

Evaluating Ontario's Potential for Food Production

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In the fields of land use and food production, policy questions arise repeatedly about the capability of the land base to meet future food needs and the extent to which production opportunities might be altered by changes in biophysical and socio-economic conditions (Beaubien and Tabacnik 1977; Hopkins et al. 1982; Lecuyer 1987; Woods 1981; World Commission on Environment and Development 1987). While recent increases in agricultural production, especially in certain developing countries, provide some optimism about the short-term adequacy of food supplies (Avery 1985; Crosson 1989), widespread concern remains in Canada and elsewhere about the prospects for satisfying long-term demands for food and other land-using commodities (Agriculture Canada 1983; Bentley 1981; Higgins et al. 1982; IUCN 1980; Pierce and Furuseth 1986).

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Conditions that influence the productive potential of agricultural land-use systems have been examined from a variety of perspectives. Studies have investigated such topics as farming in the urban shadow, land-use conversion, adoption of technological innovations, land degradation, and the use of physically marginal lands (Brklacich et al. 1987; Cocklin et al. 1983; Joseph and Keddie 1981; Sparrow 1984). Employing a wide range of approaches, these studies, taken together, have supplied information on the characteristics of production systems and the processes involved in their transformation. But agricultural analysts and public policy makers need more—such as analyses that explicitly address issues relating to the productive capacity of broad regions and to the potential of agricultural systems to meet forecasted demands or targets for food production (Manning 1987; Myers 1987; Warford 1987). These kinds of analyses, however, remain a research challenge (Flaherty and Smit 1982; Frankena and Scheffman 1980; Pierce and Furuseth 1986).

This article presents a methodology for assessing the long-term adequacy of a resource base given selected adjustments to biophysical and socio-economic conditions. It also demonstrates the practicability of the approach. A general model for appraising the long-term prospects for agricultural production is developed by modifying conventional programming methods for resource assessment. This general model is implemented for the province of Ontario and employed to estimate the extent to which various sets of targets for food production can be met or exceeded given a series of scenarios. Specified to help in the evaluation of federal development initiatives, these scenarios vary according to provincial levels of food production and possible changes in supply-side conditions such as land availability, quality, and productivity.

Production Potential and Food Needs

The relationship between food production potential and food targets is of interest for a variety of applications. In many developing countries, this relationship defines the fundamental ability to sustain the population. Chronic shortfalls in production capacity relative to food needs imply increasing dependence on food imports and international aid, or, all too often, increased incidence of malnutrition and starvation. Thus, for such countries as Indonesia and China an essential policy goal is the enhancement of domestic food production capacity to the point where it approaches or exceeds food needs. In the industrialized economies of Europe, North America, and Japan, the relationship is of interest for policy initiatives related to commodity

trading incentives and constraints, regional development, protection of farmland, and development of the domestic agricultural sector.

Concerns about the relationship between production potential and food needs in the developing world have prompted global studies of the capacity of lands to support populations (Higgins et al. 1982). Of the measurement concepts and procedures generated, of particular relevance here are the notions of resource-use feasibility, flexibility, and sensitivity (Chapman et al. 1984; Cocklin 1989; Smit et al. 1984). These concepts can be defined in terms of the relationship between, on the one hand, a region's production potential reflecting available resources, productivity levels, and so on, and, on the other hand, production targets reflecting population, consumption patterns, and trading arrangements.

When a region's potential for agricultural production surpasses projected requirements for food (feasibility), the magnitude of the excess provides a measure of the options for food production (flexibility). Should the productive capacity be only slightly larger than the production requirements, then there would be little choice (little flexibility) but to utilize virtually all of the available resources in an efficient manner. But if considerable excess capacity exists in the regional food production system, there would be, from a food production perspective, many options (much flexibility) for the use of rural resources. If the regional capacity for food production is less than projected demands for agricultural commodities (infeasibility), it is important to estimate the magnitude of this discrepancy. Relatively minor shortfalls could possibly be alleviated by increasing import levels, but major shortfalls could indicate a need for policies that would either boost the region's potential for agricultural production or trim the long-term requirements for food production.

Neither production potential nor food needs are static, and the degree of flexibility (or inflexibility) in a system depends on the conditions and targets specified. Sensitivity refers here to the degree to which flexibility is altered by a change in some variable that influences production potential or food needs or both.

To illustrate these concepts, consider the selected relationships between food production potential and aggregate demand for agricultural commodities presented for a hypothetical region in Figure 1. At T1, the production opportunities for the region are shown to exceed the demand only slightly (AE) (feasible, slightly flexible), suggesting that needs can be met but there is not a lot of slack in the system. At T2, production potential has increased, perhaps owing to technological advances, and regional demands have been reduced, possibly because of relaxed import restrictions. The gap (BF) is now

