.

Input Substitution. Moral hazard is an inherent problem with insurance. One of the most important forms of moral hazard is reduced use of inputs. The extent to which producers face incentives to engage in moral hazard depends upon the rules established for the policies. Knowing that he or she is guaranteed a minimum yield, the producer's optimal strategy from a purely economic standpoint might be to cut input use to the lowest acceptable level. To model this form of moral hazard in CRAM, one possibility is to specify alternative levels of inputs. However, the repeated contract nature of GRIP and provisions such as the Jackson Offset and Superior Management Adjustment tend to discourage the practice of moral hazard. Consequently, modifying CRAM to evaluate the impact of moral hazard may be of lesser importance than other modifications.

Accounting for Environmentally Sensitive Inputs. Chemicals and fertilizers are integral parts of food production; they also pose risks to water quality and the environment in general. The quantities applied, or loadings, of these inputs are an important indicator of the potential for environmental damage. The biological, chemical, and physical processes that determine whether applications of a given quantity will cause harm are extremely complex and not well understood. However, all agro-ecological systems have limitations on how well they can absorb and disarm chemicals and fertilizers and larger loadings always mean the systems will be taxed more and the risk of damages greater. Consequently, CRAM will be modified to account for loadings of chemical and fertilizer inputs.

Accounting of fertilizers will be done by weight (kilograms) and a value will be assigned for every crop production activity in CRAM. A separate accounting will be made for nitrogen (N), phosphorous (P), and potassium (K). The values represent the amounts of pure N, P, and K applied. The source of the nutrient (such as manure, anhydrous, or urea) is not important except that any values collected to estimate the rates applied must be converted to pure nutrient equivalents. Accounting for chemicals (that is, herbicides, insecticides, and other pesticides) will be done by dollars spent on the chemicals. A dollar accounting of chemicals is only minimal at best. A full accounting of chemical applications for specific chemicals by volume demands that a large number of chemicals and the manner in which they are applied be addressed. Choice of chemicals and rates are affected by a multitude of variables including soil, tillage, weather, tank mixes, and method of application. While such an accounting is a major undertaking it is important enough to be included in the list of future improvements to CRAM.

Agriculture Canada whole-farm and enterprise-level grain data from Saskatchewan and information collected with the "representative field sheet" and the "crop enterprise survey" for Alberta and Manitoba may be useful in determining average fertilizer (N, P, and K) rates by crop. These average crop rates can serve as the basis for application rates associated with each crop production activity in CRAM. The rates must be adjusted for alternative fallowing practices. To the extent that alternative tillage practices correspond with different yields,[7] fertilizer applications might also need to be adjusted by tillage. Chemical costs corresponding to the crop production activities in CRAM are already delineated from the total cost of production. These costs serve as the basis for estimating the costs of new activities in CRAM. The costs should reflect the extent that alternative tillage practices pose different weed and insect control problems. Agricultural census and insurance data may also be potential data sources.

Tillage Practices. Erosion rates beyond the ability of the soil to renew itself over time lead to reduced productivity and may cause offsite damage. Crop residue left at the soil surface is the most important, manageable determinant of soil erosion from water and wind. And tillage is the dominant way to manage surface residue. Consequently, alternative tillage practices are modeled in CRAM. Delineating production by tillage in CRAM makes it possible to capture incentives or disincentives in GRIP and NISA for adopting alternative tillages.

Three alternative tillage practices—defined as conventional, minimum, and no-till— are modeled for every crop production activity, where practicable, currently in CRAM. Broad definitions for these specific tillage systems are based on recommendations by Dumanski (1992) and are given as:

- Conventional—assumed to leave less than 30 percent residue (stubble) on the soil surface;
- Minimum—assumed to leave at least 30 percent of the soil surface covered with residue; and
- No-till—any system that uses some type of direct drill planter. No-till systems should leave a minimum of 70 percent of the soil surface covered with residue.

Several pieces of information need to be estimated in order to model alternative tillage practices. At the most aggregated level, costs of production, yields, fertilizer and chemical requirements, and erosion need to be estimated. In the case of the first three, the values specified for activities currently in CRAM are used as the basis for estimating values by tillage. For erosion, values are estimated using EPIC.

Adjustments to production cost will be composed of alternative variable costs of machinery operations, chemicals, and fertilizer. Specifics about machinery operations need to be collected. EPIC also requires information about machinery operations. We propose to collect this information from expert opinions. When collected, all of the information needed for CRAM and EPIC should be collected simultaneously.

Since tillage and chemicals are substitutable tools for managing weeds, insects and disease, changes in tillage may also need to be accompanied by changes in chemical schemes. Because the experts who know about tillage probably also know about the chemical strategies associated with them, it makes sense to collect information about changes in chemical use for the alternative tillage practices at the same time the information about tillage operations is being collected. Chemical costs per acre associated with each tillage practice should be collected. Information on chemical use in the form of actual quantities of some chemicals will likely prove impossible to work with since so many alternative possibilities exist. To the extent that there are yield differences among the tillage practices, fertilizer requirements should also be adjusted. In general, higher yields demand larger amounts of nutrients if other factors remain constant. It will be left to those calibrating EPIC to determine if yield differences should exist.

Data Needs and Sources. Data to calibrate four blocks of coefficients will be needed once the structure of CRAM is modified. The blocks include (1) linear objective function coefficients, (2) variance-covariance coefficients, (3) calibration coefficients, and (4) environmental accounting coefficients (Table 1). The data dimensions include one or more of the following: (1) 29 CRAM crop regions, (2) 26 crop/fallow sequences, (3) three tillage practices, and (4) four policies. The four policies are no insurance, yield insurance only, revenue insurance only, and both yield and revenue insurance.

There are three sets of linear objective function coefficients that must be estimated. Crop production costs by region, crop/fallow sequence, and tillage is one.[8]

The most promising source for these data in Manitoba and Alberta is the crop enterprise survey and the representative field data and farm-level data for Saskatchewan provided by the Policy Branch of Agriculture Canada. Expected indemnity payments for revenue and yield insurance must be obtained by region, crop/fallow, tillage, and policy. There is no direct source of indemnity payment estimates with the necessary dimensions. Therefore, necessary data components to calculate them will be collected. The components include historical crop yields, historical crop prices, the coverage level, the discount factor, crop insurance price and historical crop acreages (for Saskatchewan only).

