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Agricultural Drought Impact Evaluation Model: A Systems Approach*

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ABSTRACT

Droughts are a frequent phenomenon on the Great Plains of North America. Since the great drought of 1936–37, policy-makers have been concerned about the economic impacts of a drought and they have searched for policies that would mitigate these impacts. This paper describes the process of developing an agricultural drought impact evaluation model (ADIEM) for the prairie region of Saskatchewan. It is the first in a series of three papers. Farm and aggregate impact analysis models are described in the second paper. In the third paper, an example of a drought mitigating policy is tested using the ADIEM.

The ADIEM is an integrated systems model that contains four components: a yield–hydrology simulation model, farm business simulation models, a regional input–output model, and an employment model. The models are internally consistent and hierarchical, i.e., the output of one model becomes input for subsequent models. The ADIEM can be used in several

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ways including the evaluation of drought impacts on various types and sizes of farms, and on the regional and provincial economies. Various drought mitigative practices or public programs can also be evaluated in terms of their mitigative effects on farmers and the economy as a whole.

INTRODUCTION

Droughts are common phenomena on the plains of North America. (Droughts occur in the North American great plains in a random manner. On the Canadian prairies there are records of a scorched potato crop in 1805, and a nine-year drought in the 1890s. At least 20 serious droughts occurred in Western Canada during the 19th century. For a more complete historical account, see McKay (1980).) The province of Saskatchewan includes some of the most drought-prone areas in the country of Canada. Droughts may occur over a wide geographic area like the entire agricultural area in Saskatchewan, or may strike just a corner of the province. Droughts may last a year or more, or just a few weeks. A few weeks may be a short period of time but may be long enough to seriously inhibit the growth of plant material. Droughts can decimate pasture and hay crops, yet leave cereal and oilseed crops relatively unscathed or vice-versa.

In agriculturally dependent regions such as Saskatchewan, a severe drought can have a devastating effect on the agricultural economy, and through that on the rest of the economy. (The intent of this statement is not to suggest that all impacts of a drought are measurable or that they are all economic.) Assessment of economic costs of a drought can be a difficult task. Who suffers the economic costs? Is it the producers who may suffer substantial reductions in net income? Is it the retailers in a small town who may see reductions in quantities of goods and services sold to farmers? Is it the farm supply industry that may see profits plunge when farmers reduce their purchases of inputs? Is it the government that may have to provide assistance to distressed producers while at the same time experiencing a severe reduction in tax revenues?

Little formal modeling has been undertaken of drought in Canada; neither the impacts of drought on agriculture nor the development of mitigative programs for drought in agriculture have been studied in a comprehensive manner. It was noted at a 1979 workshop in Nebraska that a need existed for such a study. It was stated that 'there has not been much research on the ... evaluation of alternative strategies and tactics' (Rosenberg, 1980, p. 57). The workshop report recommended that in addition to farm level impacts of drought, 'the macro impacts of drought on state economies, the national economy, and international economic relations deserve exploration' (Rosenberg (1980), p. 57).

Development of a drought-proofing strategy requires the knowledge of two major items of information: (i) how does a drought affect key industries in the region and the economic conditions locally, provincially, or in the regions beyond?, and (ii) how does a specific program or measure modify the impact of a drought, as estimated above? Answers to these questions require development of an appropriate analytical framework. Prior to development of appropriate drought-proofing and mitigative policies some type of analytical model must be developed.

During 1979 the governments of Canada and Saskatchewan signed an agreement to study drought with the specific objective of developing appropriate drought mitigative measures (see Canada-Saskatchewan, 1979). This paper describes the model and related methodology undertaken under the auspices of this study.

Objectives of the study

The primary objective of this study is to develop a comprehensive systems model that is capable of assessing the economic impacts of an agricultural drought on farm and provincial economies. In particular, the model should have the capacity to answer two related questions:

(1) What is the net economic cost of a drought to a region? and
(2) What is the net economic benefit of various drought-proofing measures to farms as well as to the regional and national economies?

The purpose of this paper is to describe the structure of a systems model that was developed to answer the above two questions.

