CANADA

1/94

Agriculture
Canada

Policy
Branch

Direction générale
des politiques

Canada

[redacted]

Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment (Report 3: The Integration of the Environmental and Economic Components)

(Technical Report 1/94)

Project team:
Aziz Bouzaher, Jason F. Shogren, Derald J. Holtkamp, Philip W. Gassman,
David Archer, P.G. Lakshminarayan, Alicia L. Carriquiry, Randall K. Reese
Resource and Environmental Policy Division, Center for Agricultural and Rural Development
Iowa State University, Ames, IA 50011

William H. Furtan
Department of Economics, University of Saskatchewan, Saskatoon, Saskatchewan

R. Cèsar Izaurralde
Department of Soil Science, University of Alberta, Edmonton, Alberta

Jim Kiniry
USDA-ARS, Grassland Research Laboratory, Temple, Texas

March 1994

This report was completed under contract for the Policy Branch, Agriculture Canada.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. Introduction

Increasing demand is being placed on policymakers to assess proposed policies in terms of both the economic and environmental impacts that could occur. For instance, Canada has implemented environmental assessment and review processes during the design stage for major physical projects, together with an environmental screening process for all new policy and program proposals coming before the Federal Cabinet. In the case of major new farm income insurance and stabilization programs, Canada has taken the unprecedented step of requiring periodic post implementation environmental reviews in order to ensure that farm programs adequately integrate environmental values with economic considerations under important farm programs.

Agro-environmental problems are typically multifaceted and therefore are best studied using a multidisciplinary approach in which 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 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. In turn, the policy implications are 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 Bower (1987) and related policy issues are discussed in Nijkamp (1980).

For this study, an integrated agro-ecological economic modeling system is being constructed around Agriculture Canada's Canadian Regional Agriculture Model (CRAM) (Webber et al. 1986 and Horner et al. 1992) for Western Canada (Alberta, Saskatchewan, and Manitoba). As an initial application, and to test its performance, the system will be used to evaluate the resource neutrality of the Gross Revenue Insurance Program (GRIP) in the Prairie Provinces[1]. The GRIP is a farm program that offers insurance against yield and price risks. Concern has been expressed that GRIP is not resource neutral and will influence the intensification of production on marginal lands, leading to higher erosion rates and increased soil degradation. The program was recently the subject of a quantitative environmental assessment which was completed using an alternative methodology (EMA 1993).

A detailed discussion of the conceptual framework for the integrated modeling system has been presented in Agriculture Canada (1993a). We briefly revisit the conceptual framework shown in Figure 1 to discuss the interactions between the major system components. The two major components of the conceptualized integrated system are: (1) agricultural decision and (2) environmental. The agricultural decision component is a revised version of CRAM called RS-CRAM (denoting resource sensitive CRAM) that includes input substitution and calculation of

---

[1]Originally, it was also intended to evaluate the Net Income Stabilization Account (NISA), that was designed to protect eligible producers against income volatility (especially during low-income years). However, a well developed theoretical framework does not currently exist for NISA, so it cannot currently be evaluated with the integrated system.

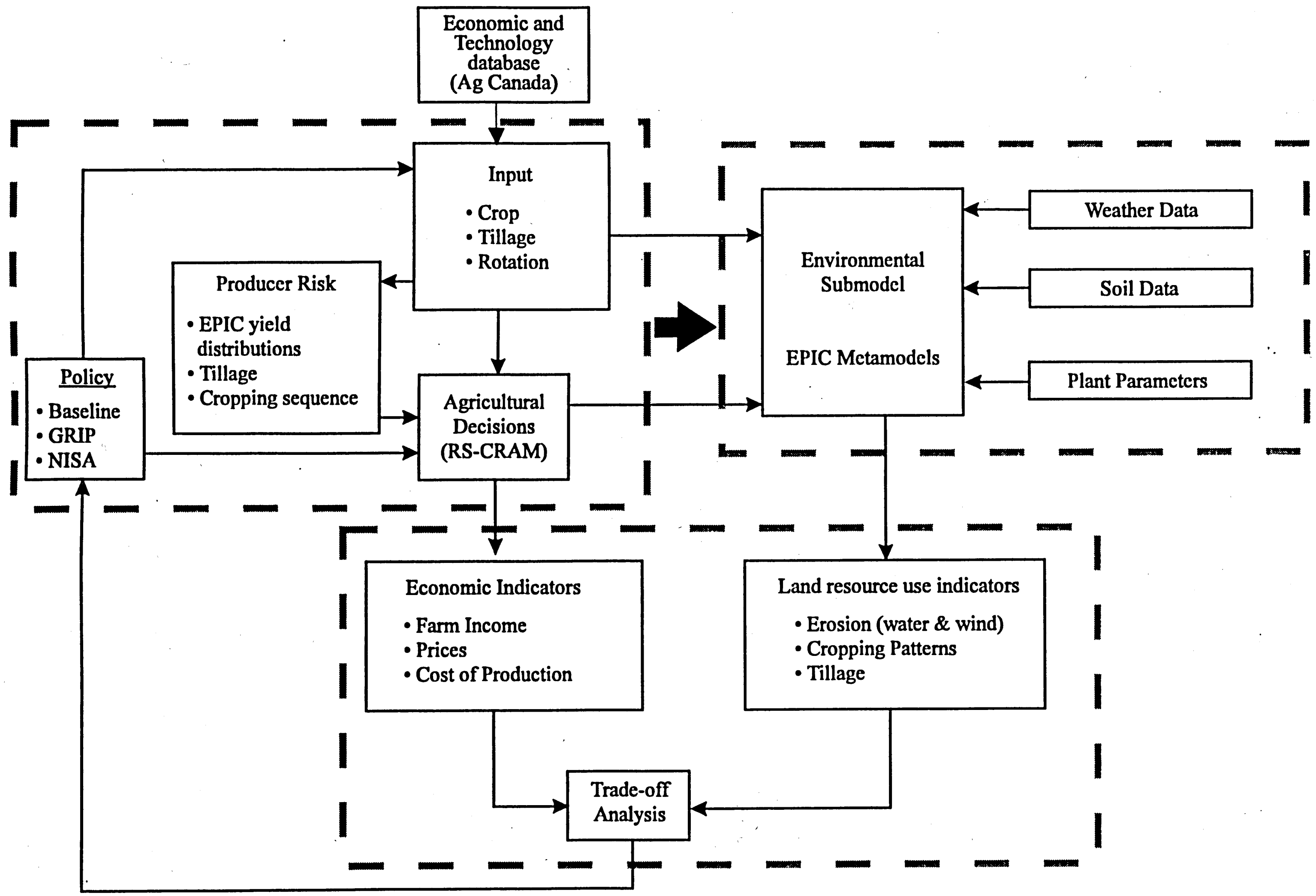

Figure 1. General conceptual framework

producer risk modules. The environmental component consists of environmental metamodels (summary response functions) that are constructed on the basis of multiple simulations performed with the Erosion Productivity Impact Calculator (EPIC), a model previously developed by the USDA-ARS to estimate the long-term impacts of erosion upon soil productivity (Williams et al. 1984). A detailed description of EPIC and results of initial tests of the model for different conditions in Western Canada are given in Agriculture Canada (1993b).

The system is initiated by defining the policy, or set of policies, to be evaluated. The policy scenario being simulated is then imposed on RS-CRAM, where management decisions are simulated based on expected producer response to risk and options available in the input substitution component. At the completion of the simulation run, RS-CRAM outputs economic indicators in the form of farm income, prices, and cost of production. As well, management parameters in the form of tillage level, crop, and crop sequence (crop following fallow or stubble) from RS-CRAM are interfaced with the environmental metamodels (Figure 1). Land resource use indicators in the form of water and wind erosion estimates are output from the environmental metamodels. A trade-off analysis is then performed to evaluate the overall economic and environmental impacts of the simulated policy scenario.

The development of the environmental metamodels for the integrated system is depicted in Figure 2. The concept of a metamodel corresponds to a hierarchical modeling approach whereby we proceed from a complex real phenomenon to a well structured simulation model and then to modeling the relationship between the inputs and outputs of the simulation model itself. This eliminates the need to repeat model runs every time a new policy is considered, a task that is prohibitively expensive.

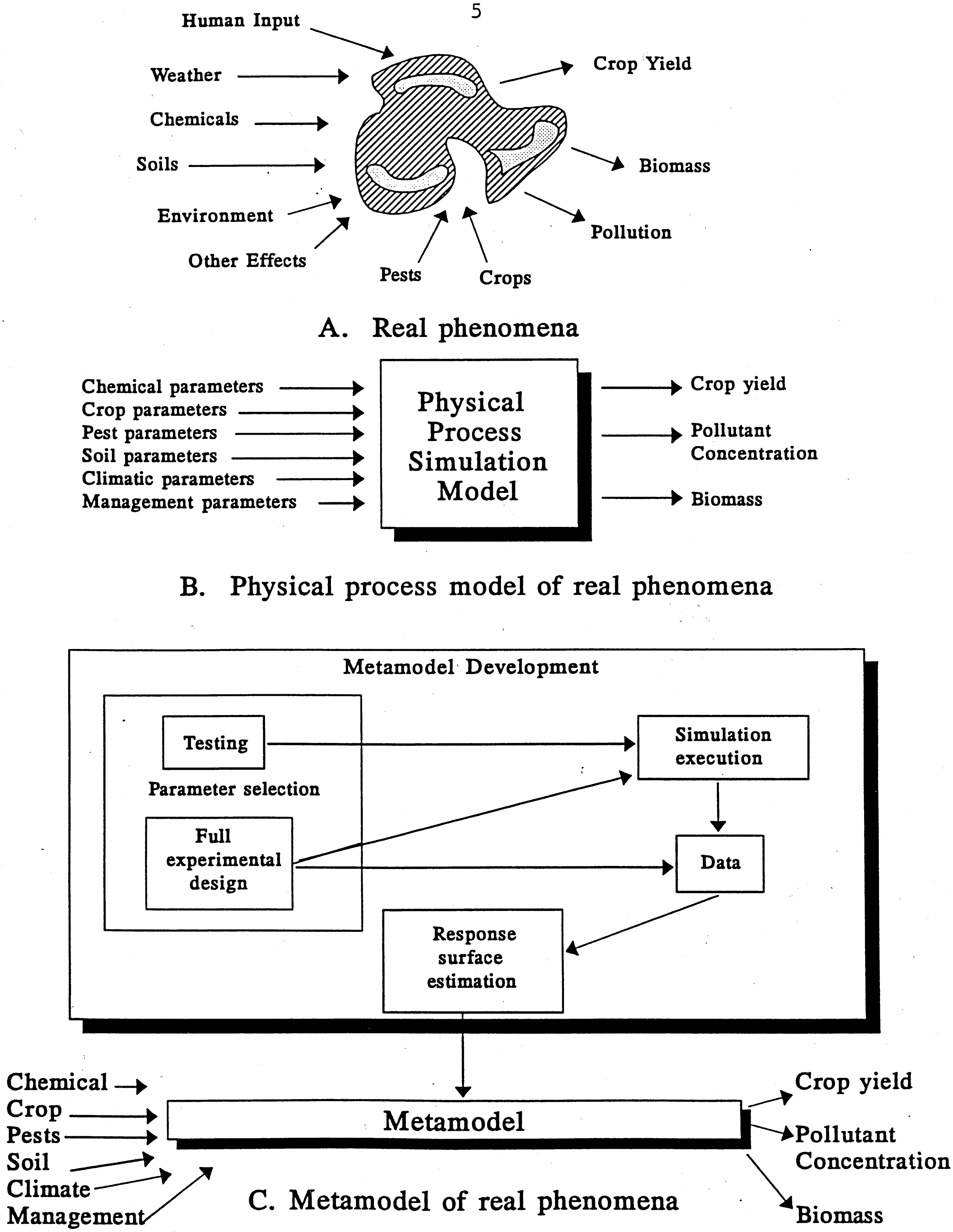

Figure 2. Schematic of the development of environmental metamodels based on multiple EPIC simulations

As shown in Figure 2, the environmental metamodels are constructed on the basis of a statistically designed set of EPIC simulations, that cover the range of relevant crop, soil, weather, and management characteristics. The simulations also provide estimates of crop yields that are used to adjust census yields used in RS-CRAM as a function of tillage. These simulations are performed prior to any policy scenario simulations performed in RS-CRAM. The metamodels are constructed using EPIC input and output from the completed simulations, and then linked directly to RS-CRAM. By taking these steps, repeated policy scenarios can be performed with the integrated system without having to execute a set of EPIC simulations for each scenario.

The metamodels also facilitate the interface of the different spatial scales that EPIC and RS-CRAM operate at. EPIC is essentially a field-scale model that is executed in this study with soil layer and landform information available at the landscape polygon level and with climatic data available at the Agroecological Resource Area (ARA) level. These natural landscape regions are considerably smaller than CRAM production regions, as shown by the overlay of the CRAM region boundaries on ARAs for the Prairie Provinces in Figure 3 (see definitions of the different regions in Table 1). Thus, the estimated environmental indicators must be aggregated up to the CRAM region level for trade-off comparisons with the economic indicators for a given policy. This task is accomplished with the environmental metamodels, which is described in section IV.

The remainder of the report covers the following topics: (1) crop and management interfaces between the environmental component and RS-CRAM, (2) experimental design, (3) EPIC simulation results, (4) structure and validation of the metamodels, (5) development of the aggregation area weights, and (6) a summary.

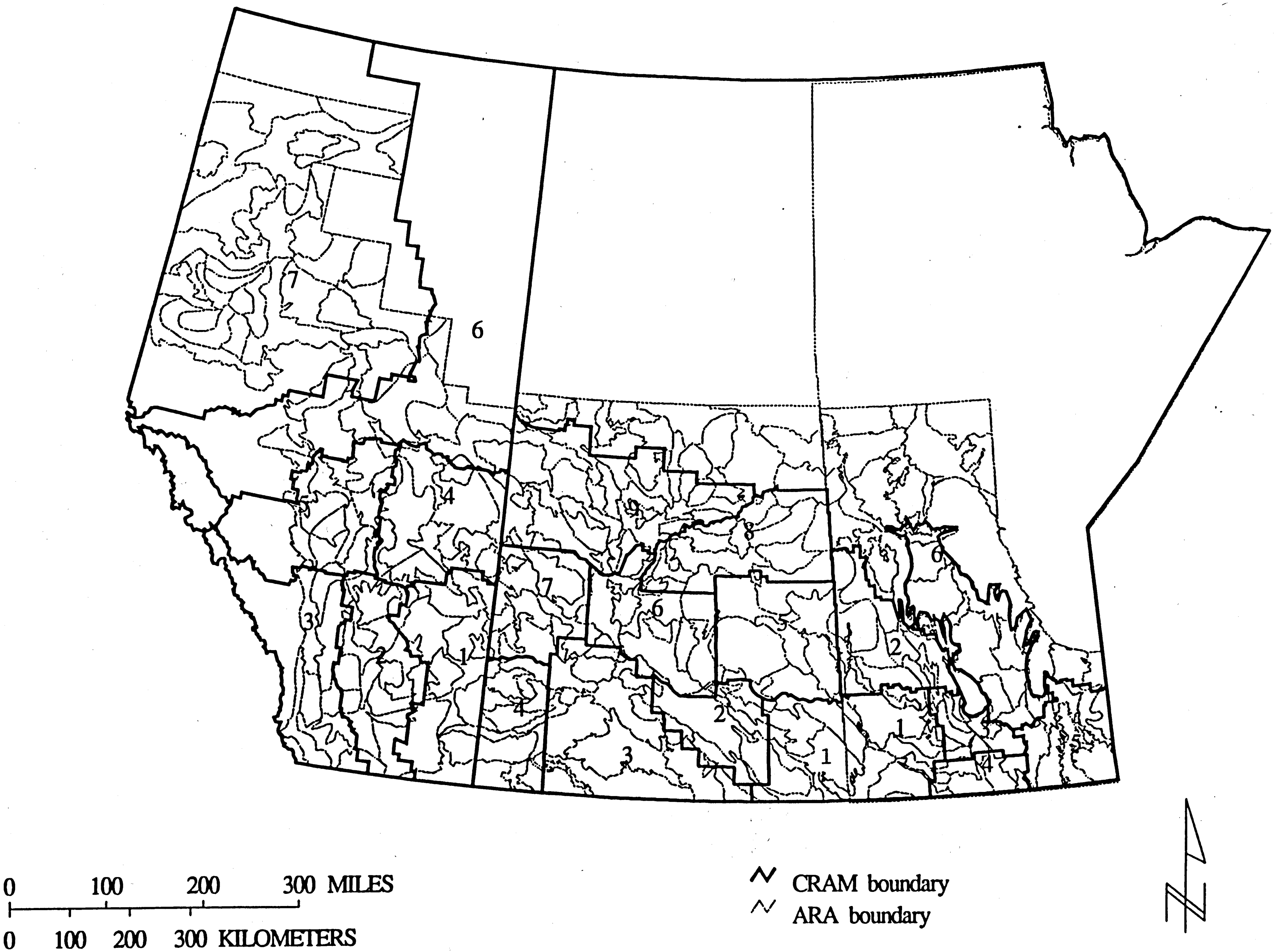

Figure 3. Overlay of RS-CRAM production region boundaries on Agroecological Resource Area (ARS) boundaries for Alberta, Saskatchewan, and Manitoba

Table 1. Definition of CRAM production regions, agroecological resource areas (ARAs) and landscape polygons

Region type	Definition
CRAM production area[a]	Each production area is comprised of one or more statistics Canada crop reporting districts. Crop reporting district boundaries are usually politically determined, although in some cases natural features such as large rivers will divide crop districts.
ARA[b]	A natural landscape unit that possesses relatively uniform agro-climate, land form, soils, and general agricultural potential at the 1:2 million scale. ARAs vary in size from under 100,000 ha to over 1,000,000 ha.
Landscape polygon[c]	A natural landscape unit that is characterized by unique combinations of soils, landforms, and parent materials at the 1:1 million scale. Dominant soil landscapes represent at least 40 percent of a polygon while subdominant landscapes represents 16 to 40 percent of a polygon. Typically, several landscape polygons exist within an ARA.