Crop yields are generated by EPIC. EPIC offers a considerable amount of flexibility for estimating yields. Yield data by the necessary dimensions (region, crop/fallow, and tillage) are not available from data sources whereas EPIC can produce yields by all three dimensions. Furthermore, a distribution of yields, by the same dimensions, can be generated for different soils and weather conditions. Agriculture Canada will provide historical crop prices and crop acreages (for Saskatchewan only). The coverage level, discount factor, and crop insurance price will be provided to CARD by Hartley Furtan (Department of Agricultural Economics, University of Saskatchewan). The third set of data are the expected insurance premiums for revenue and yield insurance by crop and policy, also from Furtan.

Variance-covariance coefficients need to be estimated by region, crop/fallow sequence, and tillage. Historical yields and prices are used to calculate the variance-covariance coefficients. The same yields and prices collected to estimate the expected indemnity may be used here.

Two sets of calibration coefficients need to be collected. The values may be used to calculate PMP coefficients or to calibrate the model by flexibility constraints or some other means. Tillage areas by region, crop/fallow sequence, and tillage will be provided by Agriculture Canada. Insurance program participation rates by region and crop are available from crop insurance data provided by Agriculture Canada's Centre for Land and Biological Resource Research.

Finally, two sets of environmental accounting coefficients must be obtained. Fertilizer rates by region, crop/fallow sequence, tillage and macronutrient, and chemical costs by region, crop/fallow sequence, and tillage are needed. The most promising sources for both are the crop insurance data or the representative field and crop enterprise survey in Manitoba and Alberta or the farm-level data in Saskatchewan.

Environmental Modeling

The environmental component is developed through "hierarchial modeling" (see Figure 3) integrating process models and response function techniques.

The Process Modeling Framework: EPIC

Degradation of prairie soils from agricultural production is a major concern in the western provinces. Prime degradation problems observed in the prairie provinces are wind and water erosion, salination, compaction, and organic matter depletion (Dumanski 1992). Additional environmental concerns have been raised over ground and surface water quality degradation from agricultural nonpoint sources of pesticides and nutrients. For this project, the primary degradation indicators are water and wind erosion that will be estimated with EPIC. Compaction, organic matter depletion, and nutrient loss indicators will also be analyzed from the EPIC simulations.

The approach to modeling soil degradation within the proposed framework (Figure 1) is based on summarizing properly calibrated EPIC simulations using the techniques of metamodels (Bouzaher 1991; Bouzaher et al. 1992). Use of metamodels allows researchers to focus only on key physical and management parameters that are policy relevant, and facilitates computational efficiency, model linkages, and integration of field-level data for regional analyses. Figure 2 shows a schematic of the data flows and EPIC simulations required to construct the environmental metamodels and estimate the yield distributions needed to develop new CRAM activities. These outputs correspond with the EPIC environmental metamodels and yield distributions shown in Figure 1. Calibration runs will be performed prior to executing the final set of experimentally designed EPIC simulations.

Data Needs and Sources. The primary input data categories for EPIC include (1) weather, (2) soil layer and landform, (3) crop coefficients, and (4) management parameters. The required data for EPIC and the current status of these data at CARD are in Table 2.

The EPIC model is driven by daily weather inputs of precipitation, maximum and minimum temperature, solar radiation, wind speed, and relative humidity. These inputs can be provided by historical weather records, generated by the EPIC weather generator, or supplied by some combination of historical and generated weather. Even if historical data are read in, the weather generator is still used for certain stochastic processes within the model. Therefore, weather generator tables have been constructed for each ARA in Alberta, Saskatchewan, and Manitoba.

Average monthly wind speeds, along with wind directions, are the primary inputs for the EPIC wind erosion submodel. Wind files for 25 stations in Alberta have already been created (Tautchin

and Dzikowski 1992); these files will be used for EPIC wind erosion calculations in Alberta. The remaining wind direction data for Saskatchewan and Manitoba will be obtained from the Canadian Climate Centre of the Atmospheric Environment Service.

Up to 21 soil layer variables may be input into EPIC. Of these, the minimum required data set includes soil layer depth, organic carbon, bulk density, percent sand, percent silt, and soil pH. These required soil layer data will be obtained from the appropriate sources in each of the three provinces. Soil landform data will be derived from the Alberta, Manitoba, and Saskatchewan Soil Landscape Databases, and from other data maintained by the Centre for Land and Biological Resources Research in Ottawa. Hydrologic group, which is a key variable used in EPIC to estimate runoff and infiltration, will have to be estimated on the basis of drainage class (permeability), textural classification, and other properties for each soil.

A generic crop growth model is used in EPIC to simulate the development and final yields of specific crops (Williams et al. 1989). EPIC crop parameters already exist for wheat, barely, oats, fall rye, flax, hay, and sunflowers. Crop parameters are under development for field peas, lentils, and canola (Kiniry 1992). Some of the spring wheat and barley parameters have already been modified to reflect the shorter Canadian growing seasons (Izaurralde 1992). Further modification of existing parameters for crops other than spring wheat and barley may also be required.

Management systems are defined here as combinations of tillage, crop rotation, and fertilizer inputs. Specific tillage systems are classified as previously described. The management systems used in the EPIC simulations are based on regional expert opinion. These systems are also defined to be as consistent as possible with the input substitution set used in CRAM.

Calibration Runs. Several stages of calibration runs will be performed prior to the final simulations required to generate the yield distributions and develop the environmental metamodels. Calibration/validation runs for several sites in Alberta have already been performed by Izaurralde et al. (1992). These simulations included both direct comparisons with research plot data and runs representative of field sites and ARAs. Based on these simulations, it was concluded that EPIC produced reasonable crop yield estimates for several Alberta scenarios including irrigated and dryland conditions, continuous and fallow cropping sequences, different soil types, simulated erosion levels, and different fertilizer rates. It was recommended that ARAs be adopted to assess the economic impact of erosion in Alberta. However, it was emphasized that EPIC should be used for relative comparisons of different scenarios as opposed to relying on it to provide absolute values, especially at the ARA level.