The paper is divided into four sections. Conceptual considerations for developing the model are described in the next section. This is followed by a section that contains an overview of the model, brief description of the various components, and procedures for using the model in a drought impact analysis. In the last section of the paper, economic impacts of the 1984–85 drought in Saskatchewan are estimated.

CONCEPTUAL CONSIDERATIONS

Concept of a drought

There is no standard definition of a drought. This is because drought takes various forms and intensities, and thus, may affect different parts of the complex social, economical and ecological system. However, previous studies (for more details see Carr, 1966 and Saarinen (1966)) have suggested three types of drought—meteorological drought, hydrologic drought, and agricultural drought. A meteorologic drought is defined as a significant decrease from the climatologically expected and seasonably normal precipitation over a wide area. A hydrologic drought is defined as the shrinkage and drying of streams and rivers, depletion of water stored in surface reservoirs and lakes, cessation of spring flows and decline of ground water levels. This type of drought is an extended and more severe form of a meterologic drought. An agricultural drought is different from the other two types, and is defined as the period when soil moisture and rainfall are inadequate during the growing season to support healthy crop growth to maturity and to prevent extreme crop stress and wilt.

In this study, it was decided that a systems model would be developed to analyze the impacts of an agricultural drought. This decision was based on several considerations, the most important being that an agricultural drought is the most frequent type of drought in the prairie economy, and has a more devastating impact on the socioeconomic fabric of the Canadian prairies than do the other two types of drought.

Economic impacts of an agricultural drought

Economic impacts of a drought are generally regarded as undesirable. Due to their timing and sequence of occurrence, two types of impacts can be identified: spasmodic, and incessant or long-term effects. It should be noted that these may not be mutually exclusive. Some of the impacts on individuals may be spasmodic, while others are incessant. Similarly, drought impacts may be classified on the basis of who is affected: impacts on individuals, impacts on the local region where the drought occurs, and impacts on the nation.

Impacts of an agricultural drought are more spasmodic and affect primarily individuals in the region of the drought. In most cases these effects are relatively short-run. The reduction of surface and soil moisture volumes has an immediate and disastrous effect on crop and fodder growth. Reduced crop yields and fodder availability affect farm income and increase the probability of a farm reaching a state of financial stress. This may lead to migration out of the region which would have incessant (long-term) impacts on the regional economy.

Impacts of a drought on a farm are felt on both crops and livestock enterprises. Livestock operations are affected by damage to range lands, low yields of range crops, increased cost of hauling water, lack of feed reserves, depleted cash reserves, and the pressing need for cash income. This may force some farmers to sell their livestock. Once livestock are sold it may take several years to build herds back to their original pre-drought level.

The incessant impacts of the drought may be felt through several spasmodic impacts. Loss of vegetative cover as a result of lack of precipitation and high temperatures may result in loss of top soil through wind erosion. This has implications for soil fertility and, therefore, for future levels of crop production.

Impacts of a drought on crop and livestock enterprises result in loss of farm income and reduced cash flow. Such financial distasters, without any public aid, may result in human suffering in a variety of forms. Such disasters prompt some farms to be sold, abandoned, or foreclosed, thereby forcing some farmers and their families to migrate out of the region. (For example, during the drought of the 1930s about one-quarter of a million people abandoned the prairies (McKay, 1980, p. 170).)