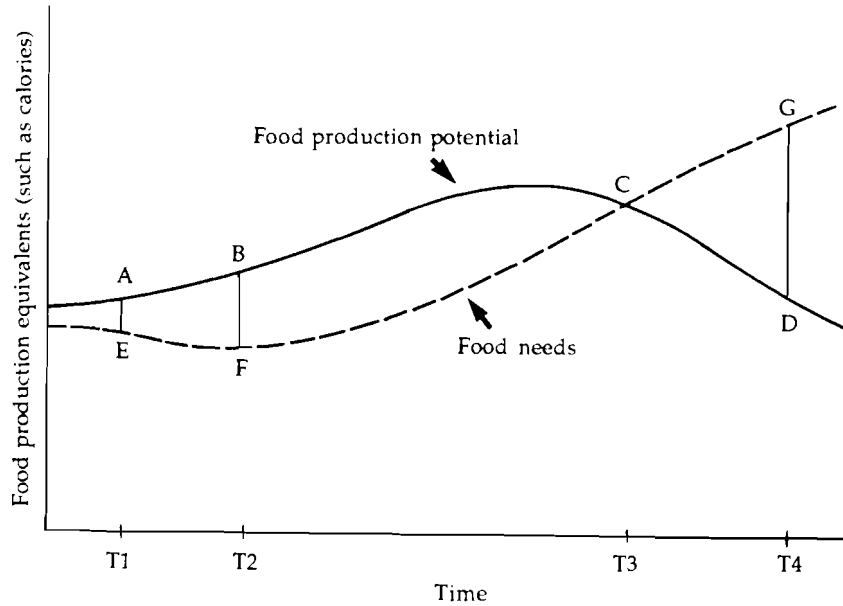


FIGURE 1 Relationship between food needs and production potential

wider (feasible, more flexible), providing the system with considerable excess capacity and a greater number of options for the use of rural resources. By T3, the regional capacity for food production has been reduced, possibly through environmental degradation, so that it equals rising demands (feasible, inflexible), caused perhaps by a growing population. At T4, demands exceed productive capacity (infeasible), creating a significant food deficit (GD) and probably having major implications for food trade or human sustenance.

This example demonstrates that the question of farmland adequacy from the perspective of food sufficiency can be couched in terms of potential production capacity relative to food needs. For current conditions, it is possible to characterize countries according to these principles. For example, North America's agricultural potential most likely exceeds its food needs and is represented by BF, whereas some nations in sub-Saharan Africa may be at point C or approaching GD.

Furthermore, conditions change over time. The hypothetical example in Figure 1 has illustrated the sensitivity of long-term prospects for agricultural production to altered biophysical and socio-economic conditions. The availability and quality of rural land resources, environmental degradation, regional development objectives, population growth, and food consumption habits are but some of the biophysical and socio-economic conditions that will ultimately determine long-term food needs and a region's potential to supply agricultural commodities. While these notions of food

production deficits and excesses, feasibility, flexibility, and sensitivity can be described conceptually, it is quite another matter to estimate numerically the direction and magnitude of the "gap" for a given region and a specified set of conditions. The following section explores the prospects for developing a tool from the conventional programming approaches to resource allocation.

Programming Methods and System Flexibility

Mathematical programming techniques have been applied to assess many problems relating to agricultural land use and food supply on a regional scale. The models are developed by integrating information on the availability of land and non-land resources, on productivity for particular activities, on levels or targets for production, and on some economic efficiency criterion relating to costs and returns to land use. The major characteristics of a production system are specified in the form of constraints and an objective function. Together these represent the various socio-economic and biophysical factors and processes that influence regional patterns of resource use and food production.

A general model can be specified for an agricultural system comprising m resource or land units (j) of different types or quality, where each resource unit can be used for one or more of n activities or land uses (i) to attain specified levels of production. The solution or allocation variables (a_{ij}) are subject to constraints on resource availability and product demands. Commonly, the constraints assume the following form.

- Resource availability. Total allocation of a particular resource unit cannot exceed the defined supply

$$\sum_{i=1}^n a_{ij} - A_j \leq 0 \quad \text{for all } j \quad (1)$$

where a_{ij} = amount (area) of resource unit j allocated to activity i , and A_j = availability of resource unit j .

- Production targets. Total production associated with a particular activity must at least meet the specified production target

$$\sum_{j=1}^m a_{ij} Y_{ij} - Q_i \geq 0 \quad \text{for all } i \quad (2)$$

where Y_{ij} = productivity (per unit area) of resource unit j for activity i , and Q_i = production target for activity i .

- Non-negativity. Negative assignments are not considered:

$$a_{ij} \geq 0 \quad \text{for all } i, j \quad (3)$$

The constraints specify the conditions that any resource-use allocation (a_{ij}) must meet. Given the available resource inputs, productivities, and production targets, a very large number of feasible solutions may exist. An objective function selects from the feasible set a solution that maximizes or minimizes some function of a_{ij} . Because these models are usually used to predict or prescribe an allocation of uses to lands, the objective function is designed to simulate a dominant allocative process (such as maximizing total profits) or to capture some specific social or economic goal (such as minimizing total costs).

This description of the conventional approach is obviously a very simplified version of the current state of the art in resource assessment procedures, but it does illustrate the basic analytical framework. Many assessments of agricultural systems have been based on this type of model and have been successfully implemented using mathematical programming techniques (Cocklin 1989; Hazel and Norton 1986; Heady and Srivastava 1975).