Further testing of EPIC has been initiated for six simulated erosion sites in Manitoba, as described by Smith and Shaykewich (1990). Comparisons will be made between EPIC yield output for spring wheat and canola versus measured yields for noneroded and artificially eroded soil (with 20 cm of topsoil scraped away) and different rates of applied fertilizer. Comparisons of EPIC yields for winter and spring wheat (both continuous and fallow cropping systems), crested wheatgrass, meadow bromegrass, altai wildrye, and Russian wildrye have already been performed by Kiniry (1992) for five sites in Alberta, Saskatchewan, Montana, and North Dakota. These simulations indicate that EPIC is estimating reasonable yields for these crops in the Northern Great Plains and Prairie Provinces region. Additional site-specific simulations will be performed with data from wheat and canola studies near Winnipeg, Manitoba (Van Deynze et al. 1992; Racz et al. 1965), selected long-term rotation studies at Swift Current, Saskatchewan (Zentner et al. 1988), and if time permits, selected long-term rotation studies at Melfort, Saskatchewan (Moulin 1993). Calibration of the EPIC crop parameters will be based primarily on these site-specific simulations.

As a further test, EPIC crop yields will be compared with historic crop insurance yield data for representative ARAs in all three provinces (assuming that crop insurance data can be obtained for each province). Specific attention will be paid to historical yield trends, especially in relation to fertilizer use patterns. Test runs will also be performed for the EPIC water balance model against water balance data produced by the PIXMOD wheat model that is available in the ARA database. Calibration of the EPIC hydrologic routine will be based on these simulations.

EPIC Simulations for Constructing Metamodels. After EPIC is calibrated, it will generate a complete set of simulations based on a statistical design incorporating soil layer and landform, climate, crops, and management practices from Alberta, Saskatchewan, and Manitoba. The statistical design and number of ARAs represented (and thus the total number of runs), are primarily a function of how much soil layer data will be available. If the data are limited to the representative ARAs mentioned previously, then the statistical design will be structured around that ARA subset. However, if complete sets of soil layer data can be obtained for each province then the design will encompass all agriculturally relevant ARAs in the three prairie provinces. It is anticipated that the same experimental design and EPIC simulation set will be adequate to produce both the yield distributions required by CRAM and by the environmental metamodels.

Metamodeling

Major advances in computer technology have made it possible to develop and simulate complex real processes using mathematical models. A variety of mathematical models are available to simulate soil erosion (Wischmeier and Smith 1978) and pesticide movement in the saturated and unsaturated soil zones (Wagenet and Hutson 1991). Although simulation models are analogs of real processes, their direct application to analysis of regional nonpoint pollution policy is limited by the expense and time required to conduct additional simulations for each new policy scenario. A policy scenario with an integrated system of models requires a mutually consistent combination of policy, environmental, agrichemical, management, and technological parameters and behavioral equations. Therefore, it is impractical to simulate each and every possible combination of these factors, especially in a system requiring both timely integration of diverse process models and integration of outcomes over a distribution of diverse input sets. A simplified tool will ease the computational burden while capturing the key process characteristics. Statistically validated metamodels are analytical tools capable of addressing both of these difficulties.

A metamodel is a regression model explaining the input-output relationship of the complex simulation model, which in turn is a computer model structure to mimic the underlying real-life process. Let g be the unknown function that characterizes the underlying real phenomena relating the response y to the input vector v, or

$$y = g(v).$$

Most simulation models mimic outcomes for a variety of possible response variables, and specification of the response of interest may not be a trivial matter.

A simulation experiment is a set of executions of the simulation model intended to approximate the values of y associated with a specified set of input vectors. The output of a simulation experiment is a data set consisting of specified input vectors and their associated responses, as determined by the simulation model. Choice of the number and values of input vectors for which the simulation model will be executed is the subject of experimental design. For statistical purposes, it would be preferable to experiment with the real life system rather than a simulation model of the system. In that case we would have a statistical model of the system rather than a metamodel. This approach is not adopted because it would mean incurring the cost and delay of waiting, in this case for 30 years of weather. It would also mean tolerating the real environmental damage associated with some experimental input vectors.

Given the output of a simulation experiment, we can specify an analytic metamodel with relatively few inputs, x_1 through x_k. Let the metamodel explaining the simulated outcome be represented as:

$$y = f(x_1, x_2, \ldots, x_k, u),$$

where u is the stochastic disturbance term. We can use standard statistical and econometric procedures to identify and estimate the function f describing the metamodel. Because of their simple and precise representation of the complex system, simulation practitioners are favoring metamodels for validation, sensitivity analysis, estimation of interactions among inputs, control, and optimization, without the need for additional simulation runs (Kleijnen 1987).

The metamodeling approach used in this study, and illustrated in Figure 3, is dependent on a properly designed statistical experiment that is both efficient and captures the most important parameters that affect soil degradation. The estimated models need to be validated against both the results of EPIC and expert opinion.

Once the metamodels are estimated and validated, they will be linked to RS-CRAM and used for policy evaluations. These models are then useful for evaluating other policy options, including alternative soil degradation restrictions, conservation rules, and tillage and rotation systems. However, the valid range of these models is restricted to the range from which model parameters have been estimated. Predictions outside of the estimation range will require additional EPIC calibrations and runs to extend the metamodels' interpolation range. The general structure of the metamodels for this study is:

$$EI_{er} = \text{Function (P, SL, WS, MP, SD)}$$

where EI_{er} is the environmental indicator e (water/wind erosion, organic matter depletion, nutrient leaching) in region r (CRAM region or ARA);

P is policy option;

SL is soil type and landform characteristics;

WS is weather station;

MP is management practice; and

SD is a stochastic disturbance.

Experimental Design

Several issues are involved in the experimental design; most of them can only be decided upon when the calibration process of EPIC is completed and the availability of the data evaluated.

Factor screening relates to the selection of the key parameters determining soil degradation indicators. These key factors will be a subset of all the physical (plant, soil, weather) and management (crop, tillage, rotation, inputs) parameters required by EPIC. Because soil erosion and other environmental impacts are processes that evolve over long periods of time and under a wide range of weather conditions, it is necessary to experimentally determine the *length of the EPIC simulation runs*. This is typically done by observing when the value of a response variable and/or its variance stabilize.

Because policy impacts need to be evaluated at the provincial level due to the difference in programs between provinces, it is necessary to use a *stratification* by province. Depending on need, stratification by ARA or CRAM region could also be accommodated.

Sampling Design. Sampling design is a key step that involves determining the number and configuration of the EPIC runs, and building metamodels of environmental indicators. Several possible approaches are being contemplated. The choice of which design is most appropriate will be made once all relevant parameters (soils, weather stations, crop rotation, tillage, policy) are identified and all data needs are resolved.