The economic impacts of the drought on the nation are normally taken to be an aggregate of individual and regional impacts. However, a simple aggregation of individual and regional impacts does not capture the entire macro-level impacts. A drought, in addition to the direct impact on agricultural enterprises, would also have secondary impacts on the rest of the economy. These secondary impacts are a result of complex inter-dependencies among industries and regions. As a drought affects a particular region, many types of impacts would be generated. Farmers would have less money to spend. This would be reflected in two types of reduced purchases: (i) reduced family living expenditures, to the extent such adjustments are possible; and (ii) reduced purchases of inputs needed either for current production or for application in the following production period. These reduced purchases eventually lead to reduced production by those non-agricultural industries that produce them; reduction in their production may lead to release of workers, thus further weakening consumer spending power. The input purchases of these industries are also reduced as a direct result of fewer purchases by other industries. This is commonly denoted as a 'ripple-effect' that results from an initial direct shock. These 'ripple-effects' are called indirect and induced impacts, and are frequently lumped into a single term—secondary impacts. (There exists a diversity of terminology for explaining secondary impacts, although indirect and induced impacts have become standard. Other terms used are: industry support impacts, consumption induced impacts, stemming-from impacts, and impacts emerging from backward and forward linkages of industries. For more details on the typology of impacts, see Richardson (1972); Zygadlo & Neihaus (1978) and Miller & Blair (1985).) Secondary impacts are not realized immediately with the occurrence of a drought; realization of such impacts depends on the nature and timing of purchases by one industry from another, nature of stock-holding policy by firms, and on various institutional factors.

Besides secondary impacts, drought has still other economic impacts on the nation. If the drought triggers government aid to drought stricken regions, other government expenditures may have to be reduced. One of the most serious consequences of a drought is the threat to a nation's source of food. If a country does not have sufficient carry-over from previous years, supply of food during a drought year may become critical. Even for exporting nations such as Canada and the United States, decreased food supply will increase prices. If food supply falls below a critical level, it may affect the country's ability to export, and its reputation as a reliable supplier of export products. Droughts also create uncertainty in resource development and use. There may be a tendency to switch production practices in response to the drought; that may result in non-optimal resource conservation practices.

The above discussion of drought impacts has focused on negative effects. This is not to suggest that all economic activity and agents are worse off because of a drought. There is no doubt that some people legitimately make money out of drought. These include people with grazing land or fodder to sell, people engaged in transporting fodder or livestock, and irrigation farms. However, such positive effects are relatively small, and result primarily from a redistribution of a lower total income stream.

METHODOLOGY OF MODEL DEVELOPMENT

Overview of the model

The following aspects of a drought were considered to be important enough to be incorporated into a systems model that could be used to study economic impacts of a drought and benefits of drought mitigative measures: (1) Effect of a drought on plant growth and crop yields; (2) Effect of a drought on crop, forage and livestock enterprises on farms; (3) Secondary effects of a drought on non-agricultural industries; (4) Effect of a drought on economic value of regional and national production; and (5) Effect of a drought on regional employment. Each of these aspects of drought were studied separately, and appropriate tools of analysis were developed to measure the impacts at each level. In particular, four components of the overall systems model (ADIEM) were developed and subsequently interlinked: a yield–hydrology simulator, a set of farm-business simulation models, an input–output model, and an employment model.

Linkages among these four types of models are illustrated in Fig. 1. The change in weather conditions, as caused by a drought, is first translated into reduced yields of cereal crops and forages through the yield–hydrology