[a]From MacGregor (1994).

[a]Based on information given by Hiley and Wehrhahn (1991) and from Dumanski (1993).

[c]Based on information given in Shields et al. (1991).

II. The Interface between RS-CRAM and the Environmental Metamodels

The data flows required to configure EPIC in order to construct the environmental metamodels are depicted in Figure 4. A statistically designed set of EPIC simulations was performed with these data that generated crop yields for RS-CRAM and erosion estimates that were used to construct the environmental metamodels. A key step in building the EPIC simulations was the development of cropping patterns and tillage systems that were consistent with those used in RS-CRAM. This allowed RS-CRAM to be directly interfaced with the environmental metamodels so that integrated analyses could be performed.

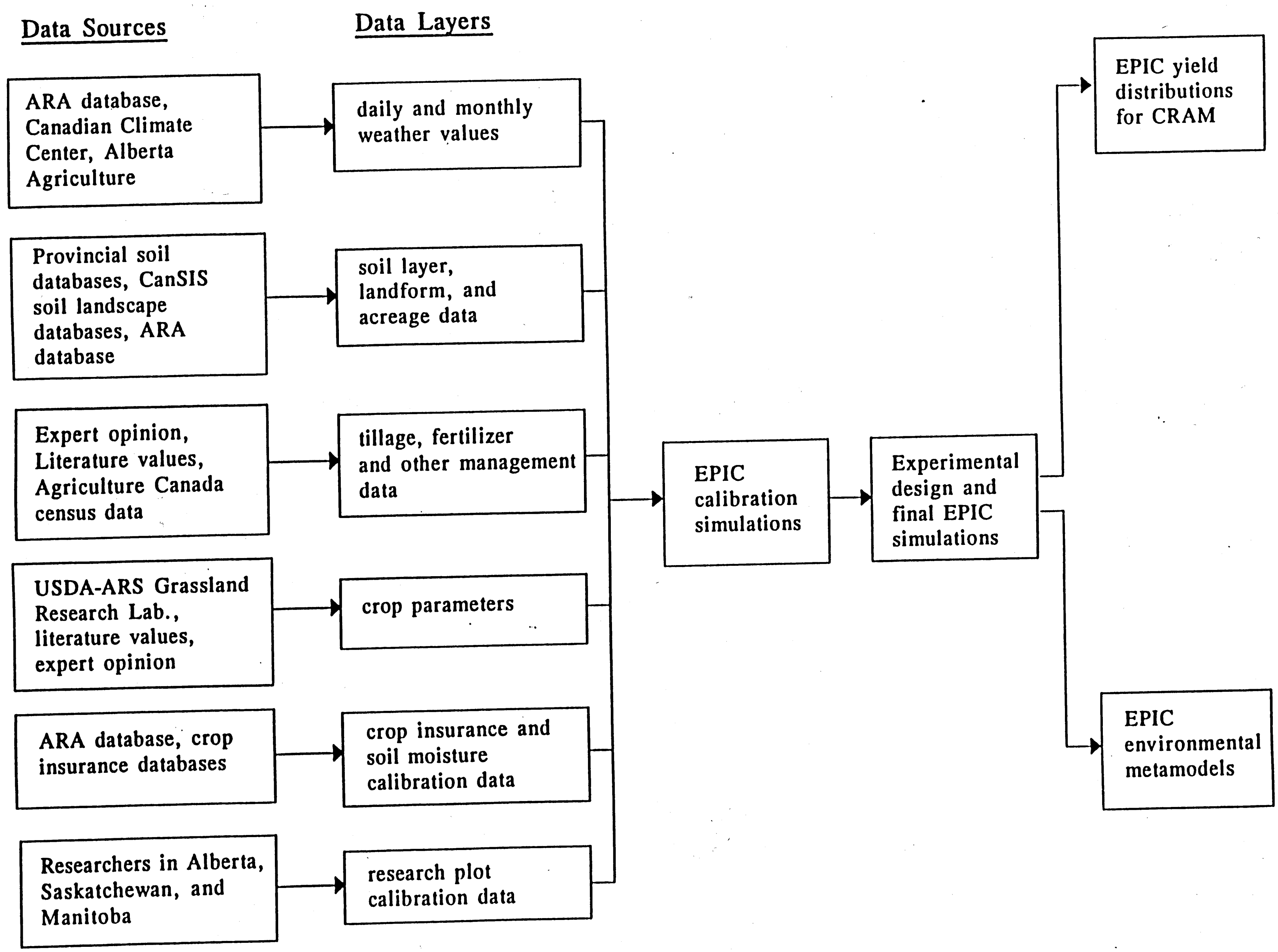

Figure 4. Schematic of EPIC data inputs and simulation runs

The general functional form of the wind and water erosion metamodels are as follows

$$Water\ Erosion_{crop\ i,\ seq.,\ prov.} = f(soil\ prop.,\ hydro.,\ weather,\ location,\ tillage,\ u_i) \tag{1}$$

$$Wind\ Erosion_{crop\ i,\ seq.,\ prov.} = f(soil\ prop.,\ weather,\ location,\ tillage,\ u_i) \tag{2}$$

Where:

crop i	=	spring wheat, barley, canola, lentil, sunflower, field pea, fall rye, alfalfa, flax, or fallow (fallow is a "crop" in this sense in that erosion impacts on fallow must also be captured)
seq.	=	crop sequence; whether the crop was grown on stubble (followed a crop) or on fallow
prov.	=	province; i.e., Alberta, Saskatchewan, and Manitoba
soil prop.	=	soil properties such as % clay, % sand, bulk density, organic carbon, % slope and so forth
hydro	=	hydrology, which is represented by hydrologic curve numbers
weather	=	average rainfall and average wind speed
location	=	the location of each ARA which is defined by the centroid coordinate of the latitude
tillage	=	three levels: conventional, reduced (conservation), and no-till
u_i	=	unknown error terms

The three variables in these functions that are important as far as RS-CRAM output is concerned are the crop, crop seq., and tillage level. In an actual policy analysis, these three outputs are interfaced directly from RS-CRAM with the wind and water erosion metamodels to estimate the environmental response to different policy scenarios. Specific crop rotations and tillage system scenarios were constructed for the EPIC simulations that reflect typical practices in the Prairies and facilitated the interface with RS-CRAM. The development of these crop rotations simulated in EPIC to facilitate the crop and crop sequence interface is discussed first, followed by a description of the tillage interface between RS-CRAM and the environmental component.

A. Development of the EPIC Rotations

Initially, the option considered was to simply run continuous cropping and crop-fallow sequences in EPIC. This would have facilitated a direct and relatively simple interface with the crop distributions available in RS-CRAM, which are specified as either following stubble or fallow. However, cropping patterns across much of the Prairie Provinces are dominated by rotations that are more complex than continuous cropping and crop-fallow sequences. Discussions with agricultural researchers from the region indicated that opting for the more simple route would have resulted in a low level of acceptance. In order to capture the effect of more complex cropping systems, a set of representative rotations were developed in consultation with different experts (Table 2) in Alberta, Saskatchewan, and Manitoba that represent the current (baseline) mix of crops in each CRAM region.

The original rotations that were proposed for the EPIC simulations, and the rationale for including them, are listed in Table 3. These rotations were chosen to reflect traditional practices that are performed in the prairies such as fallowing, as well as potential alternative practices that replace fallow with crops such as lentils and field peas. In addition, the rotation length was initially held to three years, except for rotation 2, in order to simplify the analysis and reduce the number of required runs. A five year rotation was considered necessary for rotation 2 in order to accurately reflect hay production in mixed farming systems.

Table 2. Experts consulted to obtain estimates of the percent of the total crop acres comprised by different crop rotations in each CRAM region

Province	Export/Title	Agency (location)	CRAM Regions
Alberta	Dr. Ross McKenzie, Research Scientist (soil fertility)	Alberta Agriculture (Lethbridge)	1,2,3
	Tom Jensen, Soil Conservation Specialist	Alberta Agriculture (Edmonton	4,5,6
	Garry Coy,[a] Regional Soil Specialist	Alberta Agriculture (Fairview)	7
Saskatchewan	Dr. Ken Grier,[b] Soil Scientist	Soil Science Department, Univ. of Saskatschewan (Saskatoon)	1,2,6
	Dr. Robert Zentner,[a] Economist	Agriculture Canada Research Station (Swift Current)	3,4
	Dr. Adrian Johnston, Agronomist	Agriculture Canada Research Station (Melfort)	5,8
	Stu Brandt, Researcher	Agriculture Canada Experimental Farm (Scott)	7,9
Manitoba	Peter Entz, Soil Conservation Specialist	Manitoba Agriculture (Carman)	1,2,3,4,5,6

[a]Emphasized that estimates were obtained in consultation with other colleagues at their respective sites.

[b]Farms part-time in Region 2 (Saskatoon is located in Region 6).

Table 3. Rotations included in the EPIC simulation set based on expert opinion

No.	Crop Rotations in EPIC	Rationale for Inclusion
1	Continuous Barley	Continuous cereal rotation for northern regions
2	Barley-Barley-Hay-Hay-Hay	Rotation for mixed farming system, short-growing season
3	Canola-Wheat-Barley	Common oilseed-cereal rotation under continuous cropping
4	Canola-Wheat-Fallow	Fallow effect, in comparison to rotation 3
5	Continuous Wheat	Continuous cereal, longer growing season
6	Wheat-Wheat-Fallow	1/3 fallow for moisture conservation
7	Wheat-Fallow	1/2 fallow for moisture conservation
8	Wheat-Wheat-Lentils	Alternative crop to replace fallow, adds nitrogen, longer growing season. Lentils require more days from seeding to maturity
9	Barley-Barley-Field Peas	Incorporates annual legume, adds nitrogen, cooler regions (compares with #1)
10	Wheat-Wheat-Flax	Alternative crop to replace fallow
11	Wheat-Wheat-Fall Rye	Fall rye provides spring cover
12	Wheat-Wheat-Sunflower	Rotation with sunflower for Manitoba

[a]A canola-fallow-wheat rotation was also originally proposed (to compare the fallow effect with rotations 3 and 4), but the prevailing viewpoint of several of the experts listed in Table 2 is that producers are not using it. Therefore, it was eliminated.

The rotations shown in Table 3 were then presented to the experts listed in Table 2 for their confirmation as to whether or not they accurately reflected cropping practices in their regions. While the response was generally positive, several additional rotations were suggested as being important cropping sequences that should be incorporated within the EPIC simulation set. In particular, it was stressed by Mckenzie (1993), Jensen (1993), and Johnston (1993) that canola rotations are recommended to be of four years duration in order to adequately protect canola from disease problems. Thus, several new rotations were included to accommodate this recommended practice. However, it was pointed out by Entz (1993) that many producers in Manitoba, contrary to agronomic advice, are dropping back to three-year canola rotations to take advantage of favorable market prices of canola. According to Coy (1993), many producers in the Peace River Region of Alberta (CRAM Region 7) are even growing continuous canola because of the high canola prices (the most extreme case known being 11 straight years of canola).

The additional rotations that were incorporated into the analysis are listed in Table 4. It was stressed by several of the experts that although the rotations in Tables 3 and 4 reflect cropping practices in the Prairies, most producers do not strictly follow these rotations. As noted above for canola, year-to-year cropping decisions are often driven by market forces. Weather and soil moisture conditions also influence planting decisions to a lesser degree. It is also assumed that there is no variation in the rotation mix across each CRAM production region. However, in reality there is more diversity in some of these regions, where cropping practices shift due to soil zone transitions and other agroclimatic reasons.

Tables 5-7 show the estimated percentages that the different rotations represent of the cropped acres in each CRAM region for Alberta, Saskatchewan, and Manitoba. These percentages are in some cases modifications of the original expert estimates. Estimates of one percent or less were eliminated by aggregating the percentages to other rotations, primarily to reduce the number of EPIC runs required to construct the metamodels. Further adjustments were made for some of the Alberta CRAM regions to avoid major discrepancies with the 1991

Table 4. Additional rotations included in the EPIC simulation set based on expert opinion

Rotation		Recommended by[a]
13.	Wheat-Canola-Wheat-Field Peas	Entz
14.	Wheat-Sunflower-Barley-Lentils	Entz
15.	Wheat-Sunflower-Field peas	Entz
16.	Lentils-Wheat-Fallow	Grier
17.	Wheat-Flax-Fallow	Grier
18.	Wheat-Barley-Fallow	Grier
19.	Canola-Wheat-Wheat-Fallow	Johnston
20.	Canola-Wheat-Wheat-Barley	Johnston
21.	Canola-Barley-Flax-Wheat	Johnston
22.	Continuous Canola	Coy
23.	Canola-Wheat-Barley-Fallow	Coy
24.	Canola-Barley-Barley-Wheat	Jensen

[a]See Table 2 for list of experts.

Table 5. Percent of total crop acres comprised by each crop rotation for the Alberta CRAM regions

Rotation	CRAM Regions for Alberta						
	1	2	3	4	5	6	7
1. Continuous Barley		15	30	10	15	20	5
2. Barley-Barley-Hay-Hay-Hay				8	15	60	5
3. Canola-Wheat-Barley							30
4. Canola-Wheat-Fallow							5
5. Continuous Wheat	15	15	20	20	6	2	4
6. Wheat-Wheat-Fallow				15	4		
7. Wheat-Fallow	60	45	10	5			
8. Wheat-Wheat-Lentils	3	2		4			
9. Barley-Barley-Field Peas				8	10	5	2
10. Wheat-Wheat-Flax	3	3	2	3	2		
11. Wheat-Wheat-Fall Rye			2		2		
12. Wheat-Wheat-Sunflower							
13. Wheat-Canola-Wheat-Field Peas				5	10	2	
14. Wheat-Sunflower-Barley-Lentils							
15. Wheat-Sunflower-Field Peas							
16. Lentils-Wheat-Fallow							
17. Wheat-Flax-Fallow							3
18. Wheat-Barley-Fallow	10	10	20	2			5
19. Canola-Wheat-Wheat-Fallow							4
20. Canola-Wheat-Wheat-Barley	5			10			
21. Canola-Barley-Flax-Wheat							10
22. Continuous Canola							18
23. Canola-Wheat-Barley-Fallow	4			10	3	5	10
24. Canola-Barley-Barley-Wheat		10	16		20		

Table 6. Percent of total crop acres comprised by each crop rotation for the Saskatchewan CRAM regions

Rotation	CRAM Regions for Saskatchewan								
	1	2	3	4	5	6	7	8	9
1. Continuous Barley									10
2. Barley-Barley-Hay-Hay-Hay					5		5	20	15
3. Canola-Wheat-Barley	10				5		5	10	10
4. Canola-Wheat-Fallow	10	5			5	20	30	5	10
5. Continuous Wheat	5								5
6. Wheat-Wheat-Fallow	40	25	15	15		25	10		5
7. Wheat-Fallow	20	60	70	70	15	30	10		
8. Wheat-Wheat-Lentils									5
9. Barley-Barley-Field Peas							5	5	10
10. Wheat-Wheat-Flax									5
11. Wheat-Wheat-Fall Rye						5	5		5
12. Wheat-Wheat-Sunflower									
13. Wheat-Canola-Wheat-Field Peas	10				10	5	10	5	20
14. Wheat-Sunflower-Barley-Lentils									
15. Wheat-Sunflower-Field Peas									
16. Lentils-Wheat-Fallow	5	5	5	5					
17. Wheat-Flax-Fallow			5	5		5			
18. Wheat-Barley-Fallow		5	5	5		5	10		
19. Canola-Wheat-Wheat-Fallow					40			20	
20. Canola-Wheat-Wheat-Barley					15			25	
21. Canola-Barley-Flax-Wheat					5			10	
22. Continuous Canola									
23. Canola-Wheat-Barley-Fallow									
24. Canola-Barley-Barley-Wheat									

Table 7. Percent of total crop acres comprised by each crop rotation for the Manitoba CRAM regions

Rotation	CRAM Regions for Manitoba					
	1	2	3	4	5	6
1. Continuous Barley	10	10	5		10	10
2. Barley-Barley-Hay-Hay-Hay	10	15	20	5	35	40
3. Canola-Wheat-Barley	25	35	20	10	30	20
4. Canola-Wheat-Fallow						
5. Continuous Wheat	10	5			5	
6. Wheat-Wheat-Fallow	5					
7. Wheat-Fallow		2				
8. Wheat-Wheat-Lentils			10	5		3
9. Barley-Barley-Field Peas	5	5				4
10. Wheat-Wheat-Flax				5		3
11. Wheat-Wheat-Fall Rye			2	2		
12. Wheat-Wheat-Sunflower			2	5		
13. Wheat-Canola-Field Peas	20	25	25	40	20	20
14. Wheat-Sunflower-Lentils	5		3	5		
15. Wheat-Sunflower-Field Peas			3	10		
16. Lentils-Wheat-Fallow				5		
17. Wheat-Flax-Fallow						
18. Wheat-Barley-Fallow	2	5				
19. Canola-Wheat-Wheat-Fallow						
20. Canola-Wheat-Wheat-Barley						
21. Canola-Barley-Flax-Wheat						
22. Continuous Canola						
23. Canola-Wheat-Barley-Fallow						
24. Canola-Barley-Barley-Wheat						

census data for wheat, barley, and canola. This was particularly true for the estimates received from McKenzie (1993) for Alberta CRAM regions 1,2 and 3, which were expressed in the form of "continuous grain" rather than continuous wheat, "grain-grain-fallow" as opposed to wheat-wheat-fallow, and so forth.