Assume N is the number of factorial combinations of sl soils and landforms, p tillage practices, r rotations, and o other factors. The problem of selecting a subset of all possible N combinations as input for runs for EPIC involves three alternative approaches.

We could use a procedure similar to that applied to the same problem in CEEPES (Bouzaher et al. 1993). That is, we would select a subset of soils and landforms (sl_1) through a completely randomized design within strata, where the probability of selection of every hectare is the same, and where sample is restricted to those soils and landforms that are approximately equal and represent a balanced range of relevant soil properties. Then, the EPIC model is run on the sample generated by sl_l soils and landforms selected in combination with all levels of the remaining factors. The advantage of this design is that, once results from the process model runs have been observed, there are no limitations on the family of metamodels that can be estimated.

The disadvantage to this method is that the number of soils and landforms selected, sl_1, must be "large enough" to be representative (a rough number perhaps can be obtained via power inspection).

In a small area approach to sampling, sample data from a population scattered over a large domain are used to make inferences about the average of some quantity in the population. The objective is to provide estimates for areas containing few, if any, sampling units. In this case, the population over a scattered domain is given by the N possible combinations of *sl* soils and landforms, *x p* tillage practices, *x r* rotations, and *x o* other factors. A small sample of sl_2 soils and landforms would be obtained through a design similar to the CEEPES method. EPIC would be run for the sl_2 *x p x r x o* combinations, and a mixed model would then be the class of models to be used to estimate the average of the soil degradation response over all small areas, those for which an observation is available (for which runs were carried out), and those for which there were no runs performed. The mixed model is of the general form

$$y_{ij} = x_{ij}' \beta + v_i + e_{ij},$$

where y_{ij} is the value of the jth observation (environmental indicator) for the ith small area;

x_{ij}' is a vector of explanatory variables (physical and management parameters);

β is a vector of unknown fixed parameters; and

v_i is a random effect corresponding to the i^t small area.

The estimator of interest

$$\bar{y}_i = \bar{x}_i \beta + v_j + \bar{e}_i,$$

where, under certain asymptotic assumptions, $\bar{e}_i \to 0$. The advantage of the small area approach is that it provides good (in the prediction error variance sense) estimates of all combinations of soils and other factors. The estimator obtained for $\bar{y}_i$ is a shrinkage estimator, where $\bar{y}$ is shrunk further toward some common mean as the information about the i^t small area decreases. The disadvantage is that the estimator for a combination for which no data were obtained depends very heavily on the quality of the explanatory variables. In the limiting case, where there is no information contained in the explanatory variables about the quantity of interest in the small area, the estimator for $\bar{y}_j$ is simply the overall mean.

The third approach consists of running EPIC on a fraction of the full factorial design. The fraction selected depends on budget and time constraints. The advantage of this procedure is that it provides a systematic approach to gathering data and that the fraction selected may be as small as

desired. The disadvantage is that fractional factorial designs limit the class of models that can be adjusted to the data. The smaller the fraction, the simpler the model that is estimable. For example, even in a 1/4 fraction design, only linear and some quadratic effects are estimable.

Estimation. Once a sampling design is selected, it is implemented to generate simulation data from EPIC. The data are then be used to estimate metamodels for all the indicators that EPIC can reliably generate, particularly water and wind erosion. The estimation process includes the usual steps of data diagnostics, variable selection, and other statistical tests to insure a set of "good and parsimonious" metamodels.

Validation Plan. Before the constructed metamodels are used for policy evaluation, a set of validation tests will be performed to insure their statistical integrity. These tests will include split samples and cross-validation, prediction of new data, and expert opinion. The outcome of this step may point to the need to revisit the former steps of experimental design and model estimation.

Linkages Between Economics and Environment

Model Linkages

Two types of linkages will be developed to make the integrated system operational for policy analysis. First, linkages between GRIP and NISA policies, input substitution and production technologies, and agricultural decisions will be accomplished as modifications to CRAM, producing RS-CRAM.

Second, linkages between the economic and environmental components will be accomplished (as shown in Figure 1) through passing information in the mix of management practices and input use for every CRAM region and policy scenario to the metamodels to evaluate only degradation impacts. This linkage is the fundamental relationship between farmer responses to agricultural policies and their impacts on resource use. Policy scenarios are then compared in a trade-off analysis, as illustrated in Figure 4.

Formally, the economic and environmental linkages can be described in the following way. Let:

X^p_{ir} = Vector of management practices i, in CRAM region *s*, under policy scenario *p*;

SD^p_{tirs} = Soil degradation type *t*, from management practice vector *i*, on soil type *s*, in CRAM region *r*, under policy scenario *p;*

A_{sr} = Acreage of soil type s, in CRAM region r;

E_{sr} = Vector of environmental factors in soil type s, in CRAM region r;

w^p_{ir} = $X^p_{ir} / \sum_i X^p_{ir}$, Relative weight of management practice vector i, in CRAM region r, under policy scenario p; and

v_{sr} = $A_{sr} / \sum_s A_{sr}$, the relative weight of soil type s in CRAM region r.

Then, the linkage between the economic and environmental components can be expressed as:

$$SD^p_{itrs} = F(X^p_{ir}, E_{sr})$$

where F is a metamodel estimated from EPIC data.

The soil degradation indicators can be aggregated in several ways, and particularly across management practices (by degradation type, soil type, CRAM region, and policy):

$$SD^p_{trs} = \sum_i w^p_{ir} * SD^p_{itrs}$$

Across soil type (by degradation type, CRAM region, and policy):

$$SD^p_{tr} = \sum_s v_{sr} * SD^p_{trs}.$$

Clearly, the level of aggregation will depend on the type of analysis desired, at the soil level, ARA level, CRAM region level, or province level. The framework we will develop will allow generations of soil degradation indicators at the lowest level of aggregation, by soil type. However, for consistency in trade-off analysis, the economic indicators have to be at the same level of aggregation as the environmental indicators.

Why Not Cost-Benefit Analysis?