While these models are mainly used to generate estimates of "optimal" resource allocations, they also indicate whether it would be feasible to attain the specified or targeted levels for production, and they can be used to determine the effects of alternative conditions—that is, different values for Y_{ij} , A_j , Q_i —on feasibility. Regardless of the objective function, an infeasible solution in an optimizing model of agricultural land use indicates that a foodland scarcity problem would exist under the specified conditions—that is, the productive capacity of available resources would not be sufficient to meet all the production targets. By varying the conditions, it is possible to determine whether selected changes in conditions would enhance the productive capacity to such an extent that it would be feasible to satisfy the specified food production levels.

These conventional applications of programming methods can indicate whether production potential exceeds or falls short of production needs, but they do not (and were never intended to) indicate the magnitude of any shortfall or excess in production capacity. These models were developed to select one solution from the feasible set defined by the constraints, and they provide little insight into the flexibility that exists in a production system (Brill 1979).

Our purpose here is not to simulate a market, to prescribe some "optimal" allocation for a system, or to select any particular solution. Rather, we will seek to measure a property of the system: its overall productive capacity or flexibility in meeting specified targets. The procedure should also permit identification of the degree to which flexibility in production potential is enhanced or diminished by changes in conditions—that is, its sensitivities.

The "gap" between the productive potential of the land base and the specified targets for food production is interpreted as a measure of the flexibility of the system under the specified conditions. The approach developed here for measuring this gap employs programming methods, but with a purpose and objective function entirely different from those of conventional models.

In a growing body of literature, programming tools have been used in resource analysis for purposes other than economic optimization (Cocklin 1989). One theme within this work focuses on the range of feasible solutions in a programming problem and interpretations of flexibility in resource allocation systems (Chang et al. 1982; Chapman et al. 1984; Flaherty and Smit 1987). A common application in this work is assessment of system sensitivity to changed conditions, including those related to government policies.

The approach outlined here builds on earlier attempts to evaluate the flexibility and sensitivity of food production systems (Smit et al. 1983, 1984). The procedures have been used in several practical applications to soil erosion (Smit et al. 1988), acid rain (Ludlow and Smit 1987), land drainage (Brklacich et al. 1987), and climatic change (Brklacich et al. 1989). The subsequent sections of this article present the conceptual approach, the details of the model specification for Ontario, and the results of an application commissioned by a government agency.

Assessing the Long-Term Prospects for Agricultural Production

The gap between production potential and targeted levels can be evaluated by restructuring the conventional model. The relevant biophysical and socio-economic conditions are expressed in the form of constraints. When the simple example introduced earlier is used, the resource availability constraints (1) and the non-negativity constraints (3) remain as before. The production constraints (2) are modified to allow for the specified targets to be exceeded or underachieved by some proportion p :

$$\sum_j a_{ij} Y_{ij} - p Q_i \geq 0 \quad \text{for all } i \quad (4)$$

$$p \geq 0 \quad (5)$$

In effect, p represents production associated with any allocation (a_{ij}) expressed as a proportion of the defined targets:

$$p = \sum_j a_{ij} Y_{ij} / Q_i \quad \text{for all } i \quad (6)$$

Thus, the gap between production potential and the specified targets can be measured by solving for the maximum value of p :

$$\max Z = p \quad (7)$$

where p is defined as in (6), subject to constraints (1) and (3).

This procedure measures, in the solution value p , the maximum extent to which the production targets could be met and, if possible, exceeded. If the value of the objective function ($\max p$) is 1.0, the production potential of the resource base is exactly equal to the specified production goals. A maximum value of p less than 1.0 indicates that it would not be possible to meet all production targets. For example, a maximum value of 0.8 indicates that the land base has the productive capacity to produce at levels equivalent to 80 percent of each and all production requirements. While it may be that the targeted levels could be exceeded for some uses under these conditions, it would not be possible to meet or exceed this threshold for at least one of the other uses. Thus, considering all uses together in the mix specified by the targeted levels, 80 percent is the best that can be achieved under the stated conditions.

A maximum value of p greater than 1.0 indicates that it would be possible to exceed the targeted levels of production. For example, a maximum value for p of 1.2 implies that it would be physically possible to surpass all specified targets by at least 20 percent, thereby demonstrating considerable surplus capacity or flexibility in the system.

In this approach, the programming model is used for an evaluative, rather than a prescriptive, purpose. The objective function is designed to maximize the (proportional) production potential—not because the allocative process is believed to work this way, nor because this is seen as a societal or planning goal, but because this facilitates identification of (1) how much production potential is in the system, and (2) how sensitive that potential is to changes in conditions. The maximum value of p measures the capacity of food production systems under specified conditions of resource availability, quality, productivity, and targets. Modification of the coefficients in the model to reflect possible changes in such conditions as food production targets, land availability, or crop yields indicates the sensitivity of future options for food production to specified adjustments.

An Empirical Application: Ontario

Based on the procedure broadly outlined in the previous section, an application to Ontario's agri-food sector has been constructed and implemented. The full set of equations implemented for the Ontario system, which has a finer level of resolution than that of the conceptual model, is presented in the Appendix. The main components and assumptions of this application follow.