B. Temporal and Spatial Weighting of Crop Sequences for the Metamodels

The crops chosen by RS-CRAM had to be linked directly to specific crops within the 24 rotations in order to interface the RS-CRAM crop distributions with the environmental metamodels. This was accomplished by a process of temporal and spatial weighting. Also, a distinction had to be made between those crops that follow stubble and those that follow fallow to be consistent with the methodology used in RS-CRAM. Table 8 lists whether the crops included in the rotations simulated in EPIC follow either stubble or fallow in at least one rotation. While all nine crops follow stubble at least once, only three of the crops follow fallow. This assumption was made because the other six crops do not normally follow fallow in cropping systems used in the Prairies.

Two additional points must be made regarding fall rye, sunflower and alfalfa before continuing the weighting discussion. Fall rye and sunflower were not simulated in RS-CRAM due to lack of cost data. (Sunflower was only simulated in EPIC for Manitoba, because no significant acreages exist in Alberta and Saskatchewan.) Thus it is not currently possible to link RS-CRAM output to the fall rye and sunflower erosion metamodels. However, the metamodels for these two crops can still be used independently to estimate erosion impacts.

Table 8. Possible cropping sequences that can be simulated based on the rotations simulated in EPIC[a]

Crop	Follow stubble?	Follow fallow?
Alfalfa[b]	yes	no
Barley	yes	no
Canola	yes	yes
Fall Rye	yes	no
Field Pea	yes	no
Flax	yes	no
Lentil	yes	yes
Spring Wheat	yes	yes
Sunflower[c]	yes	no

[a] See Tables 5-7 for rotations that were simulated in EPIC.

[b]Alfalfa is intended to represent all land in hay. Under the current structure of RS-CRAM, hayland is estimated in response to livestock production. Thus, little or no shifts will occur in hayland acreages, resulting in little impact in changes in erosion that can be estimated with the alfalfa metamodels.

[c]Sunflower metamodels were constructed for three CRAM regions in Manitoba. Sunflower are not currently simulated in RS-CRAM due to the lack of cost data. Thus, no links are currently possible with the sunflower erosion metamodels.

Alfalfa, on the other hand, was intended to represent all hayland in all three provinces. Under the current structure of RS-CRAM, hayland is estimated in response to livestock production. Because of this structure, little or no shift in hayland acreage will occur between CRAM regions in response to policy shocks from "crop-based" policies such as GRIP. Thus, estimates of erosion with the alfalfa metamodels for most policies will be of limited value because no reflection of acreage changes can be simulated at this time. However, the alfalfa metamodels can also be used independently for estimating erosion impacts.

To demonstrate the weighting procedure, an example for spring wheat is shown for CRAM production region 3 in Saskatchewan. The first step is to develop temporal weights that are used in the development of the metamodels prior to any actual linkages to RS-CRAM. Table 9 shows the temporal weights that are assigned to the different "wheat years" for the five rotations listed for region 3 in Table 6. The first step in calculating the temporal weights is to determine what fraction that wheat follows stubble (stubble fraction) and fallow (fallow fraction). These fractions are then summed up for both columns, resulting in totals of 0.66 and 1.49 for the stubble and fallow fractions. The weights are then computed for each wheat fraction by dividing the fraction by either the sum of the stubble fractions or the sum of the fallow fractions (e.g., the weight for the wheat stubble fraction in rotation 6 is 0.33/0.66 or 0.5).

Assuming in this example that water erosion is the indicator of interest, the temporal weights are applied to calculate the average water erosion for spring wheat following stubble and fallow for CRAM region 3 in Saskatchewan as follows

$$E_{wheat/stubble,\ weather,\ soil} = \frac{(0.5 * E_{rot6}) + (0.5 * E_{rot16})}{0.5 + 0.5} \tag{3}$$

$$E_{Wheat/fallow,\ weather,\ soil} = \frac{(0.22 * E_{rot6}) + (0.33 * E_{rot7}) + (0.22 * E_{rot17}) + (0.22 * E_{rot18})}{0.22 + 0.33 + 0.22 + 0.22} \tag{4}$$

where E is water erosion, rot is rotation, weather is the weather station, and soil is the unique soil on which the rotations were simulated. These weighted values of erosion are then used to construct the metamodels required for the actual policy analyses. The same procedure is followed for other crops and environmental indicators.

Table 9. Example of temporal weights for spring wheat for Saskatchewan CRAM region 3 rotations

Rotation number[a]	Crop 1	Crop 2	Crop 3	Stubble[b] fraction	Fallow[b] fraction	Stubble[c] weight	Fallow[c] weight
6	Wheat[d]	Wheat	Fallow	0.33	0.33	0.50	0.22
7	Wheat	Fallow	-	-	0.50	-	
16	Lentils	Wheat	Fallow	0.33	-	0.50	0.36
17	Wheat	Flax	Fallow	-	0.33	-	0.22
18	Wheat	Barley	Fallow	-	0.33	0	0.22
Totals				0.66	1.49	1.00	1.00

[a]See Table 2 for complete matrix of rotations by CRAM regions in Saskatchewan.

[b]The stubble and fallow fractions are the percentage of the overall crop years that spring wheat follows stubble or fallow within each rotation (e.g., wheat follows stubble 1 out of 3 years in rotation 6 or 0.33 percent of the time).

[c]The weights for each rotation are calculated as the fraction divided by the sum of the fractions (e.g., the stubble weight for rotation 6 is 0.33/0.66 or 0.5).

[d]Wheat that follows fallow is underlined.

To complete the metamodels, the spatial weights shown in Tables 5-7 are then multiplied across the relevant quantities in the preceding equations. For example, the final weighting of the water erosion metamodel estimates for wheat on stubble would take the final form of

$$E_{Wheat/stubble,\ weather,\ soil} = \frac{(0.5 * E_{rot6}) * 0.15 + (0.5 * E_{rot16}) * 0.05}{(0.5 * 0.5) + (0.5 * 0.05)} \qquad (5)$$

where the values of 0.15 and 0.05 that are multiplied against the previous quantities represent the spatial extent of rotations 6 and 16 as given in Table 6. This spatial weighting is held static across all crop distributions that are estimated by RS-CRAM in response to different policy scenarios.

The same weighting procedure was used to the aggregate crop yield data to the CRAM region level. The crop yields were used directly in RS-CRAM rather than building metamodels for them. An obvious feature of Tables 5-7 is that only a subset of the possible 24 rotations was simulated in each CRAM region. As a result, yields were not generated for all crops in each region. Because of this, aggregated wheat, canola, and flax yield data were extrapolated to neighboring CRAM regions to fill-in missing crop activities in RS-CRAM. These extrapolations were performed to accommodate accounting procedures and fill-in important data gaps in RS-CRAM. Many of these crop and crop sequences for which yields were extrapolated to will not be important in policy analyses. However, some of the extrapolated yields were for crop and crop sequences were shown by census data to be more important in some regions than was indicated by expert opinion (MacGregor 1994). Further discussion of the use of the EPIC yields in RS-CRAM is described in section IV.B.

The metamodels are very flexible in estimating erosion for crops that were not included for a specific region in the EPIC simulations, because they provide the ability to interpolate between rotations and regions, as well as between management, soil, and climatic inputs. For example, flax yields were extrapolated to Saskatchewan CRAM regions 1 and 2 from regions 3 and 5, respectively, that border the regions 1 and 2. Erosion estimates can easily be made with the metamodels for flax in these regions, if flax is indicated by RS-CRAM to be grown in these regions for a specific policy scenario.

C. The Tillage Interface

The management systems used in EPIC to describe different levels of tillage for each crop are listed in Table 10. These systems were constructed to represent typical systems that are used in the Prairie Provinces. Under the current assumptions, the same tillage level is always simulated across all crops and fallow periods within a given rotation. For example, no-till on fallow (chemical fallow) cannot be simulated within a wheat-fallow rotation in which conventional or reduced tillage is assumed for the wheat years. No attempt was made to capture any regional differences in management systems that occur within the three provinces. To further simplify the simulations, standard dates were assumed for each operation that do not reflect year-to-year variability due to weather and other regional climatic influences.

Seeding operations are represented by a drill planter in all of the systems given in Table 10, except for a simulated row planter in the sunflower systems. Nitrogen and phosphorous application rates (Table 11) are based on recommended best practices. The nitrogen application rates were reduced by 60 percent for crops following fallow or legume crops. The inclusion of herbicides in the management systems have no effect on crop yields predicted by EPIC because herbicide efficacy is not simulated. EPIC simulates transport and decay of applied herbicides, but these processes are not considered in this study. The replacement of tillage passes with herbicide applications for the reduced and no-till management systems shown in Table 10, however, directly impacts the amount of erosion predicted by EPIC.

Nearly all conventional tillage systems listed in Table 10 include at least one fall tillage operation as well as spring tillage operations. The reduced systems have spring tillage

Table 10. Management system operations selected for the EPIC simulations by crop and tillage level[a]

Crop	Date[b]	Tillage: Conventional	Reduced	No till
Alfalfa[c] (year 1)	September 10	Tandem disk[d]		
	April 25	Field cultivator		
	May 5	Field cultivator		
	May 7	Spike harrow[d]		
	May 10	P fertilizer		
	May 10	Seeding[e]		
	August 10	Swather (cutting)		
Alfalfa (Year 2)	June 20	Swather (cutting)		
	August 20	Swather (cutting)		
Alfalfa (Year 3)	June 20	Swather (cutting)		
	August 20	Swather (cutting)		
	August 30	Tandem disk		
Barley	October 10	Field cultivator		
	October 15	Anhydrous fertilizer		
	April 22	Field cultivator	Field cultivator	
	May 5	Spike harrow	Spike harrow	Roundup[f]
	May 10	P fertilizer	N & P fertilizer	N & P fertilizer
	May 10	Seeding	Seeding	Seeding
Canola	October 15	Field cultivator		
	October 17	Treflan[f]		
	April 25	Field cultivator	Field cultivator	
	May 5	Spike harrow	Spike harrow	Roundup
	May 10	N & P fertilizer	N & P fertilizer	N & P fertilizer
	May 10	Seeding	Seeding	Seeding
	August 30	Harvest	Harvest	Harvest

Table 10 (continued)

Crop	Date	Tillage		
		Conventional	Reduced	No till
Fallow	September 15	Field cultivator	Wide (Nobel) blade	Roundup & 2,4-D[f]
	May 15	Field cultivator	Wide (Nobel) blade	Roundup & 2,4-D[f]
	July 5	Field cultivator	Wide (Nobel) blade	Roundup[f]
	August 5	Field cultivator	Wide (Nobel) blade	Roundup[f]
Fall rye	September 15	Field cultivator		
	September 25	Spike harrow		
	September 30	N & P fertilizer		N & P fertilizer
	September 30	Seeding		Seeding
	August 10	Harvest		Harvest
Field Peas	September 10	Tandem disk		
	October 10	Field cultivator		
	April 25	Field cultivator		
	April 30	Spike harrow	Spike harrow	Roundup[f]
	May 15	P fertilizer	P fertilizer	P fertilizer
	May 15	Seeding	Seeding	Seeding
	June 1	Basagran[f]	Basagran[f]	Basagran[f]
	August 20	Harvest	Harvest	Harvest
Flax	October 15	Field cultivator		
	April 25	Field cultivator	Field cultivator	
	April 30	Spike harrow	Spike harrow	Roundup[f]
	May 10	N & P fertilizer	N & P fertilizer	N & P fertilizer
	May 10	Seeding	Seeding	Seeding
	August 30	Harvest	Harvest	Harvest

Table 10 (continued)

		Tillage		
Crop	Date	Conventional	Reduced	No till
Lentils	April 25	Field cultivator	Field cultivator	
	April 30	Spike harrow	Spike harrow	Roundup[f]
	May 10	P fertilizer	P fertilizer	P fertilizer
	June 1	Basagran[f]	Basagran[f]	Basagran[f]
	August 30	Harvest	Harvest	Harvest
Spring Wheat	October 15	Field cultivator		
	October 15	Avadex[f]		
	April 27	Field cultivator	Field cultivator	
	April 29	Spike harrow	Avadex[f]	Roundup[f]
	May 5	N & P fertilizer	N & P fertilizer	N & P fertilizer
	May 5	Seeding	Seeding	Seeding
	June 7	2,4-D	2,4-D	2,4-D
	August 30	Harvest	Harvest	Harvest
Sunflower	October 15	Tandem disk		
	April 25	Field cultivator	Field cultivator	
	May 5	Spike Harrow	Spike harrow	Roundup[f]
	May 10	N & P fertilizer	N & P fertilizer	N & P fertilizer
	May 10	Seeding	Seeding	Seeding
	August 30	Harvest	Harvest	Harvest

[a]It is assumed that these systems are representative of the crop-tillage level combinations across all three provinces; no attempt was made to capture variation in management systems between regions.

[b]Typical dates assumed for each implement pass; year-to-year variation due to weather, and regional variations, were not simulated.

[c]Commonly used tillage systems for alfalfa and fall rye are more limited than those used for the other crops.

[d]Tandem disk represents all disking in these systems while a spike harrow represents a harrow-pack (EPIC does not provide a harrow-pack option).

[e]A drill planter was assumed for all crops except sunflowers, for which a row planter was simulated.

[f]The herbicides Roundup, Treflan, 2,4-D, Basagran, and Avadex were included in the management inputs to EPIC. However, there is no simulation of herbicide efficacy in EPIC (i.e., crop growth and yield output are unaffected by herbicide inputs). Only chemical movement can be simulated for the herbicide which was not performed for this study.

Table 11. Fertilizer application rates assumed for the EPIC simulations[a]

Crop	Nitrogen application rate (kg/ha)[b]	Phosphorous application rate (kg/ha)
Alfalfa[c]	0	20
Barley	70	10
Canola	70	10
Fall rye	40	10
Field pea[c]	0	10
Flax	40	10
Lentil[c]	0	10
Spring wheat	60	10
Sunflower[d]	80	10

[a]Application rates based on recommended best management practices.

[b]Nitrogen application rates greater than 0 were reduced by 60 percent whenever a crop followed a fallow period or a legume crop.

[c]Alfalfa, field pea, and lentil are legumes and do not require nitrogen fertilizer.

[d]Sunflower application rate based on expert opinion of Shaykewich (1993).

operations but no fall tillage operations. The only disturbance of residue in no-till operations occurred at planting. Second and third year alfalfa and the fall rye conventional system are exceptions to these criteria. These conventions are similar to systems described by Lafond et al. (1993), where conventional systems included both fall and spring tillage, reduced tillage was limited to a spring tillage operation, and disturbance of residue occurred only during a planter pass for no-till.

The tillage link with RS-CRAM is based on the amount of crop residue left on the soil surface after all tillage and seeding passes have been completed, beginning in the fall after harvest. The tillage systems are defined in terms of residue coverage as: (1) less than 30 percent for conventional, (2) between 30 and 70 percent for reduced, and (3) greater than 70 percent for no-till. The management systems configured for EPIC (Table 10) conform to these categories in most cases, based on the mixing efficiencies given in Table 12. The exceptions again are second and third year alfalfa and the conventional system for fall rye. Categorization

Table 12. Mixing efficiencies of the different implements simulated in EPIC[a]

Implement	Percentage assumed mixed by each pass
Drill planter	25.0
Field cultivator	30.0
Row planter	5.0
Spike harrow	20.0
Tandem disk	50.0
Wide (Nobel) blade	10.0

[a]No residue is assumed mixed for swathing, harvest, and fertilizer operations limited to a spring tillage operation, and disturbance of residue in no-till occurred only during a planter pass.

of management systems by residue levels for RS-CRAM was performed by Shoney (1993) for tillage systems included in a set of production data available for Saskatchewan. The same technique is used for available cost data for Alberta and Manitoba to provide a consistent interface with the environmental metamodels.