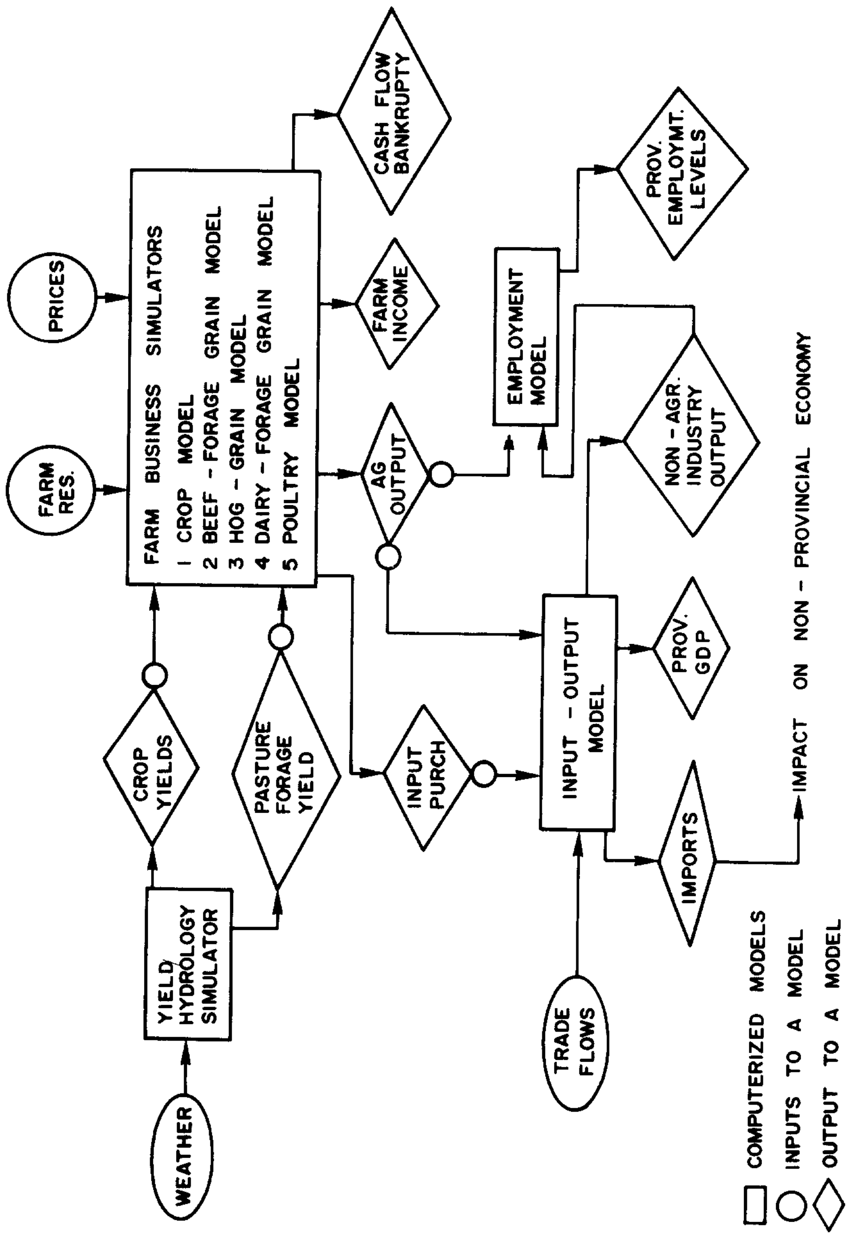

Fig. 1. Overview of drought impact analysis model.

model. (These submodels are described in more detail in the second paper of this series (Klein *et al.*, 1989).) Impacts of the drought on crop and forage yields are inputs into the set of farm-business simulation models. These models provide a number of physical and economic indicators related to impacts on the farm business of a drought condition: enterprise changes, resource use, cultural practices, farm production levels, input purchases, gross and net farm income, savings, and net cash flow. Some of these indicators are required to assess the aggregate or macro-level impacts of the drought. Macro-impacts are assessed in terms of aggregate contribution of agriculture to the provincial level of output, gross domestic product, and personal income. The level of agriculture's economic activity also leads to secondary impacts on the rest of the economy. These secondary impacts are captured with the help of an input–output model of the region. Since the region also trades with other regions, the input–output model is also used to estimate the impact of the drought on imports into the drought affected region. These reduced levels of imports determine the economic activity in the trading regions, which is used as a measure of drought impacts on other regions.

The change in level of economic activity in the region of drought is reflected eventually by changes in resource utilization among nonfarm firms. Facing bleak demand for their products, firms will first stockpile production (This would be true only for those products that are storable.) to a certain acceptable level. Further stockpiling is curtailed by reducing output through release of workers. This affects the employment level in the region. This impact of the drought was estimated with the help of an employment model.

Each of these four components of the ADIEM are described below.

The yield–hydrology simulator (This simulator was developed by the University of Manitoba under contract to the Prairie Farm Rehabilitation Administration)

Two types of yield prediction model were developed: one, for cereal crops, and the other for forage crops. The latter type of model was also used for predicting the impact of the drought on quality of pastures. The cereal crop yield model was estimated for five major crops: wheat, oats, barley, canola, and flaxseed. In general, yield of a crop was estimated as a function of technological change, level of fertilizer use, and level of soil moisture stress. (The soil moisture stress was measured with the help of the Versatile Soil Moisture Budget (VSMB) model, developed originally by Agriculture Canada. It was adapted by Kraft for this study.)