- Ontario's land resources are classified as land units on the basis of seven climate zones, six administrative regions, and seven land types (Figure 2 and Table 1).
- Nineteen agricultural land uses, representing the major crops in the province, are considered (Table 2, commodity column).
- Production (input-output) coefficients for an agricultural use may vary between, but not within, land units.
- Eight types of livestock products are considered, accounting for the majority of Ontario's livestock sector, with each livestock type producing one or two products (Table 2, commodity column).
- Livestock production is linked to the land through feed requirements for livestock.
- Demand for a product is met through a production process associated with the use of land or the use of imports. Thus, provincial production targets are based on estimated domestic demand (using provincial population and per capita consumption levels) plus exports minus imports.
- The system has a comparative static form in the sense that demands must be met from current production and the production period is one year.
- Crop and livestock product quality is uniform across the province.

The analysis summarized in this article was part of Agriculture Canada's appraisal of the long-term prospects for further development of the agri-food sector in Ontario (Agriculture Canada 1982). Here we will examine the opportunities for increasing agricultural production in Ontario given base (1981) conditions and investigate the prospects for meeting and exceeding two projections for provincial food production, assuming selected adjustments to these conditions. Figure 3 outlines five scenarios under which the prospects for food production are analyzed.

Projections for food production in Ontario to the year 2000 (Table 2) were compiled by the Regional Development Branch of Agriculture Canada (1983). The low growth projection is based on a continuation of recent trends in agricultural production in Ontario, whereas the

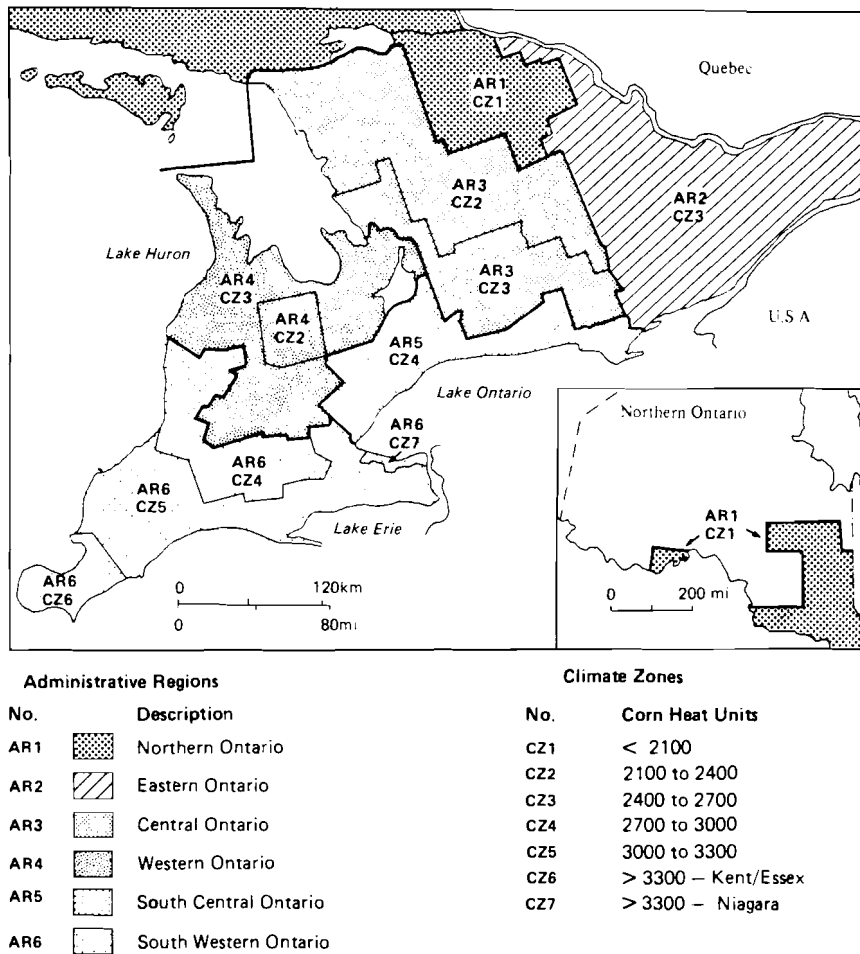


FIGURE 2 Administrative regions and climate zones of Ontario

moderate growth projection reflects a specific expansion strategy for each commodity based on historical trends in population and estimates of exports and imports.

Adjustments to supply-side conditions, selected to pertain to ongoing policy evaluation (Agriculture Canada 1982), are indicated in Figure 3. First, the amount of land available for agriculture is reduced in Scenarios 2-5 from the base level by approximately 80,000 hectares, the predicted land area needed for the expansion of the major urban centres in Ontario by the year 2000 (Cocklin et al. 1983). Second, increases in yields owing to future advances in technology and improvements in farm management are incorporated into Scenarios 3-5. Yields of all crops are assumed to increase by 1 percent per annum for

TABLE 1 Land Types

Land Type	Biophysical Characteristics
1	Well-drained loamy soils Relatively level topography
2	Fine-textured clays Moderately well to well drained
3	Coarser-textured sands and gravels, or shallow soils (less than 1 meter to bedrock) Well to excessively well drained
4	Imperfectly drained soils; tile drained
5	Imperfectly drained soils; not tile drained All poorly to very poorly drained soils
6	Extremely stony or shallow soils
7	Well-drained loamy soils Rolling to hilly topography

Source: Land Evaluation Group. 1983. "Analysis of the Production Possibilities of Ontario Agriculture: Regional Assessments of the Prospects for Sustainable Agricultural Production". Vol. I, Publication No. LEG-16, University School of Rural Planning and Development, University of Guelph.