C.1. Tillage Distribution by CRAM Region

An additional step required in interfacing tillage systems between RS-CRAM and the environmental component is the calibration of crop acreage by tillage level for each CRAM production region, to account for the differential impact of tillage. Tillage distribution data for the Prairie Provinces is currently available from two sources: (1) a survey conducted for Agriculture Canada (EMA 1993) that was performed as part of an overall macro level environmental assessment of GRIP and (2) 1991 Statistics Canada census data. Table 13 shows a comparison of the distribution of the three tillage categories by province between the EMA survey data and the census data. Obvious differences exist between the two data sources, with the census data indicating higher levels of conventional tillage being practiced in all three

Table 13. Comparison of tillage system proportions by province between the EMA survey data and the 1991 census data[a]

Province	Conventional		Reduced		No-till	
	EMA	Census	EMA	Census	EMA	Census
Alberta	56.2	72.9	36.8	24.0	7.0	3.1
Saskatchewan	51.7	63.9	36.2	25.7	12.1	10.4
Manitoba	61.9	66.8	33.9	28.2	4.2	5.0

[a]EMA tillage distribution estimates from EMA (1993); census estimates from Statistics Canada (1993).

provinces. The reason for this discrepancy may lie in that the samples were drawn from two different populations; i.e., while the EMA survey data were based only on GRIP participants the census data were obtained from the total population of producers.

Regardless of the reason for this discrepancy, a decision was made to use the tillage distribution data from the 1991 census data as recommended by Dumanski (1993), because these will become benchmark data for future studies performed by Agriculture Canada. The tillage distribution data were then disaggregated to the production region level (Table 14) by Gameda (1993) to calibrate RS-CRAM. The tillage distribution data show that the highest levels of no-till occur in Saskatchewan, with no-till being performed on over 10 percent of the cropland in five of the nine production regions. Correspondingly, the lowest levels of conventional tillage were also performed in Saskatchewan.

III. Experimental Design

On a regional scale an analysis using environmental process models is still unmanageable because of extensive simulations required to cover all ranges of different soil, climate, hydrology, management, crop, and policy options. This extensive coverage is required to capture the heterogeneity of the physical environment as well as the agricultural production practices to provide for meaningful aggregation of site-specific assessments. Due to resource limitations, time, and money, such an extensive simulation plan is impracticable. Consequently,

Table 14. Proportion of tillage systems by prairie province and CRAM region based on 1991 census[a]

Province	CRAM Region	Conventional	Reduced	No-Till
Alberta	1	63.2	27.6	9.2
	2	62.8	31.9	5.3
	3	67.2	31.4	1.4
	4	73.2	25.1	1.7
	5	85.3	13.8	0.8
	6	83.4	15.7	1.0
	7	81.9	16.5	1.5
Saskatchewan[b]	1	65.3	28.2	6.5
	2	54.9	38.1	7.0
	3	58.8	28.3	12.8
	4	52.0	41.0	7.0
	5	73.1	21.1	15.8
	6	60.7	29.3	10.1
	7	51.2	41.8	7.0
	8	74.9	21.6	3.4
	9	73.0	24.7	2.3
Manitoba	1	63.1	31.5	5.4
	2	74.0	23.5	2.5
	3	67.4	26.9	5.7
	4	63.9	31.1	5.1
	5	69.3	24.9	5.8
	6	71.5	22.7	5.8

[a]From Gameda (1993). [b]No-Till in CRAM regions 2,4 and 7 of Saskatchewan limited to 7%, though survey numbers are higher, per AAFC. Excess no-till assigned to Reduced till.

a spatial-sampling design was used that considerably reduced the simulation runs, but retained the statistical validity of aggregation and extrapolation into the *population* (the word *population* is used to denote the aggregate from which the sample is chosen).

The results from sample simulation are, however, subject to some uncertainty because only part of the population has been simulated and because of errors of measurement. This uncertainty can be reduced by increasing the sample size, but this would increase the simulations time and costs. Thus, a tradeoff must be made between the degree of precision needed and the available resources. The fact that the sample simulation results will be used for analytical rather than descriptive evaluation is also recognized in choosing the sampling design. Therefore, the design is based on probability sampling so that the frequency distribution of the estimates can be observed, when the same populations is repeatedly sampled.

A. Soil Sampling

The main motivation for selecting a sample of soils, rather than the incorporating all soils into the analysis, was to increase the efficiency of the integrated modeling procedure. In other words, the sample selected satisfied statistical optimality criteria, and thus summarized all the information available in the full set of soils. The soil sampling procedure was performed with soil layer and landform data available from the environmental database described in Agriculture Canada (1993b). Soil layer data were available for each province at the ARA level. However, soil landform (soil slope and slope length) data were available only at the landscape polygon level, which are smaller regions than ARAs. The relative sizes of the ARAs and landscape polygons can be seen from Figures 5-7 and 8-10, which show the CRAM region boundaries overlayed on the ARAs and landscape polygons for each province individually (the shaded areas in Figures 5-7 show the ARAs that were dropped in the process of merging the data to produce the environmental database).

The total populations of ARA, landscape polygon, soil series, slope, and slope length combinations are 1,423 for Alberta, 1,081 for Saskatchewan, and 119 for Manitoba (Table 15). In some cases, the dominant and subdominant soil within a landscape polygon shared identical slope gradient and slope length characteristics. For the landscape polygons where this occurred, the subdominant soils that cover a smaller area of a given landscape polygon were restricted from further consideration in the sampling process. Thus, the actual populations of unique combinations that were sampled from were reduced to 957 for Alberta, 725 for Saskatchewan, and 96 for Manitoba. The sampling rate for Alberta and Saskatchewan was 10 percent. However, a 30 percent sampling rate was used for Manitoba because of its smaller population.

The soil layer data were checked for detection of obvious outliers. Validation of the data consisted mostly in comparing the values of the soil properties in the database with the typical ranges for each of those properties. The information available for each soil in the database

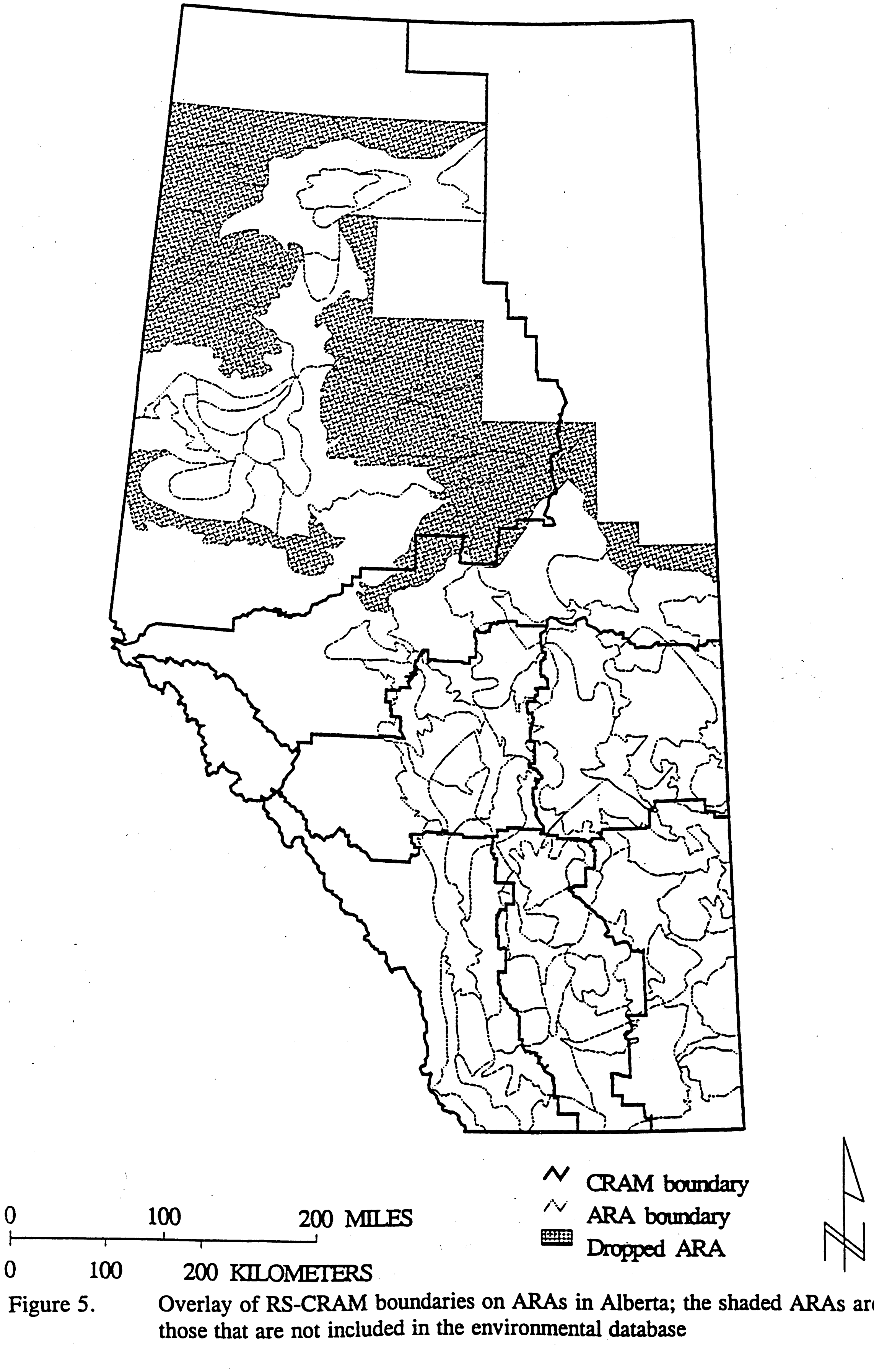

Figure 5. Overlay of RS-CRAM boundaries on ARAs in Alberta; the shaded ARAs are those that are not included in the environmental database

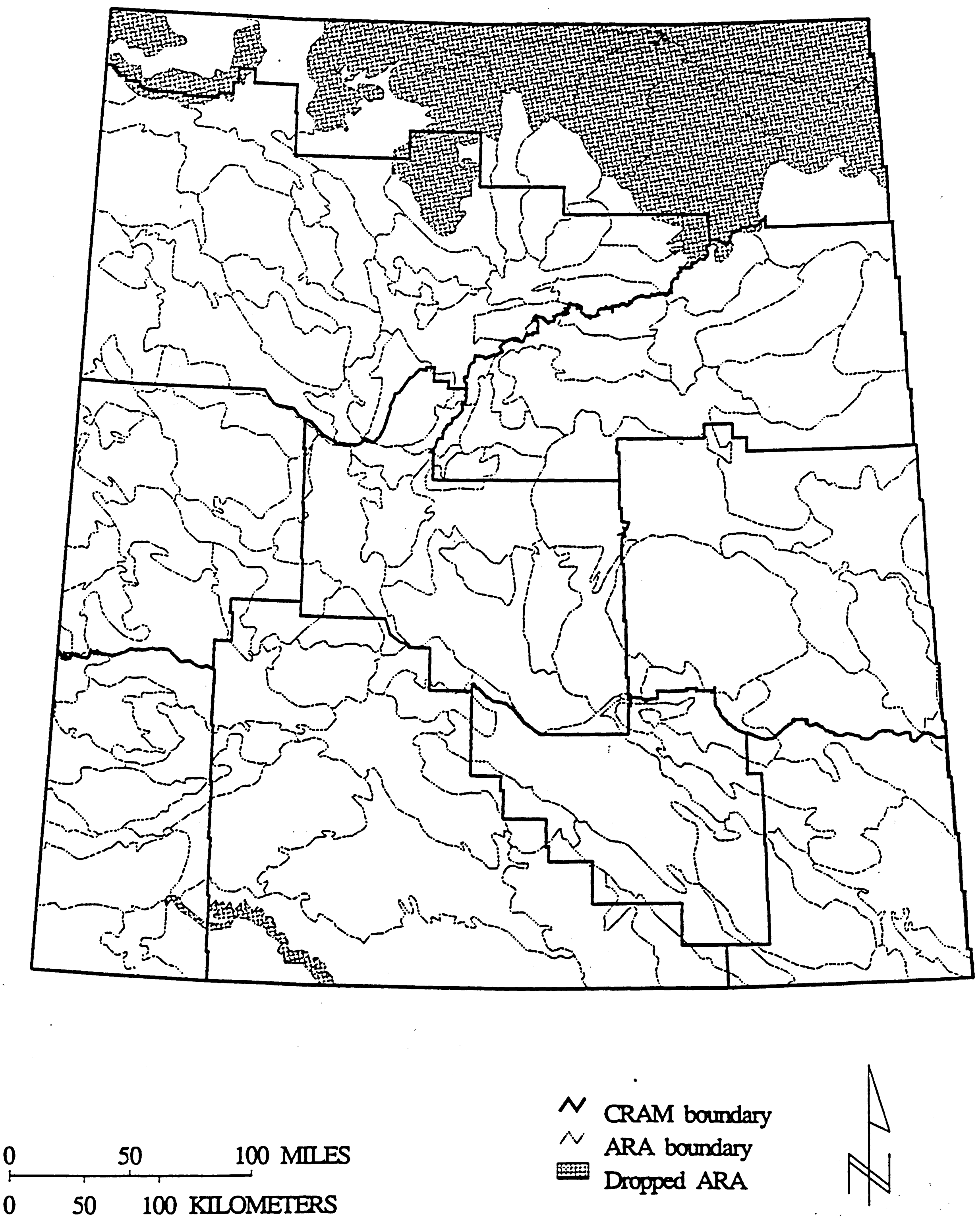

Figure 6. Overlay of RS-CRAM boundaries on ARAs in Saskatchewan; the shaded ARAs are those that are not included in the environmental database

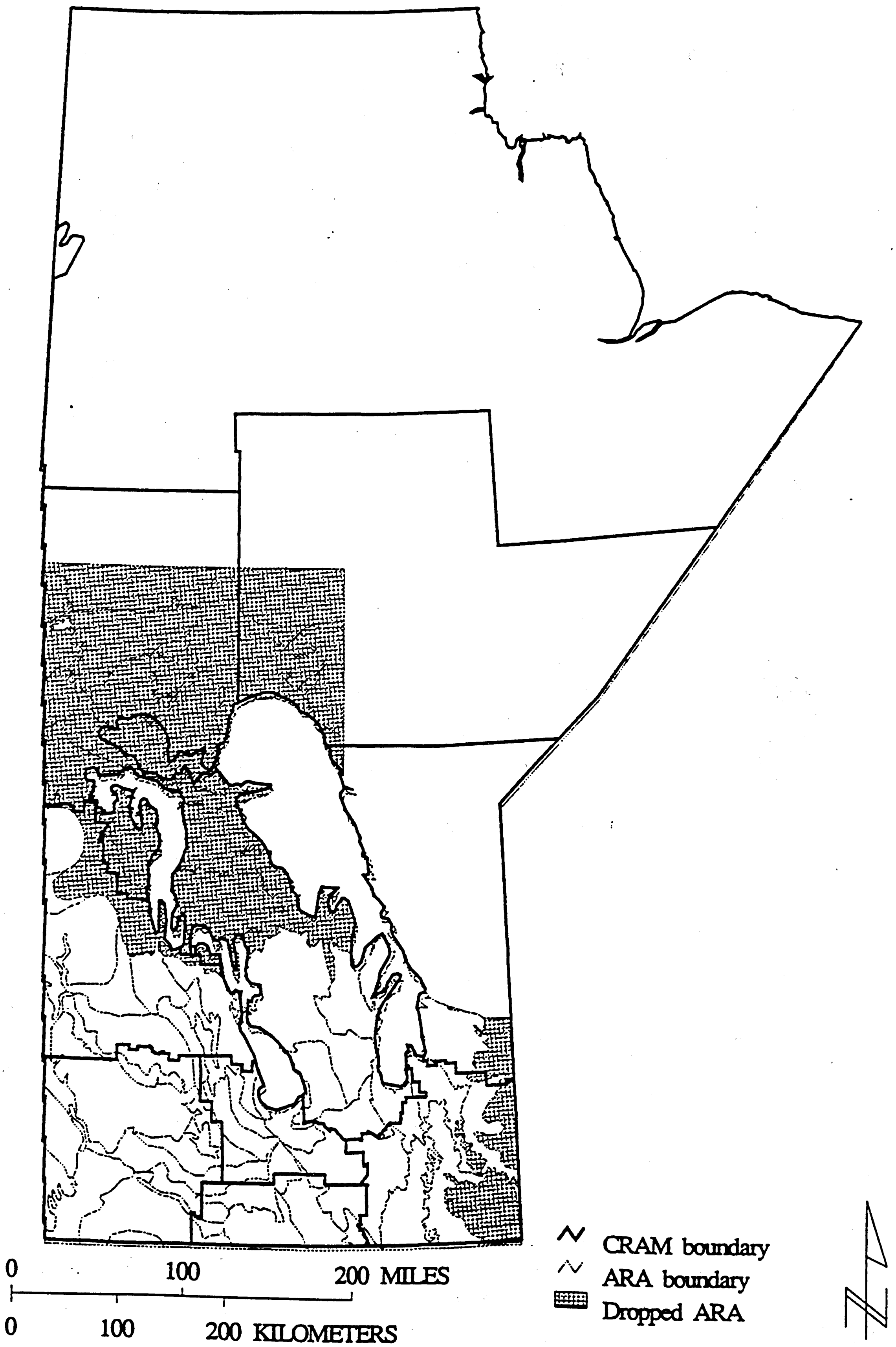

Figure 7. Overlay of RS-CRAM boundaries on ARAs in Manitoba; the shaded ARAs are those that are not included in the environmental database