Farm business simulators

The farm business simulators were designed to study alternate resource paths available for changes in the organization of the farm enterprises. Since enterprise combinations differ across the province, simulation models were developed to capture typical farm situations. In particular, five farm level simulation models were developed or modified: (1) dry land and irrigated crops model, a variation of that reported in Zentner *et al* (1978); (2) beef cattle–forage–grain model, a modified version of that reported in Klein & Sonntag (1982); (3) hog–grain model, a modified version of that presented in Sonntag (1971); (4) dairy cattle–forage–grain model (Klein & Klein, 1982); and (5) poultry model similar to that reported in Klein *et al.* (1981). The farm business simulators proceed through a series of steps resembling the decision process used by farm operators. In particular, each model simulates the choices regarding alternative methods of production, e.g., rotations, crops, numbers of preseeding tillage operations, machines, planting dates, fertilizer application rates, cattle, hog and dairy feeding and ingredients for use in poultry diets.

The major output of the farm business simulation models includes: levels of various inputs used in the production process, gross and net farm income, projected net worth, variability in income, net worth and cash flow, family consumption expenditures and income tax paid.

A more complete description of the farm level simulation models is contained in the second paper in this series (Klein *et al.*, 1989).

Input–output model

An input–output (I–O) model portrays the interdependence of one economic sector with other economic sectors, or on forces outside the region. The I–O model adapted for the ADIEM systems model contained 12 major sectors and 72 commodities. This commodity-by-industry framework is called a rectangular input–output model. (For a more technical description of rectangular input–output models, see Miller & Blair (1985).) The model was solved to determine consumers' income and expendiures given a specified level of final demand for various products produced by the industries.

The impacts of the drought on the rest of the economy are estimated by first determining the direct impacts of the drought on agriculture (with the aid of the farm business simulators). These results are inputs for generating secondary impacts of the drought on the rest of the economy.

A more complete description of the I–O model is presented in the second paper in this series (Klein *et al.*, 1989).

Employment model

Employment levels associated with a given drought impact were estimated by using the concept of an employment production function, where the level of employment in an industry is related to its level of output.

The four subcomponents of the drought model (ADIEM) were developed first for the province of Saskatchewan. However, a drought frequently affects a smaller region. To measure the economic impacts of a local drought the province was divided into four regions. (Procedures used for regionalizing the provincial economy are described in the second paper in this series (Klein *et al.*, 1989).) For each region, a regional input–output model was constructed. Similarly, the regional nature of farm production was simulated by using different aggregates of various farm simulation models. These aggregates were selected to reflect the structure of farms in each region of the province.

Operationalizing ADIEM

Prior to implementation, the ADIEM was checked for comparability of input data and for results from each of the components, because results from a lower level model become inputs to a higher level component of the ADIEM. A major problem was encountered in making the results of farm business simulation models compatible with the transactions table used for the input–output model, both at the regional and the provincial levels. The two types of models use data series that are completely different in nature. Aggregation of farm level results does not equal the aggregate values (purchases) used by the input–output model. This is partly because of a lack of sound basis for aggregating micro models, and partly due to differences in complexity and details between the two lower level models. Farm level simulation models, though comprehensive in analyses of enterprise activities, were not sufficiently descriptive of non-enterprise related expenditures, e.g., electricity use, fuel used for driving the truck to an urban centre for shopping activities.

The following procedure was followed to make the models compatible. The year 1980 was chosen as the year for validation of the ADIEM. Hydrological data for various regions for two crop years, 1979 and 1980, were used to construct yields of various cereal crops and forage crops in the province. The results of the farm simulation models were developed for both of these years, and weighted so that they reflected expenditure patterns for the 1980 calendar year. Minor discrepancies between the results of farm level and input–output models were mechanically adjusted. The models were used to validate the 1980 agricultural output and input structure, as well as the 1980 level of gross domestic product, imports, and employment. (For a more complete description of the aggregation procedures and methods of rationalizing farm and aggregate level models, see the second paper in this series (Klein *et al.*, 1989).)