Note: Ontario's land resources are classified according to biophysical characteristics that are relevant to the production of crops.

20 years (1981-2000). Third, advances in technology and farm management also are expected to result in a more efficient conversion of feed crops to livestock products such as milk. This factor, along with the increases in the forage requirements of Ontario's beef herd expected as a result of expanding cow-calf operations, are considered in Scenarios 2-5. Finally, in Scenario 5 it is assumed that an additional 482,000 hectares of land throughout Ontario are drained and available for agriculture (Brklacich et al. 1987). This on-farm drainage of imperfectly to poorly drained soils is an effective remedial measure to improve the quality of lands and thereby increase crop yields.

For all five scenarios, other factors are assumed to remain constant (Figure 3). The quality of the land resource is assumed to be maintained by rotating row crops with forages and cereals and by using 5 percent of the land base for non-crop soil conservation practices such as windbreaks and stream buffers. The production of grain corn, soybeans, and winter wheat is limited to lands on which yields would be sufficient to generate a profit under base economic conditions (Land Evaluation Group 1984). These constraints reflect a desire to assess options for sustainable production, where sustainability is addressed through maintained land quality and economic viability.

Finally, regional levels of crop production are maintained at or above base levels (Table 3), except in the few cases in which projected provincial targets for production are less than base provincial levels.

TABLE 2 Alternative Growth Projections for Ontario's Agri-food Sector to Year 2000

Commodity	Low Growth Projection			Moderate Growth Projection	
	Current Production ^a (000 tons)	Prov. Prod. Requirement (000 tons) ^a	Change from Current (%)	Prov. Prod. Requirement (000 tons) ^a	Change from Current (%)
<i>Crop Products</i>					
Grain corn ^b	4,693	6,777	44	7,382	57
Oats ^b	664	528	-21	528	-21
Barley ^b	1,059	1,418	33	1,418	33
Winter wheat ^b	639	1,092	71	1,152	80
Soybeans ^b	707	1,080	52	1,200	70
Canola	—	110	—	220	—
Haylage ^c	5,165	6,022	17	6,708	30
Corn silage ^c	7,022	8,793	25	9,861	40
Grazing and rough grass ^{cd}	2,866	3,989	39	4,543	58
Apples	137	215	57	291	113
Peaches	28	23	-19	37	30
Grapes	64	98	51	113	75
Peas	29	38	30	44	48
Sweet corn	142	231	62	277	95
Tomatoes	439	595	36	700	60
Potatoes	369	385	4	385	4
Tobacco	88	76	-14	76	-14
White beans	62	65	5	65	5
<i>Livestock/Livestock Products</i>					
Chicken	141	180	28	180	28
Turkey	43	40	-7	40	-7
Pork	208	373	79	413	98
Beef	266	310	17	363	37
Mutton and lamb	1	3	320	4	400
Milk products	2,520	2,580	2	2,580	2
Eggs	127	125	-2	125	-2
Horses ^e	250	250	0	250	0

a. 1976-1981 average. Compiled by Agriculture Canada, 1983. "Provincial Profile: Commodity Projections to the Year 2000". Unpublished report, Regional Development Branch, Agriculture Canada, Toronto.

b. Livestock feed requirement based on feed crop to livestock product conversion rates developed by the Land Evaluation Group, 1984. "Analysis of Production Possibilities of Ontario Agriculture: Prospects for Growth in Ontario's Agri-Food Sector under Alternative Conditions of Supply and Demand". Vol. II, Publication No. LEG-18, University School of Rural Planning and Development, University of Guelph.

c. Based on feed requirements to support specified levels of production of livestock products. Conversion coefficients were developed by the Land Evaluation Group (see note b).

d. Grazing and rough grass are converted into a hay crop equivalent.

e. Thousands of units.

For example, provincial demands for oats, peaches, and tobacco are expected to decrease in the future. Consequently, the future provincial production targets of these crops are below base levels, and regional crop production levels are adjusted accordingly (Land Evaluation Group 1984).