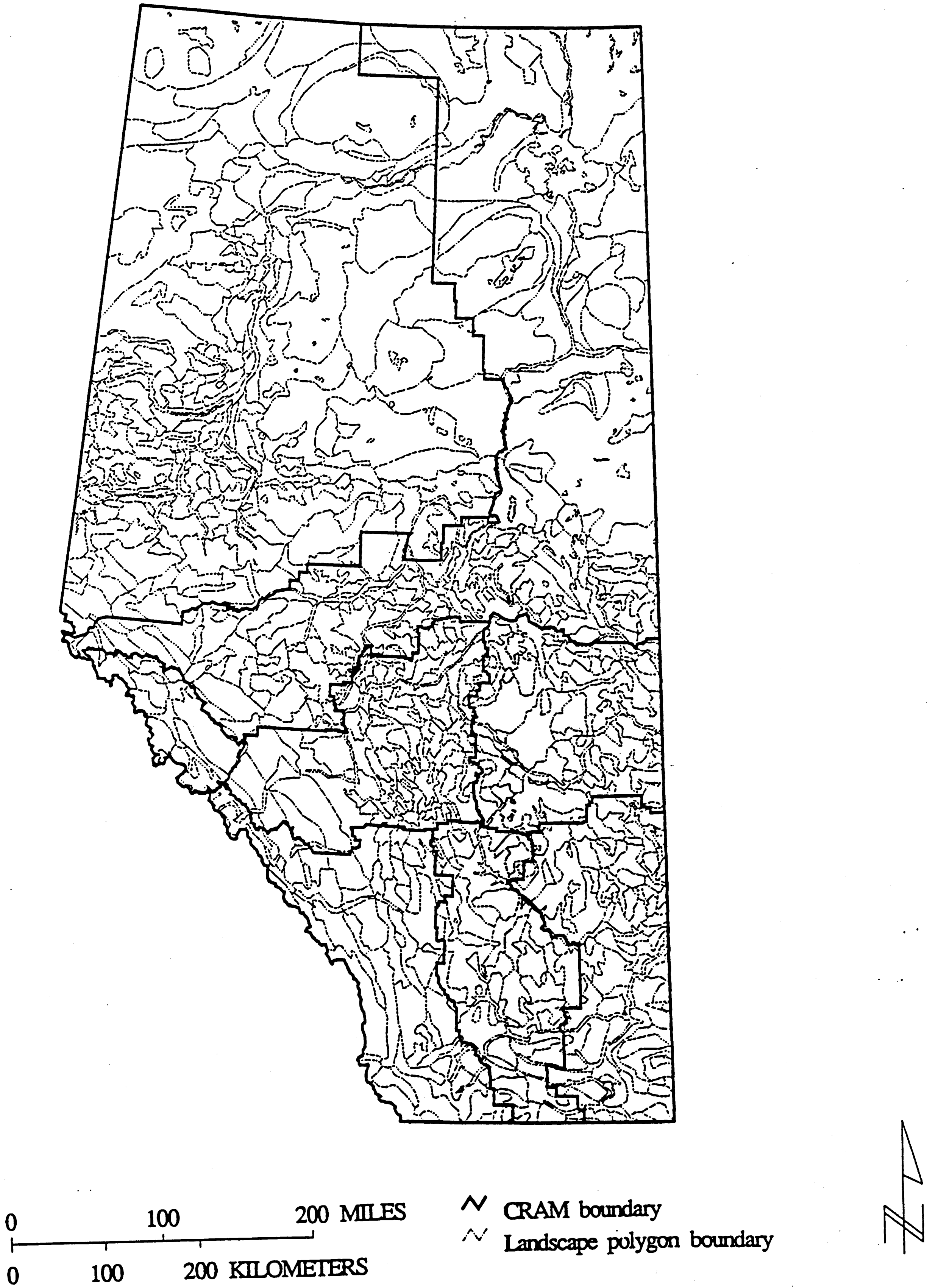

Figure 8. Overlay of RS-CRAM boundaries on landscape polygons in Alberta

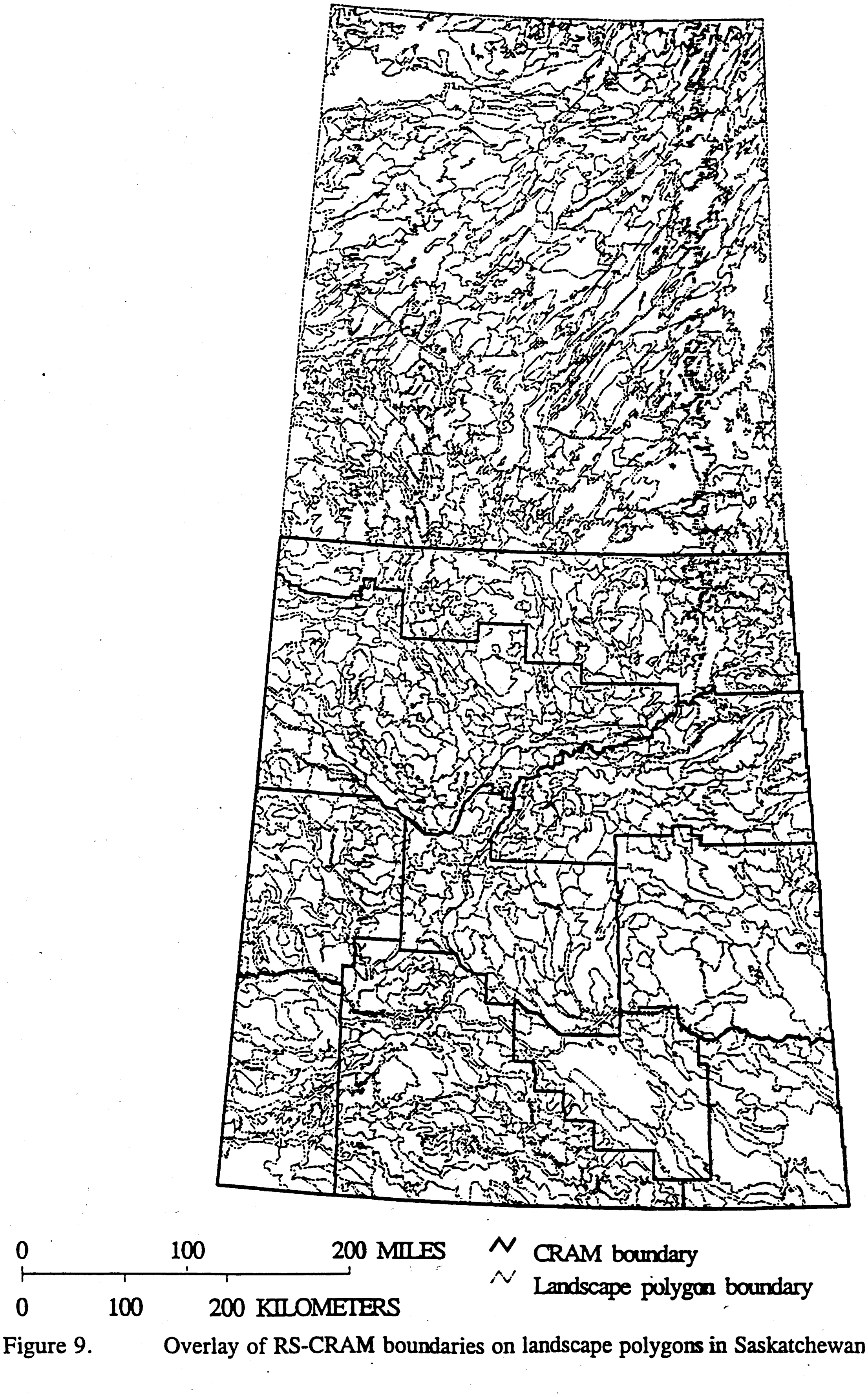

Figure 9. Overlay of RS-CRAM boundaries on landscape polygons in Saskatchewan

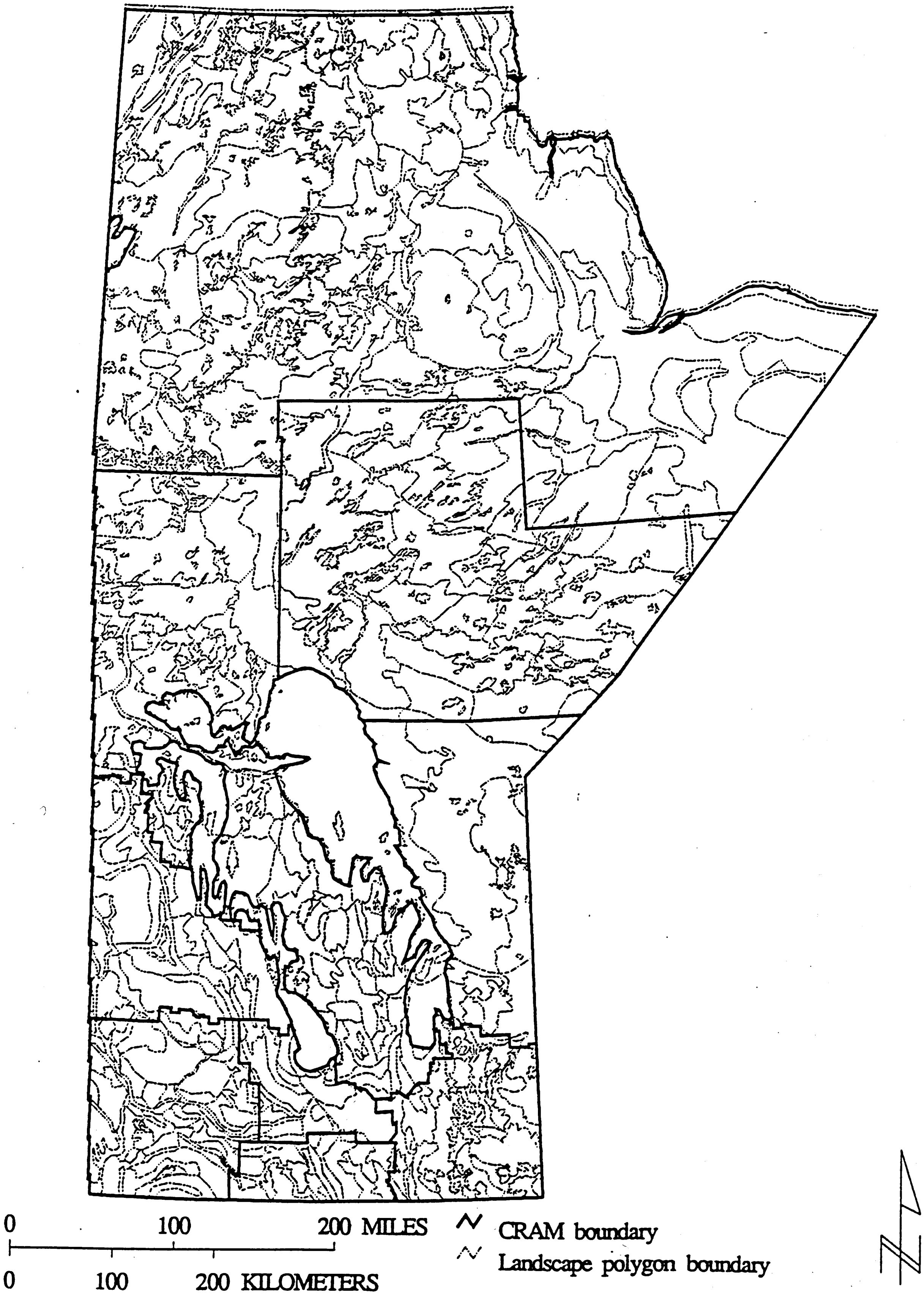

Figure 10. Overlay of RS-CRAM boundaries on landscape polygons in Manitoba

Table 15. Summary of ARA, landscape polygon, and soil code totals after merging the soil layer, landscape database, ARA area, and ARA-LP cross-match files[a]

Province	Total records[b]	Unique ARAs	Number of ARAs dropped[c]	Unique polygons	Total ARA - polygon combinations[d]	Number of polygon codes dropped[e]	Unique soil codes	Number of soil codes dropped[f]
Alberta	1,423	80	19	425	986	622	98	22
Manitoba	119	40	23	105	105	144	45	14
Saskatchewan	1,081	106	12	669	669	226	130	390

[a]A detailed of the merging process is given in Agriculture Canada (1993b).

[b]There are more records than landscape polygons because double accounting is made for those polygons that have both dominant and subdominant soils.

[c]The ARAs dropped were predominantly nonagricultural and are not relevant for this study.

[d]Because landscape polygons can exist in more than one ARA in Alberta, there is a total of 986 ARA-polygon combinations in the final data set instead of 425. These 986 polygons are in fact unique for the simulations preformed for this study, because of differing climate between ARAs.

[e]The landscape polygons dropped were either located in an excluded ARA or posessed a dominant and/or subdominant soil code(s) that did not have matching layer data in the soil layer files.

[f]Soil codes dropped exist in the soil layer files but do not exist as a dominant or subdominant soil in any of the landscape polygons.

included estimates of several soil attribute values for different layers, where the number of layers varied from a minimum of 3 to a maximum of 7 layers. The depth of each layer was variable as well. The soil sampling was performed for the attributes of the surficial layer of each soil because the focus of this current effort is on the surficial processes of wind and water erosion.

A straight forward sampling method is to use a simple random sampling, that is selecting n units out of the N such that every one of the ${}_{N}C_{n}$ distinct samples has an equal chance of being selected. This method was less precise[2] for this effort because the soil information is layered with properties of each profile varying both within and across the soil types. A typical soil is characterized by soil profiles; physical factors, such as clay, sand, silt, permeability, organic matter content, pH, and bulk density; erodibility factors, such as k-factor, slope, and slope length; hydrological factors, such as hydrologic groups A to D (classified based on the rate of infiltration, with soils in group A having the maximum infiltration and soils in group D having the minimum infiltration) and available water. EPIC requires, at a minimum, layered information on the following soil properties: percent sand, percent silt, percent organic matter, bulk density, and pH. Therefore, a stratified random sampling with a complete factorial design was used. If intelligently used, stratification nearly always results in a smaller variance for the estimated parameters compared to a simple random sample (Cochran 1977).

The next step was to limit the number of factors (soil properties) to be considered in the sample allocation to those considered to be the most important.[3] Simple correlation estimates between factors were used as a guide to restrict the set of factors used in determining the allocations. Important EPIC soil inputs were also used as a guide in limiting the soil factors to be considered for sample allocation. Five soil factors were identified: clay, sand, bulk density,

---

[2]The precision of any estimate made from a sample depends both on the method by which the estimate is calculated from the sample data and on the plan of sampling.

[3] Since the best allocation for one factor will not in general be best for another, some compromise must be reached in a sampling design with several factors.

organic matter, and cation exchange capacity (CEC). These factors were stratified into three levels (high, medium, and low) and four units were sampled from each of the 15 strata (3 levels and 5 factors) *without replacement*. This stratification, where the sampling fraction is the same in all strata, is described as stratification with proportional allocation. This stratification provides a *self-weighting* sample. Soil selection within each stratum was done in such a way that the probability of selection was proportional to the number of acres of arable land. A list of the soils included in each of the samples, together with the average values for each of eight attributes (clay, sand, organic matter, bulk density, cation exchange capacity (CEC), pH, and calcium carbonate), are given in Tables A.1-A.3. in Appendix A.

In summary, the resulting sample of soil types was *self-weighting* (soils in all levels of each property are represented at similar proportions), *balanced* (each cultivable acre in the watershed had equal probability of selection), and *representative* of the population of soils in each province. Figure 11-13 show the relative frequency distribution of percent clay, percent sand, percent organic matter, and CEC compared between the population and the sample for Alberta, Saskatchewan, and Manitoba, respectively. The mean, standard deviations, minimum, and maximum values of the soil properties of the six populations and samples are also shown in Tables A.4-A.6 in Appendix A. The summary statistics and the frequency distributions confirm uniform and representative allocation.

B. Meteorological Inputs to the Metamodels

The meteorological inputs used for the EPIC simulations were those available at the ARA level. Daily values of precipitation, maximum temperature, and minimum temperature were input from the aggregated "historical" weather records provided for each ARA from the environmental database as described in Agriculture Canada (1993b). All other weather inputs were based on 30-year climate normals that are also contained within the environmental database. Average ARA elevation values were also input to satisfy the requirements of the Penman-Monteith subroutine that was used to calculate evapotranspiration for the EPIC runs.