Cost-benefit analysis, as the name suggests, emphasizes benefit measurement by placing, as far as possible, a monetary value on environmental improvements, or conversely, monetary valuation of damage accrued to society from environmental deterioration. The CBA assumes the existence of a "social welfare function" and aims at maximizing this function. The basic assumption of a social welfare function, which is the existence of preferences and fulfilling those preferences, involves value judgment. For most environmental problems, particularly water quality and air pollution problems, measuring benefits/damages in purely monetary terms is not possible because of the absence of

market and price signals. Recent progress in nonmarket valuation research has produced several methods, such as contingent valuation, hedonic pricing, and travel cost to overcome this problem (Brookshire et al. 1982). These methods are applicable only when the people are aware of the cause and effect linkage (dose-response relationship) of environmental damages so they can articulate their preferences, which is not the case for most environmental problems (OECD 1989). Therefore, indirect procedures through physical damage function estimation are employed.

In addition to these problems, CBA is plagued by value judgment in situations where it is not possible to measure benefits in monetary terms. Questions such as how to value loss of life or limb are judgment-loaded. Furthermore, benefit estimation is uncertain, ignores distributional issues, and tends to concentrate solely on economic efficiency impacts. There also are conceptual limitations in applying CBA for environmental pollution problems (Pearce 1976), not withstanding the practical problems of limited information, nonconvexities, and complexities in empirically estimating shadow prices for environmental goods (Dasgupta 1982). Finally, the core of the integrated modeling framework is the linkage between various processes (socioeconomic and environmental). It is impractical for CBA to trace and capture all these linkages.

Computer Implementation

For reasons of portability and maintainability, GAMS scripts will be used wherever practical. Within limits of machine memory, GAMS can run on all relevant platforms, including ULTRIX, where performance is better. EPIC runs will be performed on DEC ULTRIX workstations. C++ programs and ULTRIX (UNIX) shell scripts will be written to prepare input, control the runs, and summarize output. Metamodels will be created as GAMS scripts, unless complexity or performance advantages of C++ make it more practical to switch. If C++ is used for these functions, it will be made to operate on the PC. New CRAM input substitutions will be calculated by GAMS scripts. Other CRAM modifications will continue to be written in GAMS language, including Risk and GRIP policies. New CRAM summary programs will be written in GAMS or C++.

Conclusions

Timely environmental impact assessment of agricultural policies such as GRIP and NISA is mandated by Canadian law. This report outlines the integrated agro-ecological economic system approach that will be used to evaluate the impact of GRIP and NISA on the environment in western Canada. Its focus is on soil degradation. By taking existing economic and process models, such as

CRAM and EPIC, from the shelf, modifying and integrating them, a timely quantitative analysis is possible. In this manner an integrated modeling system is built.

An integrated approach such as this requires input from experts in many disciplines including agricultural engineers, agronomists, economists, and soil scientists. Using blocks based on established models enables technical specialists in many disciplines to evaluate the system's structure and performance.

The integrated system will eventually be used to evaluate a baseline scenario that includes crop insurance but not GRIP or NISA. The baseline will be compared with several scenarios, including GRIP and NISA. Furthermore, separate runs will be made to evaluate differences between the 1991 and 1992 policy rules and provisions (see Appendix A).

This report is the first in conjunction with this project. Future reports will focus on the experimental design of the metamodels used to estimate erosion impacts, the final form of the integrated system, and the results of the policy evaluations.