CONDITION	SCENARIO 1 (Base scenario)	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
1. Provincial targets for food production	Current production levels	Low growth projection	Low growth projection	Moderate growth projection	Moderate growth projection
2. Land availability	5.34 million ha	Urban expansion reduces total to 5.26 million ha	Urban expansion reduces total to 5.26 million ha	Urban expansion reduces total to 5.26 million ha	Urban expansion reduces total to 5.26 million ha
3. Crop productivity	Current rates	Current levels	Current levels	Current levels	Current levels
4. Conversion of feed crops to livestock	Current rates	More efficient conversion of feed crops to milk products and increases in the forage requirements of Ontario's beef herd	More efficient conversion of feed crops to milk products and increases in the forage requirements of Ontario's beef herd	More efficient conversion of feed crops to milk products and increases in the forage requirements of Ontario's beef herd	More efficient conversion of feed crops to milk products and increases in the forage requirements of Ontario's beef herd
5. Agricultural land drainage	Rotation of row crops with forages and cereals and 5% of land base used for non-crop soil conservation	Limited to lands currently drained in Ontario	Limited to lands currently drained in Ontario	Limited to lands currently drained in Ontario	Limited to lands currently drained in Ontario
6. Soil conservation practices	Grain corn, soybeans, and winter wheat limited to areas where profitable under base economic conditions	Grain corn, soybeans, and winter wheat limited to areas where profitable under base economic conditions	Grain corn, soybeans, and winter wheat limited to areas where profitable under base economic conditions	Grain corn, soybeans, and winter wheat limited to areas where profitable under base economic conditions	Grain corn, soybeans, and winter wheat limited to areas where profitable under base economic conditions
7. Economic conditions	Maintained at or above base year except when provincial requirements are less than base provincial production levels	Maintained at or above base year except when provincial requirements are less than base provincial production levels	Maintained at or above base year except when provincial requirements are less than base provincial production levels	Maintained at or above base year except when provincial requirements are less than base provincial production levels	Maintained at or above base year except when provincial requirements are less than base provincial production levels
8. Regional levels of crop production	Maintained at or above base year except when provincial requirements are less than base provincial production levels	Maintained at or above base year except when provincial requirements are less than base provincial production levels	Maintained at or above base year except when provincial requirements are less than base provincial production levels	Maintained at or above base year except when provincial requirements are less than base provincial production levels	Maintained at or above base year except when provincial requirements are less than base provincial production levels

Change from base conditions.

FIGURE 3 Scenario specification: food production for Ontario and selected adjustments to supply-side conditions

TABLE 3 Regional Base Levels of Crop Production: Ontario, 1981 (thousand tons)

Crop	Northern	Central	Western	Eastern	South Central	South Western
Hay	401	432	1,474	1,278	563	1,016
Fodder corn	29	358	2,235	1,239	637	2,522
Grazing grass	382	478	1,385	1,194	430	860
Rough grass	61	30	97	84	33	27
Grain corn	-	86	768	262	383	3,194
Oats	48	37	236	99	64	180
Barley	41	41	501	78	101	295
Soybeans	—	1	14	4	9	676
White beans	—	—	15	—	—	47
Winter wheat	—	15	62	6	53	502
Apples	—	2	30	5	36	61
Peaches	—	—	—	—	—	28
Grapes	—	—	—	—	—	64
Peas	—	—	2	—	8	19
Sweet corn	1	5	10	6	35	86
Tomatoes	—	—	—	—	29	409
Potatoes	—	10	206	12	22	119
Tobacco	—	—	—	—	2	85

Source: Land Evaluation Group, 1984. "Analysis of the Production Possibilities of Ontario Agriculture: Prospects for Growth in Ontario's Agri-Food Sector under Alternative Conditions of Supply and Demand". Vol. II, Publication No. LEG-18, University School of Rural Planning and Development, University of Guelph.

The various supply-side conditions and the production targets for the system are specified appropriately for each scenario in the constraints for each run of the model. The full set of equations is presented in the Appendix.

Provincial Prospects for Agricultural Production Relative to Production Targets

The effects of changing conditions on the prospects for meeting food production targets in Ontario under all five scenarios considered in this analysis are summarized in Figure 4. Under the base scenario (Scenario 1), the value of the objective function, $\max p$, is 1.30. This indicates that the productive capacity of lands available for agricultural production in Ontario exceeds 1981 provincial levels of production for all products by 30 percent. Thus, under base conditions there is considerable excess capacity in Ontario's agri-food system. An overall increase in agricultural production of up to 30 percent is technically feasible without expanding the land base or increasing its productivity. Of course, it would be possible to increase the production of particular products beyond 30 percent, but this would not be possible for all products simultaneously. For some products an increase beyond