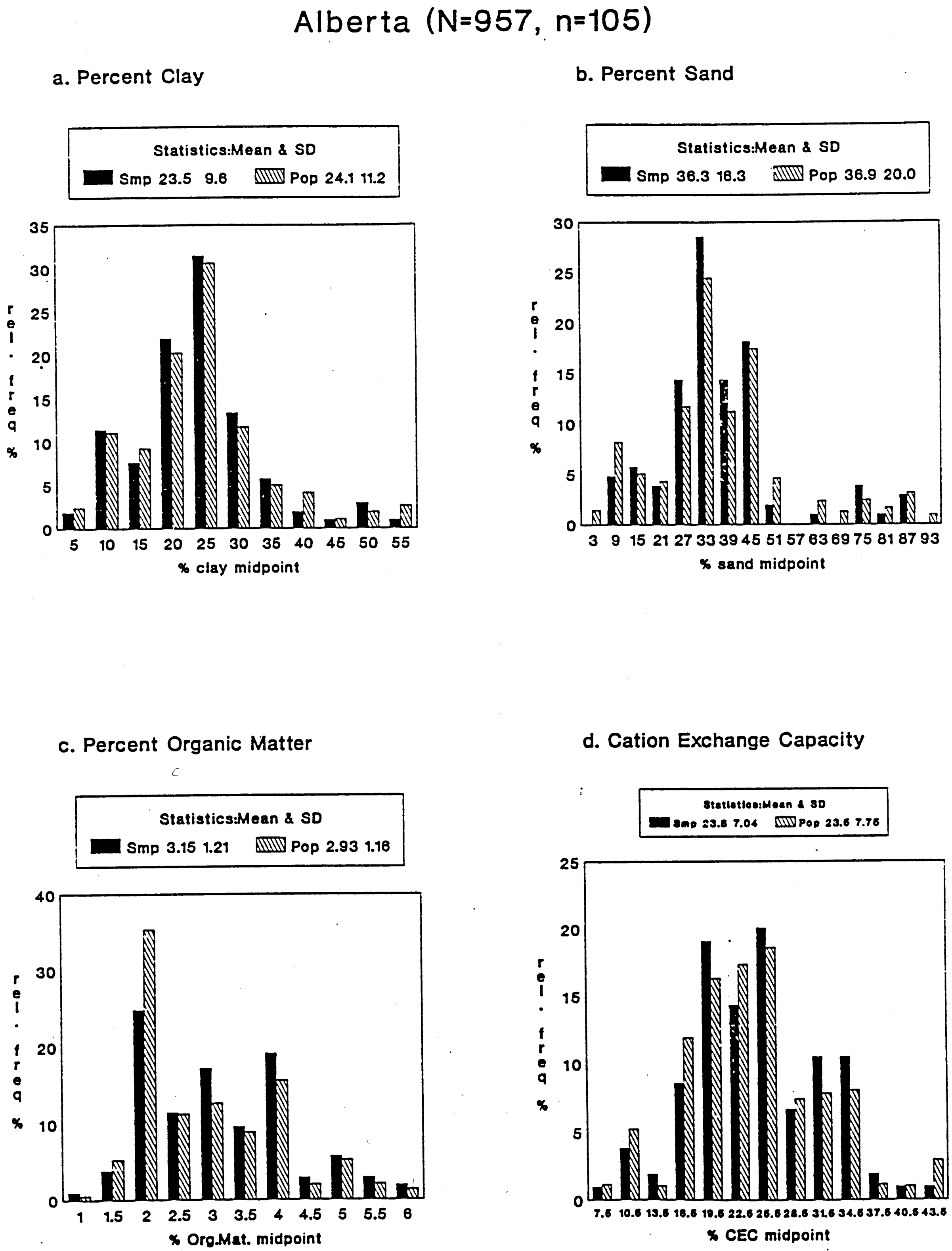

Figure 11. Comparison of means, standard deviations, and frequencies between the sampled soils and original population of soils in Alberta for: (a) percent clay, (b) percent sand, (c) percent organic matter, and (d) cation exchange capacity

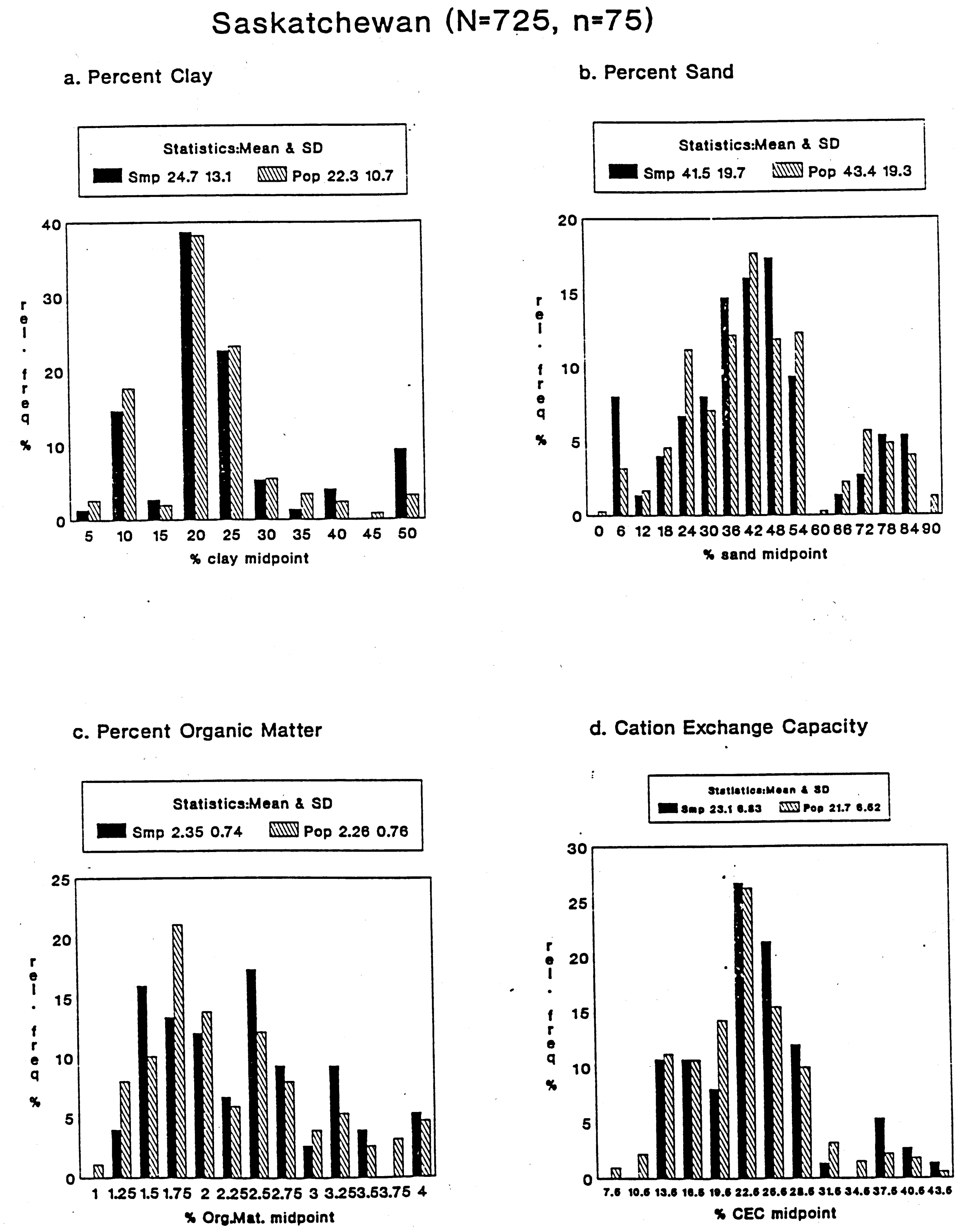

Figure 12. Comparison of means, standard deviations, and frequencies between the sampled soils and original population of soils in Saskatchewan for: (a) percent clay, (b) percent sand, (c) percent organic matter, and (d) cation exchange capacity

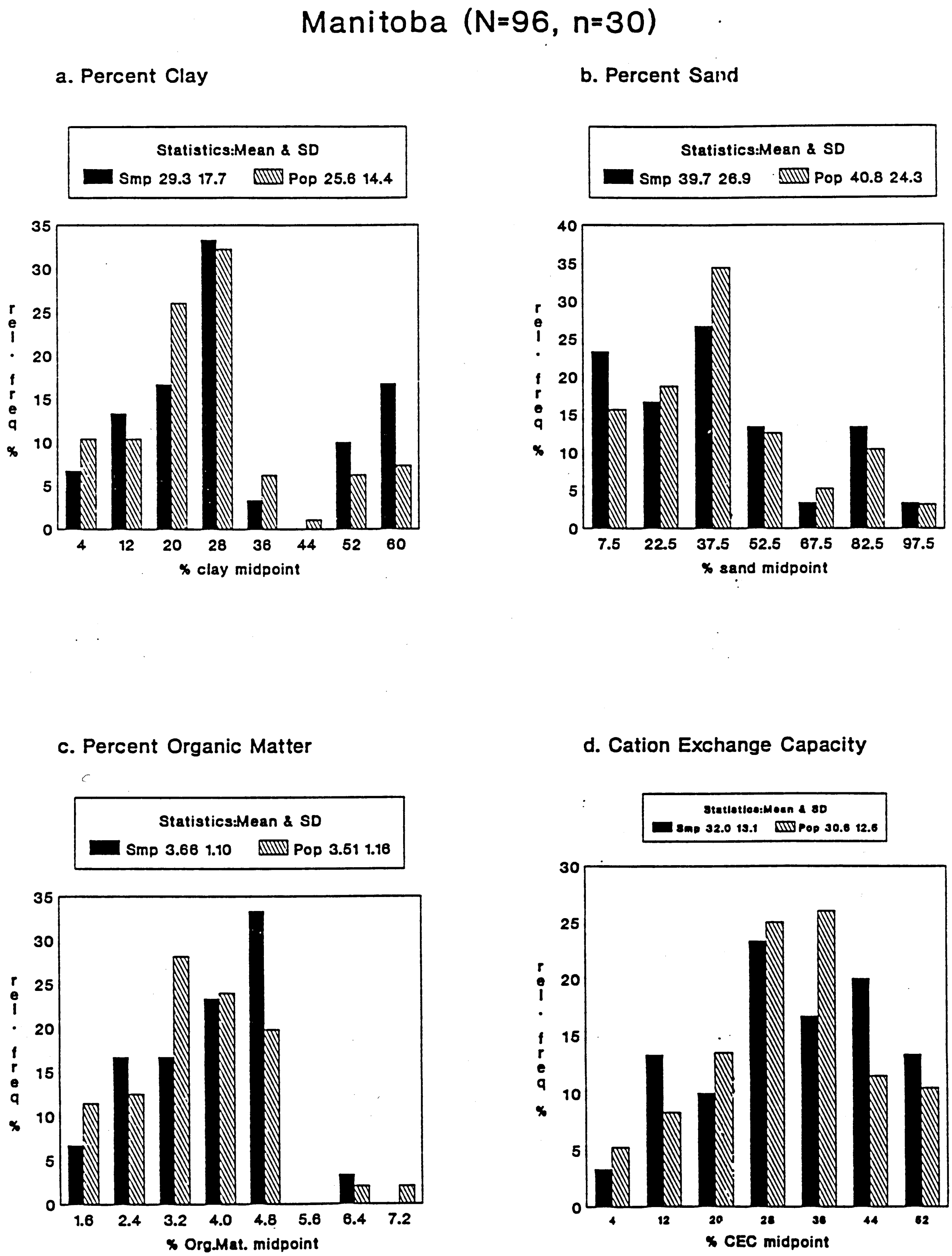

Figure 13. Comparison of means, standard deviations, and frequencies between the sampled soils and original population of soils in Manitoba: (a) percent clay, (b) percent sand, (c) percent organic matter, and (d) cation exchange capacity

Weather impacts on crop yields and the environmental indicators were factored into the metamodels in terms of location and average annual meteorological values. Additional temporal refinement (i.e., daily, weekly, or monthly values) of weather parameters was very difficult to incorporate into the metamodels. The location of the weather and wind stations for the metamodels was identified by the centroid latitude and/or longitude coordinates of each ARA. Further discussion of how these location and average meteorological values were used within the metamodels is provided in section V.

C. Simulation Plan

An automatic input file builder and control program written in C++© was developed to generate the input files, execute the EPIC simulations, and extract the pertinent output data from the standard EPIC output files, to facilitate the construction of the environmental metamodels. Figure 14 shows the different datasets that were linked together in Paradox© in order to build the input records that were required by the input file builder and control program. Sampled soils, hydrologic groups, ARA centroid coordinates (latitudes and longitudes), wind velocities and directions, average ARA elevations, and rotations were linked together in a consistent manner so that each piece of information could be referenced spatially by landscape polygon, ARA, CRAM region, and province.

As noted previously, the sampled soils are located spatially by landscape polygon and ARA. In the process of linking the sampled soils with the CRAM regions by ARA, several ARAs were encountered in each province that "linked" to more than one CRAM region (i.e., parts of these ARAs lie in two or three CRAM regions). For Saskatchewan and Manitoba, all ARA - CRAM region combinations were included in the final simulation. This resulted in a total of 9,750 and 4,455 simulations being performed for Saskatchewan and Manitoba, respectively. For Alberta, it was estimated that approximately 15,000 simulations would be required if every ARA-CRAM combination was accounted for. Thus, in situations where an ARA linked to more than one CRAM region in Alberta, only the combination with the largest area was included in the final

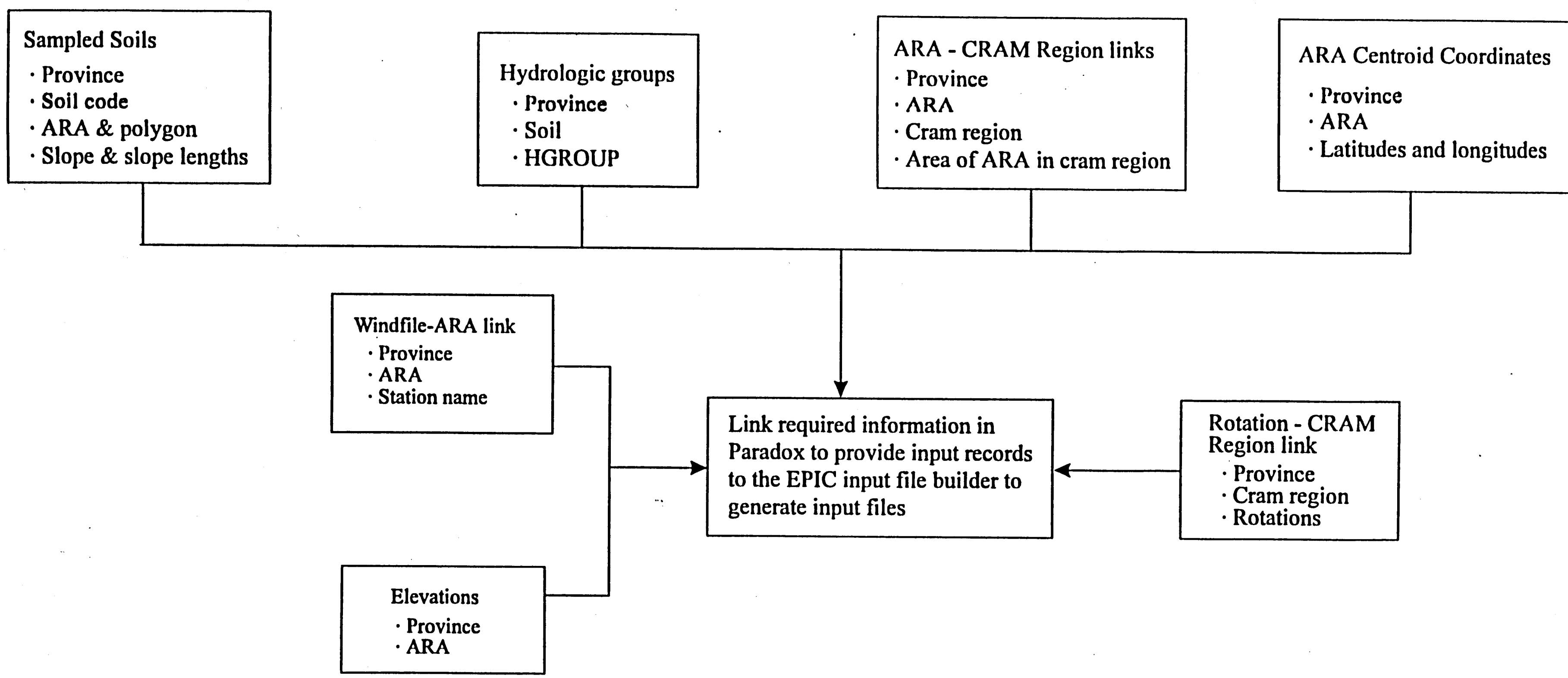

Figure 14. Information flow to construct input records that will be used to generate EPIC input files for the Prairie Provinces

simulation set in order to reduce the number of required runs. This resulted in a total of 7,734 EPIC simulations being performed for Alberta.

The EPIC simulations were performed with 31 years of weather data available for each ARA as described in Agriculture Canada (1993b). Both annual and summary information are extracted from the output data. The annual information is required so that crop specific environmental indicators can be linked directly to the RS-CRAM crop distributions in the manner described in section II.B. For the annual output, the first year is assumed to be an initialization year and was eliminated when condensing the output. The summary information provides estimates of average crop yields and environmental indicators that are rotation specific rather than crop specific. The summary data are based on all 31 years of the EPIC output.