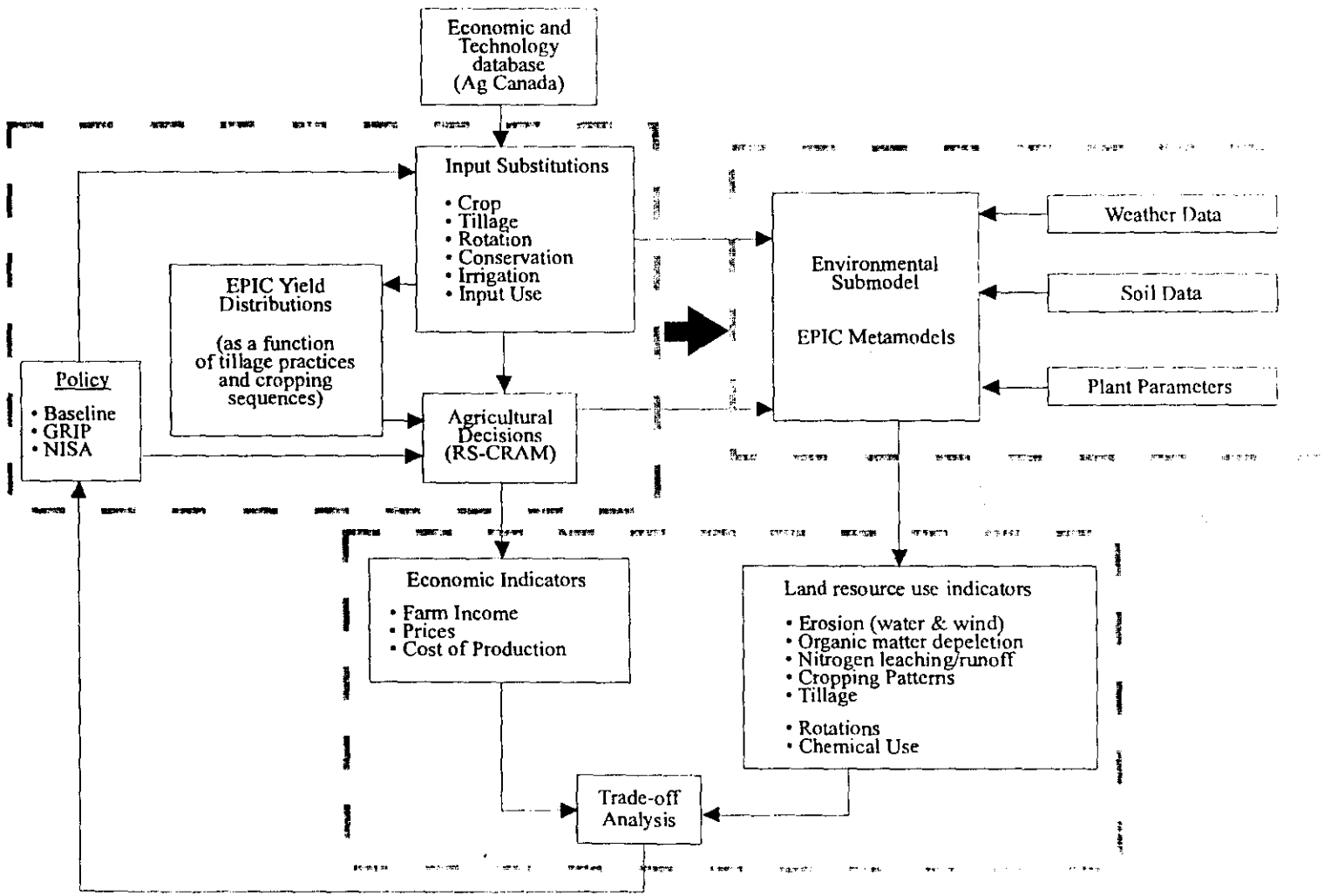

Figure 1. General conceptual framework

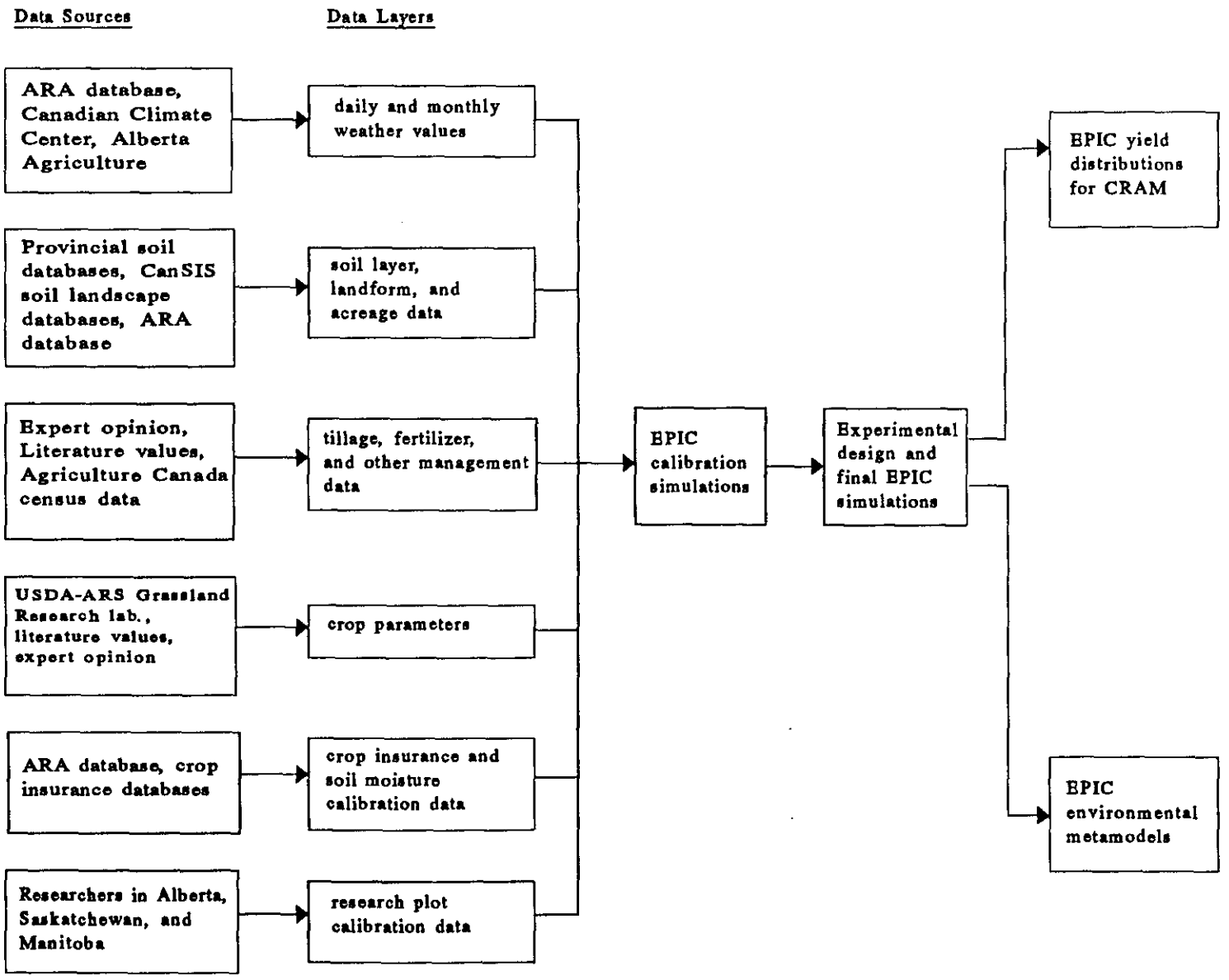

Figure 2. Schematic of EPIC data inputs and simulation runs

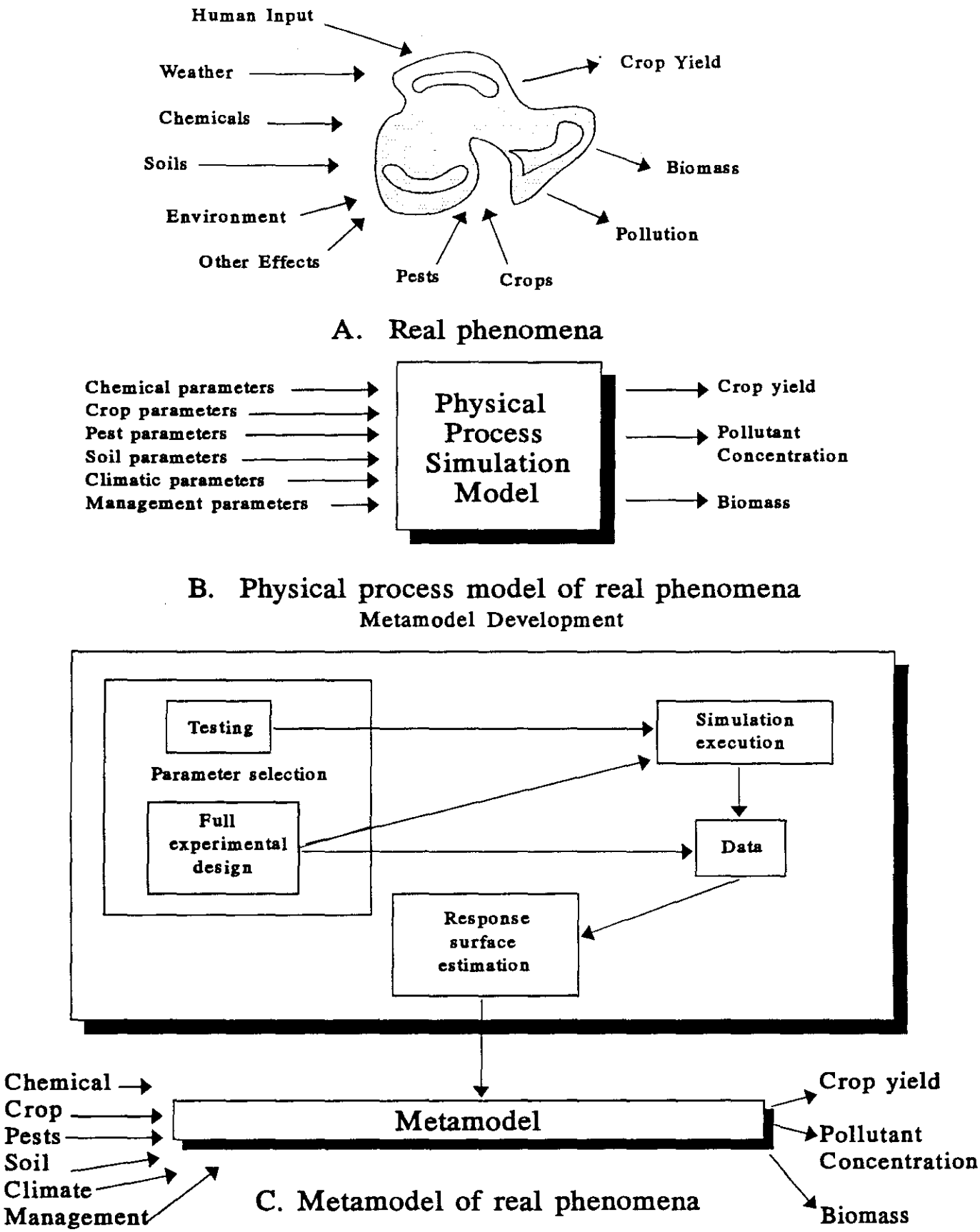

Figure 3. Process of metamodel development

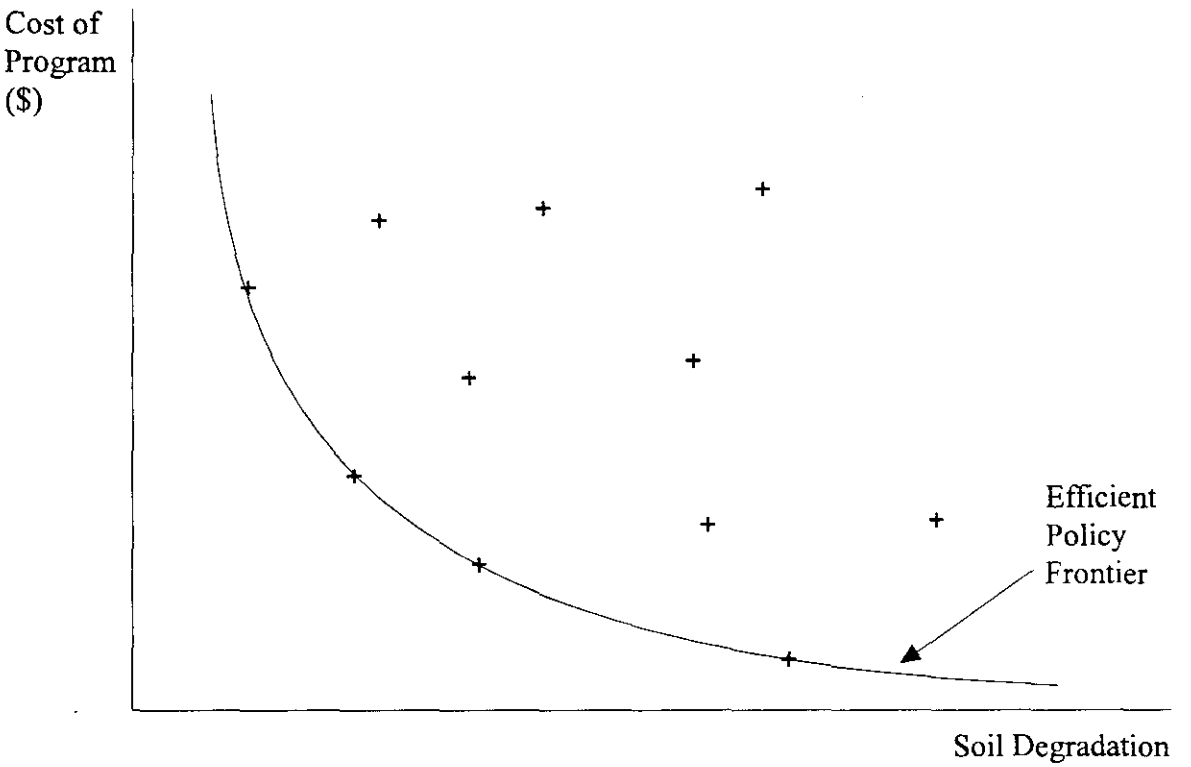

Figure 4. Program costs and soil degradation trade-offs

Table 1. Data needs for modified version of CRAM

Linear Objective Function Coefficients	Components of Data	Potential Source(s)
Crop Production Costs Region Crop/Fallow Tillage		Representative Field[b] Crop Enterprise Survey[b] Farm Level Data[b]
Expected Indemnity Payments for Revenue & Yield Insurance Region Crop/Fallow Tillage Policy	Historical Crop Yields Historical Crop Prices Coverage Level Discount Factor Crop Insurance Price Historical Crop Acreage[a]	EPIC[c] Agriculture Canada[d] H. Furtan[e] H. Furtan[e] H. Furtan[e] Agriculture Canada[d]
Expected Insurance Premium for Revenue Yield Insurance Region Crop Policy		H. Furtan[e]
Variance-Covariance Coefficients		
Revenues - (time series) Region Crop/Fallow Policy	Historical Crop Yields Historical Crop Prices	EPIC[b] Agriculture Canada[c]

Table 1. (continued)

	Components of Data	Potential Source(s)
Calibration Coefficients		
Tillage Areas Region Crop Tillage		Agriculture Canada[c]
Insurance Program Participation Region Crop		Crop Insurance Data[d]
Environmental Accounting Coefficients		
Fertilizer Application Rates Region Crop/Fallow Tillage Macronutrient		Crop Insurance Data[d] or Representative Field[a]
Chemical Costs Region Crop/Fallow Tillage		Crop Enterprise Survey[a] Farm-level Data[a]

[a]Saskatchewan only.