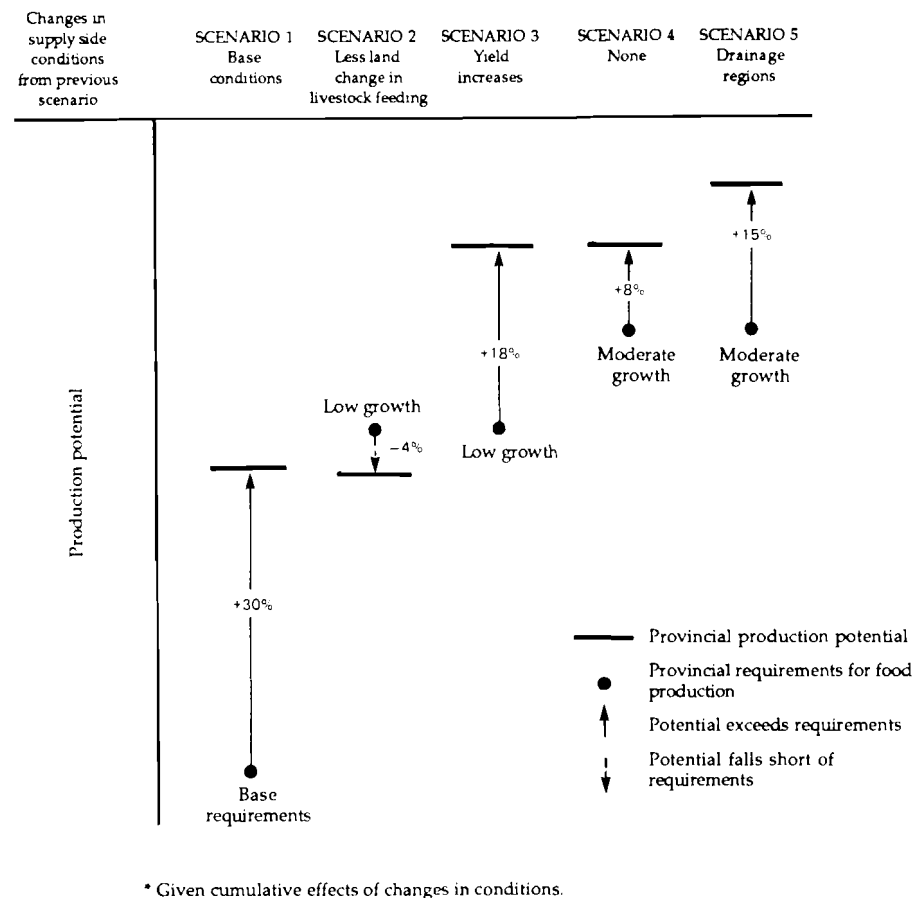


FIGURE 4 Effects of changes in conditions on the prospects for meeting food production requirements in Ontario

30 percent would be possible only at the expense of increasing other products by less than 30 percent. The methodology permits the identification of those products, lands, or other conditions that constrain the maximum value of p , but their analysis is beyond the scope of this article.

Scenario 2 differs from the base conditions in that provincial food targets are increased assuming a low growth projection, land availability is decreased, and feed crops are converted to livestock products more efficiently. Under this scenario, it is not possible to meet all of the production targets even if the current excess capacity in

Ontario's agri-food system is utilized as efficiently as possible. The production potential of Ontario's land resource base falls short of the targeted levels for production by about 4 percent ($\max p = 0.96$). As Figure 4 indicates, the productive capacity of the system under Scenario 2 is reduced only slightly because of the change in land supply, but the production targets are increased to such an extent that the production potential becomes insufficient.

Scenario 3 assumes that technological developments increase yields by 22 percent. With this additional assumption, the production potential of the province's land base is enhanced such that it is technically feasible to surpass the low growth targets for agricultural production by 18 percent (Figure 4). $\max p$, under the conditions specified in Scenario 3, is 1.18. This implies that changes in crop productivities can substantially affect the prospects for agricultural production in Ontario. If yields continue to increase, production prospects in Ontario appear to be more than sufficient to meet the production levels of the low growth projection.

The supply-side conditions specified in Scenario 4 are identical to those specified in Scenario 3. But Scenario 4 assumes a moderate growth projection for food production, and targets in Ontario are increased accordingly (Table 2). Under these conditions, the objective function value is still greater than 1 ($\max p = 1.08$), indicating that Ontario's agri-food system would continue to have surplus capacity (Figure 4). But the surplus is considerably lower than that specified for the low growth projection in Scenario 3.

These analyses show that the productive capacity of a foodland system is influenced greatly by estimates or assumptions about future food needs or targets. Changes in supply-side conditions also can be readily assessed for a given set of production targets. This is illustrated with Scenario 5, which assumes drainage of farmlands currently plagued by excess moisture. Such on-farm drainage increases the productivity of the soil and enhances crop yields. This change in the quality of agricultural lands throughout Ontario would increase the gap between the moderate growth targets and production potential from 8 percent (Scenario 4) to about 15 percent (Scenario 5). This again illustrates the sensitivity of Ontario's agri-food system to changes in crop yields.

Summary and Conclusions

This article describes a procedure that uses mathematical programming techniques to assess the degree to which the overall productive capacity of Ontario meets, exceeds, or falls short of

production requirements given alternative scenarios. These scenarios vary with respect to provincial levels for food production and possible changes in such supply-side conditions as land availability, quality, and productivity.

The analysis indicates that under base conditions the productive capacity of Ontario's agricultural land resources exceeds current production of all crops by about 30 percent. This surplus capacity, however, would not be sufficient to meet even relatively conservative production increases through to the year 2000. When production targets are increased to reflect a low growth projection coupled with decreased land availability owing to future urban expansion, the production potential of Ontario's land resource base falls short of targeted levels by approximately 4 percent. Results from other scenarios indicate that even though yield increases stemming from improved crop varieties and land drainage could boost the provincial production potential beyond projected targets for agricultural production, an overall decline in the options for land use would remain.

Applications in this article are restricted to agricultural production in Ontario, and the findings refer to production levels that are technically feasible rather than predicted or recommended patterns. Socio-economic constraints on the use of land are considered to the extent that existing regional production levels are assumed to be at least maintained and cash cropping is limited to lands on which yields would be sufficient to generate a profit. Other adjustments to supply and demand conditions that might influence the opportunities for agricultural production, such as those for political circumstances (for example, trade policies or production incentives) or environmental changes (for example, soil degradation or air pollution), are not considered in this analysis. The methodology is sufficiently adaptable, however, to accommodate a wider range of scenarios and to be applied in other regions and resource sectors.