The ADIEM can be used to estimate the economic impacts of a drought and to estimate economic effectiveness of farm management or policy measures for mitigating impacts of a drought. The drought impacts are estimated by running the model for a given set of hydrological data, and comparing the results with those in the validation run. The difference between the two sets of results provides the analyst with an indication of economic impacts of the drought.

The ADIEM can also be applied in evaluating drought mitigative impacts of a given government program. Economic conditions can be simulated with a particular program or farm management initiative in place and compared against the situation when they are not implemented. Impacts of the farm or government policy changes can be assessed under conditions of drought and normal weather patterns.

In the following section, results for the first type of application are illustrated. An application of the second type is described in the third paper in this series (Klein & Kulshreshtha, 1989).

ECONOMIC IMPACTS OF 1984–85 AGRICULTURAL DROUGHT

The ADIEM was used to estimate economic impacts of the 1984–85 agricultural drought in Saskatchewan. The starting point in the use of the ADIEM was to estimate yields under drought conditions. The yield–hydrology relationships coupled with personal judgement of analysts were used to estimate these yields (see Table 1). Yields for most crops were affected by the drought during 1985, particularly in the brown soil zone of southwest Saskatchewan. For example, wheat yields in the brown soil zone declined from 12·9 bu./acre in 1984 to 7·7 bu./acre in 1985.

The estimated yields were inputs into the farm simulation models. Crop and beef farms in all regions of Saskatchewan were simulated under 1984 and 1985 yields. Results were compared to those that would have been attained under a normal situation. These results were aggregated to the regional level and are shown in Table 2. The largest reductions in household incomes are observed for cereal farms in Regions I and II, i.e. those in the southern half of the agricultural area in Saskatchewan. Beef farms in Region II are also affected to a large degree.

TABLE 1
Estimated Grain Crop and Oilseed Yields, 1984 and 1985, By Soil Type and Seedbed, Saskatchewan Regions

Region	*Soil type*	*Seedbed*	*Yield in bushels/acre for*											
			Wheat		*Durum*		*Barley*		*Flax*		*Oats*		*Rapeseed*	
			1984	*1985*	*1984*	*1985*	*1984*	*1985*	*1984*	*1985*	*1984*	*1985*	*1984*	*1985*
I	Dark	Stubble	14·2	14·2	17·1	16·2	21·2	27·7	7·9	9·9	23·8	27·5	9·6	14·0
	Brown	Fallow	20·5	20·6			31·8	41·8	11·0	13·8			14·0	20·5
	Black	Stubble	17·6	23·4	21·3	28·4	29·8	43·5	11·3	16·0	30·9	54·9	9·4	16·1
		Fallow	22·7	36·8					15·1	21·4			14·5	24·6
II	Brown	Stubble	12·9	7·7	16·9	9·6	22·7	15·0	9·5	6·4	24·3	16·7	9·9	14·1
		Fallow	19·8	11·8					14·2	9·6			11·5	22·5
III	Dark	Stubble	16·1	21·6	18·4	26·0	22·6	35·5	10·7	15·2	27·6	46·9	6·0	14·1
	Brown	Fallow	23·3	31·2			33·8	53·2	14·9	21·4			14·0	20·7
	Black	Stubble	22·5	28·1	26·3	36·7	42·8	59·3	18·7	21·3	48·3	62·7	9·4	15·4
		Fallow	35·3	44·1					24·9	28·4			14·6	23·6
IV	Dark	Stubble	16·4	18·6	22·1	19·4	27·0	39·6	12·3	12·5	33·8	45·1	9·6	15·5
	Brown	Fallow	26·6	26·8			40·5		17·3	17·5			14·0	22·6
	Black	Stubble	21·4	23·6	20·6	25·9	30·4	44·8	17·9	19·9	46·5	52·7	9·4	17·7
		Fallow	33·6	37·0			45·6		23·9	26·5			14·5	27·2