Permutations of each crop rotation were run to obtain yield and erosion rate estimates for each crop and tillage level for all 30 years of annual weather data simulated. For example, rotation 3 in Tables 5-7 was run three times for each tillage level, soil, landscape polygon, ARA, and CRAM region combination that was included within the statistically designed EPIC simulation set. The permutations in this case would be canola-wheat-barley, barley-canola-wheat, and wheat-barley-canola. This allows for average yields, erosion rates, and nutrient loss rates to be calculated over the long-term 30-year period for each crop and tillage level. Yield distributions were also determined with this data over several years that were utilized in the risk component of RS-CRAM as described in section IV.B.1.

Average yields of each crop in the rotation are also obtained for each permutation of a rotation in the summary output. These average yields are essentially the same is the averages calculated from the 30 years of annual output, except that slight differences will occur because the first year is included in determining the average. However, yield distribution information can not be obtained from the summary output. Erosion and other environmental indicators in the summary output are rotation specific rather than crop specific. These outputs, most useful as ancillary information to the actual policy scenarios, relate the impacts of rotations rather than specific crops on erosion and other environmental indicators.

D. Further Calibration of EPIC

Further calibration of the EPIC model, beyond that reported in Agriculture Canada (1993b), was performed prior to executing the final simulations to construct the environmental metamodels. The testing focused primarily on the wind erosion component of the model and the crop yield estimates. One result of these efforts was some code changes to correct a problem in how EPIC was simulating the breakdown of crop residue. This was a departure from the previously stated plan in section IV of Agriculture Canada (1993b) that "no modifications are being made to the structure or code of EPIC in adapting the model to the Prairie Provinces." In addition, modifications were also made to some of the crop parameters and wind erosion inputs previously discussed in Agriculture Canada (1993b).

The key code modification made in EPIC by Williams (1993) was to the calculation of the crop residue decay rate in order to overcome a consistent over accumulation of crop residue for Prairie Province conditions, a problem that was not detected in previous calibration efforts. The residue decay rate is calculated in EPIC in a manner that no decay of the residue will occur when climatic conditions become too dry or too cold. Apparently, these conditions were being continuously exceeded for the Prairies, resulting in a build-up of too much crop residue over time. The problem was corrected by changing the original function

$$DECR = \text{maximum}\ (0.001,\ 0.05 * CA * CS) \tag{6}$$

to

$$DECR = \text{maximum}\ (0.01,\ 0.05 * CA * CS) \tag{7}$$

where DECR is the crop residue decay rate, CA is a parameter that affects the decay rate based on the carbon to nitrogen and carbon to phosphorous ratios in the soil, and CS is a parameter that affects the decay rate as a function of both temperature and soil water. By changing the value .001 to .01, the minimum decay rate was increased by an order of magnitude. As well, a separate code modification was made to the temperature calculations of the CS variable to further ensure that there would not be a build-up of crop residue.

Another code change was also made by Williams (1993) to allow a more aggressive conversion of standing dead crop residue to flat residue following a tillage pass, to further reduce the possibility of residue build-up. This was accomplished by changing the function

$$STD = STD_0 * e^{(-56.9 * PD * EF^2)} \tag{8}$$

to

$$STD = STD_0 * e^{-56.9\ 8\ PD * EF)} \tag{9}$$

where STD is the standing dead crop residue (t/ha) after tillage, STD_o is the standing dead crop residue (t/ha) prior to tillage, PD is the plow depth (m), and EF is the mixing efficiency (given for the specific implements in Table 12). The net result is less standing dead crop residue and ultimately less residue coverage by eliminating the exponent on the EF value.

Tests preformed with previously constructed data sets for research plots at the Agriculture Canada Swift Current Research Station show that these code changes had a definite impact on EPIC yield estimates. Figures B.1 and B.2 in Appendix B show plots comparing simulated and measured results for a 25-year continuous wheat rotation, before and after the code changes were made, respectively. Similar plots of the wheat-fallow rotation are shown in Figures B.3 and B.4. The simulated yields in Figures B.1 and B.3 are plots of the EPIC output reported in Agriculture Canada (1993b).

The accuracy of the simulated average yields improved following the code changes. Average yields of 1.3 and 1.8 t/ha were predicted by the modified EPIC for continuous wheat and wheat-fallow, as compared to the measured yields of 1.32 and 1.97 t/ha for the same rotations (Figures B.2 and B.4). However, the accuracy of the simulated standard deviations declined, changing from 0.66 to 0.77 for continuous wheat (Figures B.1 and B.2) and from 0.6 to 0.9 for wheat-fallow (Figures B.2 and B.4). The measured standard deviations were 0.65 for both rotations. Some visual improvement can be seen of the tracking of year-to-year yields for continuous wheat with the modified EPIC. However, no clear improvement can be seen for the year-to-year tracking of the wheat-fallow rotation yields following the code modifications.

Other sensitivity tests of the code changes showed that the modification to equation (8) had a relatively minor effect on the simulated residue amounts as compared to the change made to equation (6). It is stressed that the code changes discussed here were made on the basis of obvious, logical expectations and were not tested against any actual measured data. Further testing of this component should be performed in future work, as discussed in section V.B.

D.1. Wind erosion input values

Another departure from a previous conclusion stated in Agriculture Canada (1993b) is the appropriate value of the "power parameter of the modified exponential wind speed distribution" (UXP), an important input to the wind erosion submodel. Initial testing results discussed in Agriculture Canada (1993b) led to the conclusion that the most appropriate value for UXP was between 0.5 and 0.6. However, it was discovered after the fact that the wind erosion estimates were being heavily influenced by the excessive accumulation of crop residue described above.

Following the corrections for the residue problem, further testing was perforemd for rotation, soil, and wind data reflective of conditions at Swift Current, Saskatchewan. These tests indicated that potentially excessively high wind erosion values could result if a UXP value of 0.55 was used for the analysis. Potter (1993) suggested a value of 0.3 for UXP, which was assumed for the EPIC simulations. Ultimately, it may be determined that the best value lays somewhere between 0.3 and 0.55, a point that is discussed in more detail in section IV.

Another important assumption that greatly impacts wind erosion results for the three Prairie Provinces is the aggregation of the climate stations with wind speed and direction data to the ARA level. As briefly discussed in Agriculture Canada 1993b, this step was accomplished using the Thiessen polygon weighting technique, the results of which are shown in Figure 15. The influence of an individual climate station (total area represented by the climate station) is

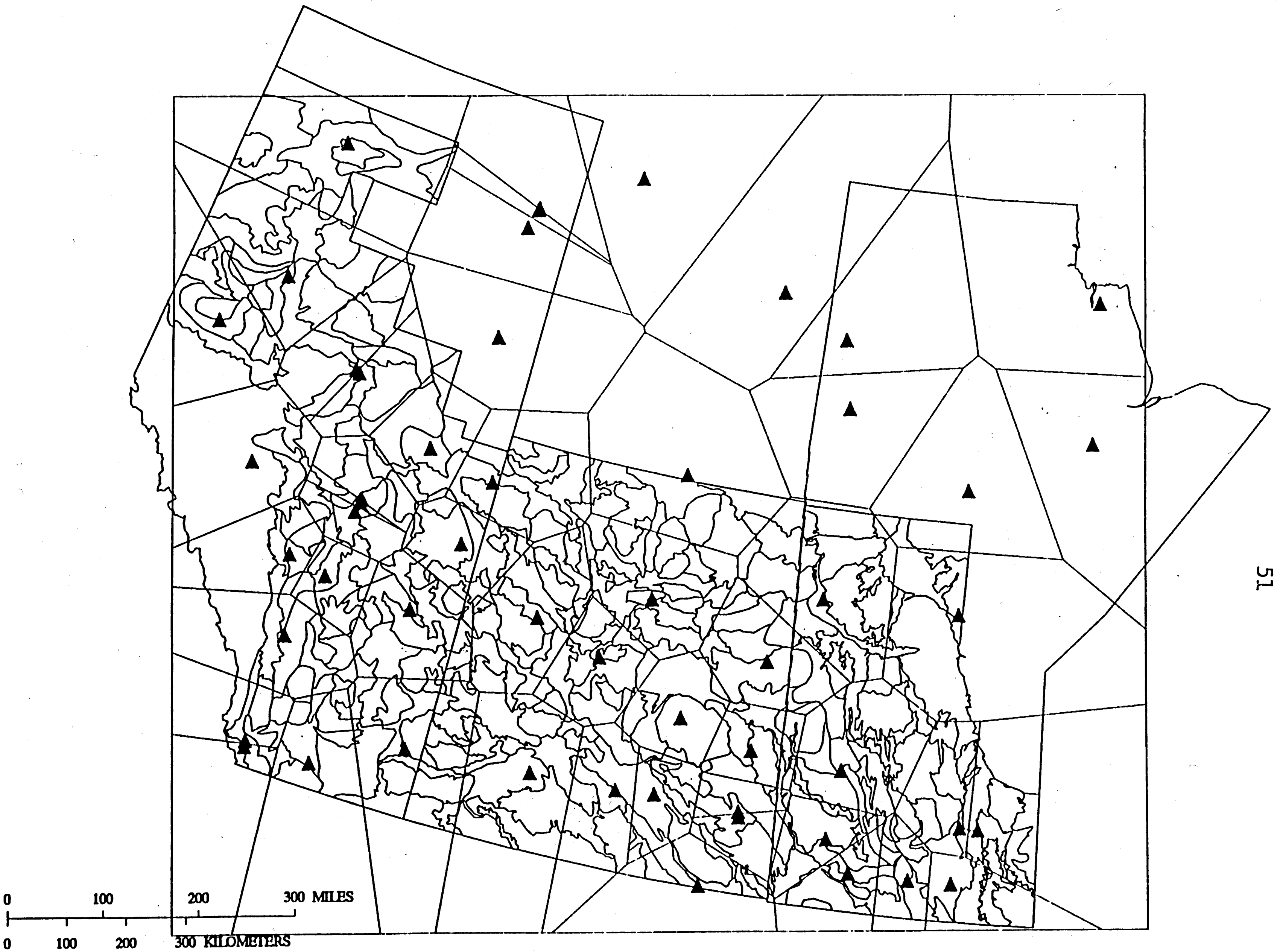

Figure 15. Aggregation of climate stations with wind data to the ARA level using the Thiessen polygon weighting technique; boundaries of the polygams determined for each climate station are shown on the map

depicted by the polygon that surrounds it. An individual ARA is assumed to have the same wind characteristics as the climate station that dominates the ARA, i.e., the climate station with the polygon that covers the majority of the land area in that ARA. It can be seen from Figure 15 that in some cases climate stations near province borders dominate ARAs in neighboring provinces.

A final calibration step for the wind erosion model was the modification of three EPIC crop parameter inputs defined as the standing live biomass (BW_1), the standing dead residue (BW_2), and flat residue (BW_3). These three parameters are used to determine the effectiveness of the vegetative cover of each crop in protecting against wind erosion. Values for these three parameters were previously given in Agriculture Canada (1993b) for all nine crops. The BW values for alfalfa, barley, fall rye, and spring wheat were considered reliable and were left unchanged (Table 16). However, the reliability if the BW values for canola, flax, field pea, lentil, and sunflowers were less certain, so additional effort was put forth to determine reasonable BW values for these two crops as well as canola, field pea, and flax.

Previous studies have been conducted related to estimation of the vegetative effects of different crops for wind erosion modeling (Troeh et al. 1991, Skidmore and Williams 1991, and Skidmore and Nelson 1992). However, these studies shed little light into determining appropriate BW parameters for the five other crops. Discussions with Williams (1993) and Skidmore (1993) also provided no further insight, other than the fact that the determination of values for the BW parameters can be a highly subjective process.

Values for the canola, field pea, flax, and lentil BW parameters were arrived at on the basis of descriptions by Coy (1993) of relative residue amounts generated by each crop, and their observed effectiveness of protection against erosion. In general, these crops are considered to be less effective for wind erosion protection, reflected by the lower values assumed for the three categories shown in Table 16. Sunflower BW values were set equal to previously developed values for corn (Table 16) as recommended by Shaykewich (1993), because sunflowers are a row-crop that offer limited protection (like corn) against wind erosion.

Table 16. Wind erosion factors assumed for the EPIC simulations[a]

Crop	Wind Erosion Parameters		
	BW_1	BW_2	BW_3
Alfalfa	3.39	3.39	3.39
Barley	3.39	3.39	1.61
Canola	1.27	0.6	0.73
Fall rye	3.39	3.39	1.61
Field pea	2.27	0.60	0.40
Flax	2.27	2.27	0.73
Lentil	1.27	0.63	0.73
Spring wheat	3.39	3.39	1.61
Sunflower	0.43	0.43	0.21

[a]BW_1, BW_2, and BW_3 are the EPIC crop wind erosion parameters for standing live biomass, standing dead crop residue, and flat residue, respectively.

D.2. Crop parameter, curve number, and default value inputs

Modifications were made to several other crop parameter values that were previously listed in Agriculture Canada 1993b. A revised list of crop parameter values is given in Table C.1. of Appendix C. Runoff curve numbers assumed for the simulated cropping systems were 63, 75, 83 and 87 for soil hydrologic groups A, B, C, and, D, respectively. These curve numbers are representative of small grains grown in straight rows under good hydrologic conditions. The small grain curve numbers were used because each rotation had at least one small grain included in it. The application of the curve numbers and soil hydrologic groups for simulating runoff of precipitation in EPIC is further described in Agriculture Canada (1993b).

Values for default values assumed in the EPIC simulations are given in Table C.2. of Appendix C. Included in this list are the options used for simulating evapotranspiration (Penman-Monteith method) and water erosion (the Modified Universal Soil Loss Equation or MUSLE). Details on the different options available to simulate evapotranspiration and water erosion can also be found in Agriculture Canada (1993b). The values of 2.0 km for the default field width and length values for the wind erosion submodel reflect the wide open areas that occur across much of the Prairie Provinces. Sensitivity runs of the field dimensions indicated that no impact occurs on wind erosion estimates for field dimensions greater than 1.0 km.

IV. EPIC Simulation Results

Results of the EPIC simulations used to build the environmental metamodels are given in Tables D.1-D.9 in Appendix D. Predicted average wind erosion rates by CRAM region for Alberta, Saskatchewan, and Manitoba are presented in Tables D.1-D.3. Correspondingly, average water erosion rates are listed in Tables D.4-D.6. These results are given as averages of all runs performed for a given crop and crop sequence combination within each CRAM production region. These "averages" represent only a sample of soils and ARA weather conditions within each CRAM region (see Figure 2 for map showing the CRAM regions). Thus, the erosion results shown in Tables D.1-D.6 can be potentially skewed, depending on which soils, wind stations, and other characteristics were included in the sample. However, the goal here was to depict major trends observed. A complete execution of all soil, weather, and cropping pattern combinations would likely produce different average erosion rate values for each CRAM region. Execution of all possible combinations will be performed with the metamodels when evaluating different policies.

Average crop yields predicted by CRAM region are presented in Tables D.7-D.9 of Appendix D. The EPIC yield results, and how the generated yields will be used in CRAM, are discussed in section IV.B.

A. Wind and Water Erosion Results

Wind erosion was the dominant erosive force in Saskatchewan and Manitoba for the majority of crops and CRAM region combinations. In Alberta, water erosion tended to dominate except in CRAM regions 1 and 2 in the southern part of the province. On average, the highest wind and water erosion rates in each CRAM region occurred during fallow periods, although in some cases greater rates were predicted for crops following a fallow period.

Decreasing tillage had a marked effect on reducing wind and water erosion for virtually all crops following stubble in every CRAM region-province combination. However, this trend was not as clear for crops which followed fallow, where the erosion rates even increased slightly in some cases. These results suggest that a preceding fallow period has a great impact on the total amount of erosion that occurs in the following crop year, irregardless of how much tillage is performed. It is also an indication that much of the erosion predicted on fields where crops follow fallow occurs in the early spring prior to seeding (underscoring the fact that EPIC-generated erosion rates for each crop are based on estimates covering a full calendar year and not just the cropping season).

As expected, the highest wind erosion rates were predicted in southern Saskatchewan and southern Alberta where the highest wind speeds occur in the regions around Swift Current and Lethbridge. Predicted average wind erosion rates were 27.7 and 25.2 t/ha for conventional-tilled summer fallow in Saskatchewan CRAM regions 3 and 4, and 19.7 t/ha for conventional-tilled summer fallow in Alberta CRAM region 2. Wind erosion rates declined to the east and north of CRAM regions 3 and 4 in Saskatchewan, although erosion rates still exceeded 10 t/ha for conventional-tilled fallow in CRAM regions 2 and 6. In Alberta, the next highest average wind erosion rate was 8.5 t/ha under conventional-tilled summer fallow in CRAM region 1. The highest average wind erosion rate predicted for Manitoba was under conventional-tilled fallow (9.2 t/ha) in CRAM region 1, in the southwest corner of the province.

A maximum average water erosion rate (12.3 t/ha) was predicted for conventional-tilled fallow in Alberta CRAM region 3, which was probably due to steeper slopes that exist in the foothills of the Rocky Mountains. The maximum average water erosion rate (3.5 t/ha) in Saskatchewan occurred on conventionally-tilled canola following fallow in CRAM region 6, while in Manitoba the maximum average rate (3.0 t/ha) occurred in CRAM region 2.

One factor that affected both the wind and water erosion predictions was that the EPIC predicted yields were consistently higher than average census yields previously used in CRAM, as described in section IV.B. It can be expected that higher erosion rates will occur for lower crop yields, because the amount of biomass and subsequent standing and lying residue amounts will be reduced. This is especially true for canola and lentils, for which the EPIC predicted yields were particularly high.