[b]Culver, D. Policy Branch, Agriculture Canada, Ottawa, Ontario.

[c]Gassman, P. Resource and Environmental Policy Division, Center for Agricultural and Rural Development, Ames, Iowa.

[d]MacGregor, B. Policy Branch, Agriculture Canada, Ottawa, Ontario.

[e]Furtan, H. Department of Agricultural Economics, University of Saskatchewan, Saskatoon, Saskatchewan.

Table 2. Required data for EPIC and current status of data at CARD

Required Data	Data Components	Intended Application	Status
ARA Database weather data for AL, SK, and MN[a]	·31-year (1955-85) historical daily weather files ·30-year climate normals (1951-80)	·EPIC calibration runs ·Construction of EPIC weather generator files using daily data and solar radiation normals	Received; weather generator files have been processed (except for relative humidity data)
Other ARA Database files[a]	Soil moisture, land use, soil temperature, and other data for AL, SK, and MN	EPIC calibration runs	Received
AL wind speed and direction data[b]	Average monthly wind speeds and directional components	EPIC wind erosion submodel	Received in EPIC format
SK and MN wind speed and direction data[c]	"	"	Not received
CanSIS soil landscape database for AL, SK, and MN[d]	Soil slope and other landform properties at the landscape polygon level	EPIC soil landform inputs	Received; must be processed
Soil layer data for AL[e]	Representative soils for specific ARAs	EPIC soil layer inputs	"
Soil layer data for SK[f]	Cultivated soils across entire province	"	"
Soil layer data for MN[g]	Representative soils for specific ARAS	"	"
MN crop insurance data[a]	Average yields and fertilizer applications by crop, soil, and practice for approximately 20 years for representative ARAs	Construct soil files for EPIC	Received
SK crop insurance data[a]	"	"	Not received
AL crop insurance data[a]	"	"	"
Cross-match files[a]	Link soil landscape polygons to ARAs	Construct soil files for EPIC	Received
Representative soil files[a]	Representative soil codes for each ARA as given in the ARA database	EPIC calibration runs	Received

Table 2. (continued)

Required Data	Data Components	Intended Application	Status
Data for 6 sites in Manitoba[h]	·Historical daily weather data for nearest weather stations· Management, yield, soil, and simulated erosion data for each site	EPIC calibration runs	Received
Swift Current, Saskatchewan rotation data[i]	·Long-term crop rotation data ·Management, soil, and weather data	"	Received
Melfort, Saskatchewan rotation data[j]	"	"	Not received
Canada/Alberta agreement on soil, water,and cropping research and technology transfer (CARTT)[k]	Contains detailed information on tillage type, total number of passes, and costs for crops grown by specific producers in Alberta.	Define EPIC crop and management systems	Received
AL management and cropping systems[l]	"	"	"
SK management and cropping systems	"	"	Not received
MN management and cropping systems	"	"	"
ARA area files[a,l]	Total areas of all agricultural ARAS in AL, SK, and MN	Determine total area of each soil in each area for the experimental design	Received

[a]Kirkwood, V. Centre for Land and Biological Resource Research, Agriculture Canada, Ottawa, Ontario.

[b]Tautchin, M. Alberta Agriculture, Conservation and Development Branch, Edmonton, Alberta.

[c]Teeter, G. Climate Centre, Climate Information Branch, Atmospheric Environment Service, Downsview, Ontario.

[d]Schut, P. Centre for Land and Biological Resource Research, Agriculture Canada, Ottawa, Ontario.

[e]Tajek, J. Alberta Agriculture, Edmonton, Alberta.

[f]Padbury, G. Agriculture Canada Research Branch, Saskatoon, Saskatchewan.

[g]Fraser, W. Centre for Land and Biological Resources Research, Manitoba Land Resource Unit, University of Manitoba, Winnipeg, Manitoba.

[h]Sheykawich, C. Department of Soil Science, University of Manitoba, Winnipeg, Manitoba.

[i]Zentner, R. Agriculture Canada Research Station, Swift Current, Saskatchewan.

[j]Moulin, A. Agriculture Canada Research Station, Melfort, Saskatchewan.

[k]Appleby, T. Production Economic Branch, Alberta Agriculture, Edmonton, Alberta.

[l]Izaurralde, C. Department of Soil Science, University of Alberta, Edmonton, Alberta.

Note: Data for the individual components of this project have been or will be provided by the researchers and organizations noted here.

APPENDIX A. POLICY SCENARIOS AND EXPECTED RESULTS

Policy Scenarios

- GRIP/NOGRIP (with crop insurance), by Province
- GRIP 91/92 (differences)
- NISA
- 10 percent maximum increase in acreage for program crops

Expected Results

- Conceptual paper
- Experimental Design/Metamodeling paper
- Integrated System (RS-CRAM) and Linkages paper
- Policy Evaluation paper

ENDNOTES

1. Average gross margin is currently calculated over three years, but as records are improved it will eventually be calculated over five years.

2. Initially, we specify the quadratic form of the objective function for the risk component. Experiments with CRAM are performed to determine if computational problems exist. If computational problems arise due to the size of the model, linearization techniques, like MOTAD, will be investigated further.

3. Observed values from survey data of land use patterns, for example, will reflect a relatively larger share of "risky" land use in the presence of risk-sharing institutions than would be the case in their absence. If the model is specified without such institutions, the level of ϕ that produces the best fit with the survey data will be lower (i.e., reflecting less risk aversion) than would be the case otherwise.

4. Leontief technology implies constant resource requirements per unit of activity.

5. The methodology is also adaptable to other decision criteria such as the Mean Standard Deviation criteria.

6. Alternatively, assuming perfect foresight, the expected revenue insurance payment may be calculated using the supply and demand relationships to determine the market revenue component as endogenous price multiplied by expected yield.

7. Application rates for fertilizers, all else equal, reflect the yield goal or potential of the crop. Lower yield potential translates into lower nutrient requirements.

8. Production activities in CRAM are specified separately for crops grown on land fallowed the previous year and crops grown continuously year after year.

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