TABLE 2
Farm Level Simulation Results of Drought Impacts, 1984–85 Drought, Saskatchewan

Farm type and expenditure item	*Change from normal level in (000$)*			
	Region I (Southeast)	*Region II (Southwest)*	*Region III (Northeast)*	*Region IV (Northwest)*
Cereal farms				
Fuel and oil	−197	−146	−39	−140
Machinery repairs	33	−286	−13	−136
Insurance	−1 000	−1 580	37	−1 302
Household income	−79 352	−67 258	−4 851	−19 713
Indirect taxes	−15 018	0	3 720	2 245
Beef farms				
Fuel and oil	−62	−168	4	−1
Feed	186	404	166	179
Equipment	−177	−390	16	9
Machinery repairs	−177	−390	16	9
Household income	−7 619	−15 644	−2 957	−2 821
Income taxes	−2 632	−8 203	1	−347

Aggregate economic impacts of the 1984–85 drought on the Saskatchewan economy are shown in Table 3. Gross domestic product in the province is reduced by $313 million because of the drought. Almost 80% of this loss is in the form of reduced personal household incomes. Other regions in Canada and other countries are also affected by the Saskatchewan drought. The Canadian economy (excluding Saskatchewan) sells $72 million less to the province; the rest of the world (excluding Canada) sells $9 million less to the province.

Employment losses in the province are also generated by the drought. A total of 1,187 full-time equivalent workers are lost, most of which are in the trade and services sectors (Table 4).

TABLE 3
Aggregate Economic Impacts of 1984–85 Drought on Provincial Economy

Item	*Unit*	*Amount*
Gross domestic product at market prices	Mill $	−313·2
Household income	Mill $	−249·8
Imports from Canadian sources	Mill $	−72·0
Imports from foreign sources	Mill $	−9·0

TABLE 4
Change in Employment of Various Sectors as a Result of 1984–85 Drought, Saskatchewan

Sector	*Change in employment (Full-time equivalent workers)*
Agriculture	8
Forestry/Fisheries	13
Non-fuel mining	1
Fuel mining	1
Agricultural processing	128
Other manufacturing	42
Construction	38
Utilities	12
Trade	331
Transportation and Communications	25
Financial services	113
Other services	475
Total	1 187

SUMMARY

This paper is the first of three papers dealing with modeling of an agricultural drought. In this paper, an overview of the Agricultural Drought Impact Evaluation Model (ADIEM) has been provided. The model, in fact, consists of a series of interlinked sub-models. Each of these sub-models uses as input the results of one or more previous sub-models. Analysis is sequential in nature starting with effect on yield, then tracing the effect of the drought on the farm all the way to the economy as a whole. The model was applied in this paper to the 1984–85 drought. In terms of farm level impacts, farm income (measured as household income) was reduced by $79.4 million on cereal farms in southeast Saskatchewan, and by $67.3 million on cereal farms in the southwest. For the province as a whole, the loss was $200.2 million. This translates into a loss of $250 million at the provincial level. The income multiplier of a drought such as that which occurred in 1984–85 is estimated at 1·25. Furthermore, the provincial economy loses 1,187 full-time equivalent jobs—one for every $168.6 thousand loss in farm household income.

Agricultural droughts can have a significant impact upon local and regional (provincial) farm and general economy. Tracing the effect of the reduced crop and forage yields resulting from a drought, the ADIEM is

capable of estimating the economic costs of a drought, both in terms of income levels and employment. One limitation of the model should be noted, however. An implicit assumption of the analysis is that demand function for crops and livestock products in the drought regions is perfectly elastic. For local droughts, and particularly in the context of Saskatchewan cereal crops where market price is determined internationally, such as assumption is tenable. However, for forage crops and livestock products, such is not the case. Since these markets tend to be more local (or regional), there may be significant changes in price level, further accentuating the drought impacts. Similarly, interrelationship between feedgrains prices and livestock prices were not incorporated. For analyzing the impacts of droughts that are widespread to major grain producing regions of North America, these would be serious limitations of the ADIEM. However, the methodology presented here is valid for analyzing local or regional droughts.

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