Policy analysts and decision makers frequently seek information about the capacity of regional resources to meet future requirements for food, fibre, and other products and amenities. The procedure outlined in this article provides a systematic means of addressing long-term opportunities for rural land use and food production. This procedure also permits assessment of the extent to which these opportunities might be compromised or enhanced by adjustments to biophysical and socio-economic conditions which ultimately influence regional production potential and production requirements.

Appendix: Specification of the Ontario Agri-food Model

Notation

Solution Variables

a = area (ha) of land allocated to a use
 p = degree to which provincial production potential exceeds or falls short of total food requirements

Parameters and Coefficients (Known Values)

A = availability (ha) of land for crop production
 K = cropping sequence coefficient
 Q = provincial requirement (kg) for a crop product
 R = regional demand (kg) for a crop product
 Y = crop product yield (kg/ha)

Subscripts

c = climate zone t = land type
 i = crop product u = land use
 r = region

Subscript Definitions

Climate Zones ($c = 1,2,3,\dots,7$)

Seven relatively homogeneous climate zones, identified on the basis of intervals of 300 corn heat units, are defined for the Ontario system and illustrated in Figure 2.

Regions ($r = 1,2,3,\dots,6$)

Six administrative regions, identified on the basis of municipal boundaries and current patterns of agricultural production, are defined and illustrated in Figure 2.

Land Types ($t = 1,2,3,\dots,7$)

Ontario's land resources are disaggregated into land types, which are relatively homogeneous for crop productivity levels. The biophysical characteristics associated with each of the seven land types defined for the Ontario system are presented in Table 1.

Land Uses ($u = 1,2,3,\dots,19$) and Crop Products ($i = 1,2,3,\dots,19$)

The 19 agricultural land uses that account for the vast majority of Ontario's agricultural land base are considered for the Ontario system.

One corresponding crop product is associated with each land use. A summary of the land uses and crop products of the Ontario system follows (crop products marked with an asterisk include products for livestock feed and human consumption).

No.	Land Use	Crop Product	No.	Land Use	Crop Product
1.	Hay crops	Haylage	10.	Winter wheat	Wheat*
2.	Fodder corn	Corn silage	11.	Apples	Apples
3.	Improved pasture	Grazing grass	12.	Peaches	Peaches
4.	Unimproved pasture	Rough grass	13.	Grapes	Grapes
5.	Grain corn	Grain corn*	14.	Peas	Peas
6.	Oats	Oats*	15.	Sweet corn	Sweet corn
7.	Barley	Barley*	16.	Tomatoes	Tomatoes
8.	Soybeans	Soybeans*	17.	Potatoes	Potatoes
9.	White beans	White beans	18.	Tobacco	Tobacco
			19.	Canola	Canola

Constraints

Non-negativity

These constraints prohibit negative allocations of the solution variables.

$$a_{ctu} \geq 0 \quad (A1)$$

$$p \geq 0 \quad (A2)$$

Land Availability

The area of land allocated for each land unit to all uses cannot exceed the availability of that unit.

$$\sum_{u=1}^{19} a_{ctu} - A_{ct} \leq 0 \quad (A3)$$

Agricultural Production

The provincial production constraints compare Ontario's food production capacity with provincial crop demand.

$$\sum_{c=1}^7 \sum_{r=1}^6 \sum_{t=1}^7 a_{ctu} Y_{ctui} - pQ_i \geq 0 \quad (A4)$$

Crop production in each region must meet or exceed the agricultural production level specified for that region.

$$\sum_{c=1}^7 \sum_{t=1}^7 a_{ctu} Y_{ctui} - R_i \geq 0 \quad (A5)$$

Land-use Restrictions

These constraints ensure that only land-use patterns that maintain environmental quality are considered. In particular, wide row crops ($u = 2,5,8,9$), if grown on a continual basis, would result in environmental degradation and are designated as depleting crops. Environmental quality can be maintained by rotating depleting crops with replenishing ($u = 1$) and companion ($u = 1,6,7,10$) crops. The full set of crop rotations are presented in Land Evaluation Group (1983). The following two restrictions are placed on land-use patterns for each land unit.

1. The area of all replenishing crops in the crop rotation must be at least equal to some factor for the depleting crops.

$$K' \sum_{u=1} a_{ctu} - \sum_{u=2,5,8,9} a_{ctu} \leq 0 \quad (A6)$$

where $K' = \frac{\text{minimum number of years for replenishing crops}}{\text{maximum number of years for depleting crops}}$

2. The area of all companion crops in the rotation must be at least equal to some factor for the depleting crops.

$$K'' \sum_{u=1,6,7,10} a_{ctu} - \sum_{u=2,5,8,9} a_{ctu} \leq 0 \quad (A7)$$

where $K'' = \frac{\text{minimum number of years for companion crops}}{\text{maximum number of years for depleting crops}}$

Objective Function

The objective function employed in this model of the Ontario agri-food system provides a direct measure of the relationship between the province's overall production capacity and the total demand for all crops. This measure is obtained by solving for the maximum value of the solution variable p .

$$\max Z = p \quad (A8)$$

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