A.1. Comparisons with cumulative measured erosion rates

Published studies reporting erosion rates in Western Canada are very limited. Cumulative erosion rates have been estimated for sites in central and west-central Saskatchewan, primarily with the aid of Cesium-137 (^{137}Cs) that was deposited in the Prairies in the early 1960s from radioactive fallout. Erosion measurements using this method reflect total net rates of erosion that occurred over time for specific landscapes, with erosion occurring on upper slope positions and deposition occurring at the bottom of the slope. These erosion rates are a composite of erosion effects and include the effects of wind, water, and "tillage" erosion. Tillage erosion is a phenomenon believed to be caused by tillage implements, which physically remove topsoil off the upper slopes of hilly terrain and deposit it on lower slopes and/or in deposition areas.

Initial testing of the ^{137}Cs method to estimate erosion was performed by de Jong et al. (1982) near the Saskatoon area. An average annual erosion rate of about 6 t/ha was estimated for a cultivated soil classified as a Black Chernozem, during an 18-20 year period. de Jong et al. (1983) then used ^{137}Cs estimated erosion rates for five sites in the regions of Saskatoon and Prince Albert. Rotations of cereal crop - fallow or cereal crop - canola - fallow were grown at these sites on soils classified as Dark Brown, Black or Dark Gray Chernozems with slopes ranging between 8 and 18 percent. Average annual erosion rates of 9-25 t/ha were estimated for upper slope positions over a 20-25 year period. The annual net soil loss (upper slope erosion minus lower slope deposition) across all five sites was about 4.2 t/ha.

An erosion rate of 2.3 t/ha was estimated using the ^{137}Cs method[4] for a cultivated soil classified as a Black Chernozem located in central Saskatchewan (Voroney et al. 1981). The land form consisted of knolls and depressions. The sampling was performed on a 100 m slope with a four percent gradient.

Erosion estimates were made with ^{137}Cs for several cultivated sites located mostly in the Dark Brown soil zone near Unity in West-Central Saskatchewan (Kiss et al. 1986). Calculated annual mean erosion rates were 23, 27, and 48 t/ha for 0-3, 3-10, and 10-24 percent slope ranges. The highest erosion rates were estimated for the upper slope positions, which was attributed primarily to wind and tillage erosion. In a separate study, Mermut et al. (1983) used a transect method to estimate the extent of erosion for a site south of Unity. The soil at this site was classified as Dark Brown Chernozem and was assumed to have been under cultivation for 70 years. It was calculated that mean annual soil losses of 74 t/ha and 21 t/ha occurred at these sites for backslopes of 7.5 and 2 percent. They concluded that erosion is more severe from the extreme slope positions of the clay soils they studied then from the medium-textured knolls that were examined by de Jong et al. (1983).

Martz and de Jong (1987) used ^{137}Cs to measure soil erosion at 174 sites within a 178 ha watershed located 40 km southwest of Saskatoon. Virtually all of the basin had been in a crop-fallow rotation since 1944. Annual erosion losses exceeding 11 t/ha (considered the allowable limit for wind erosion) were calculated at 44 percent of the sites. The mean net erosion across the 174 sampling sites was close to zero, indicating that little sediment export from the basin occurred.

The ^{137}Cs method was used by de Jong and Kachonoski (1988) to estimate erosion levels for 26 benchmark sites that had been established around potash mines, primarily on coarse or medium textured soils in the Brown Soil Zone of Saskatchewan. These sites had been cultivated

---

[4]The erosion calculations were performed by C. Hubbard, Department of Soil Science, University of Saskatchewan.

since at least the mid-1960s with crop-fallow and crop-crop-fallow rotations. Annual Erosion rates of 6-100 t/ha were estimated for 21 of the sites, with an average erosion rate of approximately 28 t/ha[5]. No signs of water erosion were observed but indications of severe wind erosion were noted at several of the sites.

Interpretation of these results is difficult when considering specific estimates of wind and water erosion rates for different landscapes. Assuming that the estimates made with the ^{137}Cs and landscape analysis techniques are accurate, it would appear that EPIC may be underestimating the total soil erosion rates for upper slope positions of some landscapes in central and west-central Saskatchewan. A key factor could be the phenomena of tillage erosion, which de Jong (1993) believes may be the dominant form of erosion for upper slope positions on hilly terrain in the Prairies. This type of erosion effect cannot be simulated by EPIC or any other model we are aware of.

Several of the ^{137}Cs erosion studies indicated that wind was a greater source of erosion than water for many landscapes in central- and west-central Saskatchewan. Assuming that Saskatchewan CRAM regions 6 and 7 are representative of these regions, it can be seen from Tables D.2 and D.5 that the EPIC erosion results are consistent with this trend. According to de Jong (1993), the predicted average wind erosion rate of 10.3 t/ha for conventionally-tilled fallow in CRAM region 6 is consistent with expectations.

It is stressed again, however, that the absolute magnitudes of the averages shown in Tables D.1 - D.6 are highly influenced by the specific runs that were performed for the statistically designed set of EPIC simulations. For example, six different wind stations were represented in the 26 simulations performed for each soil, crop, crop sequence, and tillage combination for Saskatchewan CRAM region 6. Of these, eight of the runs were performed with North Battleford wind data and five were executed with Regina wind data for parts of ARAs that

[5]One site was measured twice with a net gain of 6.6 t/ha estimated in 1984 and a net loss of 0.6 t/ha estimated in 1985. Erosion rates could not be estimated using ^{137}Cs at five of the sites.

occupy only small areas within CRAM region 6. For a weighted average based on crop acreages of all soils in region 6, it can be expected that the wind erosion results based on the North Battleford and Regina data would have much less influence on the overall average erosion rate.

A.2. Comparisons with wind erosion measurements

To date, the only actual experiment in which wind erosion has been measured has been for one site in western Canada near Lethbridge, Alberta (Larney 1993). A total of 144 t/ha of soil was estimated to be eroded for a completely exposed (no residue cover) fallow field, from 16 events that occurred from April 1991 to May 1992. No direct comparison can be made between the EPIC results and these measurements. However, the maximum average wind erosion rate estimated by EPIC for conventionally tilled-fallow over the 31-year simulation period in southern Alberta was 165 t/ha. This clearly shows that the model is capable of predicting erosion rates of the magnitude measured near Lethbridge. In fact, this may well be an overprediction for the simulated conditions. Further tests of the wind erosion submodel are required to better assess its accuracy and the most appropriate value of UXP[6].

Coote (1984) describes one other attempt to "measure wind erosion" by Jenkins (1982), who calculated the erosion rate that occurred during a wind erosion event that lasted a few hours on a freshly planted field near Winnipeg, Manitoba. An erosion rate of at least 133 t/ha was estimated, based only on the amount of soil that was blown into a neighboring roadside ditch. This would have to be considered a catastrophic event, especially in Manitoba. It is impossible to make any comparisons between the EPIC results and this measurement.

---

[6]Potter (1993) will test the EPIC wind erosion model with data from the Lethbridge site (Larney 1993), as well as for an additional site in Texas. The results of these tests should provide additional insight as to the proper value for UXP.

A.3. Comparisons with water erosion measurements

Measurements of water erosion in the Prairies have been reported by Toogood (1963), Chanasyk and Woytowich (1987), Nicholaichuk and Read (1987), Nolan et al. (1992), and van Vliet and Hall (1991). Direct comparisons between these measured values and the EPIC predictions are again impossible. However, some qualitative comparisons between the measured values and the EPIC results can be made.

Total rainfall-induced erosion over a ten-year period was determined by Toogood (1963) for fallow after wheat, wheat after fallow, and grain and hay crops grown in rotation at a site near St. Alberts, Alberta (located in Alberta CRAM region 4). Average rates measured were 2.1 t/ha for fallow after wheat, 0.9 t/ha for wheat after fallow, 0.5 t/ha for wheat after stubble, 0.3 t/ha for barley after stubble, and 0.24 t/ha for hay after stubble (average of first and second year hay crops).

Total erosion measured by van Vliet and Hall (1991) was 4.9 t/ha for a fallow-canola-barley rotation (rotation 1) and 1.0 t/ha for a canola-barley-barley underseed to red fescue-fescue-fescue rotation (rotation 2) over a six-year period (1983-89) at a site near Fort St. John in the Peace River Region of British Columbia. The average erosion rate over four fallow years in two replications of rotation 1 was 1.7 t/ha. Similar erosion rates measured for barely and canola in rotation 1 were 0.6 and 0.1 t/ha, respectively. However, when comparing the two crops for the same climatic year, erosion rates measured on barley were always smaller. Snowmelt runoff accounted for 39 percent of the total erosion measured over six years for rotation 1 and 80 percent of the total erosion measured for rotation 2.

Chanasyk and Woytowich (1987a) measured sediment yields over seven-day snowmelt runoff periods in 1982 and 1983 for four plots located at La Grace in the Peace River Region of Alberta. One plot was seeded to fescue while permutations of a fallow-canola-barley rotation were planted on the other three plots. Sediment yields of 2.0, 0.4, and 0.26 t/ha were measured for fallow, barely, and fescue in 1982 as a result of seven days of continuous snowmelt (erosion measured for a canola plot was considered suspect). Erosion amounts estimated for 1983 were 0.25, 0.11, 0.08, and 0.06 t/ha for fallow, barely, canola, and fescue. The lower sediment yields in 1983 were due to a four-day freeze that interrupted the runoff event after the second day of snowmelt runoff.

Sediment yield and nutrient losses in snowmelt runoff were measured by Nicholaichuk and Read (1978) over a six-year period (1970-75) for wheat-fallow rotations grown on four plots at Swift Current, Saskatchewan. The majority of the erosion occurred in the spring of 1971 due to very high runoff events, with maximum erosion rates of 1.9 and 1.7 t/ha measured for summerfallow and fall-fertilized summerfallow. The six-year erosion averages for stubble, fallow, and fall-fertilized fallow were 0.1, 0.4, and 0.9 t/ha.

The magnitudes and trends of the EPIC water erosion results tabulated for corresponding CRAM regions in Tables D.4 and D.5 are in general agreement with the values measured in the studies by Toogood (1963), van Vliet and Hall (1991), Chanasyk and Woytowich (1987a), and Nicholaichuk and Read (1978). For example, average erosion rates predicted by EPIC for Alberta CRAM regions 4, 5, and 6 are consistent with Toogood's measured values, showing that the highest erosion will occur for fallow periods, that more erosion will occur on wheat following fallow as compared to stubble, and that barely and hay are more effective at controlling erosion than wheat. It is noted that the erosion rates estimated by Toogood (1963), Chanasyk and Woytowich (1987a), and Nicholaichuk and Read (1978) would likely have been higher if both rainfall and snowmelt-induced erosion would have been considered in each study.

According to Nicholaichuk (1967), snowmelt runoff accounts for over 85 percent of the total runoff from agricultural watersheds in Western Canada. The sediment yield measurements made by van Vliet and Hall (1991), Chanasyk and Woytowich (1987a), and Nicholaichuk and Read (1978) reveal that soils in the Prairie Provinces can be very susceptible to snowmelt-induced water erosion. Izaurralde et al. (1993) tested the EPIC snowmelt model by comparing predicted runoff and erosion amounts against data collected by Chanasyk and Woytowich

(1987b) in 1985 and 1986 in the Peace River Region. It was concluded that EPIC correctly identified the runoff period due to snowmelt but underpredicted the observed runoff and sediment yields. Further testing and code modifications of the EPIC snowmelt submodel would likely yield improvements.

Nolan et al. (1992) performed several erosion studies at different sites in the Alberta Peace River Region using a rainfall generator. Total soil loss measured for bladed fallow (Noble blade) and chemical fallow treatments were 11 to 17 times less, respectively, than the erosion measured for conventional fallow at Skiff, Alberta. No significant difference was observed between the total amounts of eroded sediment measured for the bladed and chemical fallow treatments. Crop tillage comparisons were also performed for conventional, reduced, and no-till treatments at two locations. However, the specific tillage implements and cropping systems were not described and thus little inference can be drawn from the results.

In general, EPIC predicted water-erosion rates for reduced (bladed) fallow are a factor of two or less as compared to conventional fallow across CRAM regions in all three provinces (Tables D.4-D.6). Similarly, estimated no-till (chemical) fallow erosion rates are generally a factor of 3 to 5 less than those estimated for conventional fallow (Tables D.4-D.6). These reductions are not as strong as those measured by Nolan et al. (1992). This may be an indication that EPIC is overpredicting erosion for the no-till and reduced-till fallow treatments.

A.4 Comparisons with previous global estimates of erosion

Coote (1984) estimated potential water erosion rates for the Prairie Provinces (Table 17) based on previous erosion estimates made by Dickinson and Wall (1978) for small drainage basins in southeastern Ontario. It was assumed that the distribution of soil erodibility and topography factors in Western Canada were the same as those estimated previously for southeastern Ontario. On average, the EPIC estimates in Tables D.4-D.6 are lower that those shown for hay in Table 17, with close to an order-of-magnitude difference in Manitoba. Also, Table 17 shows the same erosion rates for cereals, canola, and flax, but EPIC predicts

Table 17. Estimated potential water erosion rates for major crops in Western Canada (t $ha^{-1}yr^{-1}$)[a]

Crop	Manitoba	Saskatchewan	Alberta (excluding Peace River region)
Summer fallow	10.4	7.4	4.9
Horticultural crops, potatoes and sugar beets	7.8	5.6	3.8
Beans and peas	6.5	4.6	3.1
Corn and sunflower	4.5	3.2	2.1
Cereals, canola and flax	2.9	2.1	1.4
Hay	2.2	1.6	1.1
Pasture	0.3	0.2	0.2
Range	1.4	2.0	0.7

[a]From Coote (1984).

significantly less erosion to occur on barley as compared to flax, canola, and wheat.

Table 18 shows composite EPIC erosion rate statistics at the province level for barley, canola, and wheat, the three major crops grown on the Prairies. The highest water erosion values were predicted for Alberta, followed by Manitoba and lastly Saskatchewan. This is partially the reverse of the relative amounts estimated by Coote (1984), which show the highest water erosion rates for cereals, canola, and flax occurring in Manitoba, followed by Saskatchewan and then Alberta (Table 17). A primary reason for this is the very high water erosion rates predicted by EPIC in Alberta CRAM region 3, relative to the estimates in all other CRAM regions, as reflected in Tables D.4-D.6 and Table 18.

In the testing phases of EPIC it was noted that the USLE produced consistently higher erosion rates than those estimated by the MUSLE. Use of the USLE would likely have resulted in consistently higher water erosion rates as compared to the MUSLE predictions reported here. As an additional check, Tajek (1994) compared the predicted EPIC water erosion rates with

Table 18. Composite statistics for EPIC predicted erosion rates for barley, canola, and wheat by province and cropping sequence

Province	Cropping sequence	Erosion type	Observations[a]	Mean	Standard development	Minimum	Maximum
Alberta	Stubble	Wind	945	0.61	2.0	0.0	34.0
	Stubble	Water	945	0.81	2.9	0.0	41.2
	Fallow	Wind	513	1.99	4.7	0.0	47.8
	Fallow	Water	513	2.76	7.4	0.0	65.3
Saskatchewan	Stubble	Wind	1200	1.36	2.6	0.0	29.7
	Stubble	Water	1200	0.33	0.8	0.0	7.2
	Fallow	Wind	750	5.63	8.1	0.0	49.0
	Fallow	Water	750	1.53	2.5	0.0	13.3
Manitoba	Stubble	Wind	558	1.91	4.2	0.0	38.8
	Stubble	Water	558	0.51	0.6	0.0	4.5
	Fallow	Wind	63	5.39	8.2	0.0	41.2
	Fallow	Water	63	1.94	2.1	0.0	7.4

[a]Each observation represents a 30-year average erosion rate predicted for barley, canola, or wheat.

previously estimated USLE values (Tajek et al. 1985) for a subset of landscape polygons in Alberta. For most of these polygons, 31-year average erosion rates from the summary output for the wheat-fallow rotation were mapped. Erosion rates for the continuous barley rotation were mapped for some of the landscape polygons that lie farthest to the north[7]. These erosion rates were mapped in an effort to be as consistent as possible with the cropping factors that had been used for the previous USLE estimates.

Figure 16 shows the resulting map produced with the EPIC predicted erosion rates for the landscape polygons included in the statistical design. Erosion rates were mapped based on the following erosion potential categories: negligible (< 6 t/ha), slight (6-11 t/ha), moderate (11-22 t/ha), severe (22-33 t/ha), very severe (33-55 t/ha), and extreme (> 55 t/ha). Categorically, these erosion rates are in good agreement with those mapped previously for the same polygons using the USLE (Figure 17). For some of the polygons, the EPIC MUSLE values indicate negligible erosion levels while the USLE showed that slight erosion risks would be expected. This is a confirmation that the MUSLE often predicts lower values than the USLE. However, there were some landscape polygons for which the estimated MUSLE value was greater than the erosion estimate predicted with the USLE.

Extreme erosion risk was predicted by EPIC for two landscape polygons shown in Figure 16, which are located in Alberta CRAM region 3. Tajek had to use USLE bare soil estimates for the these two polygons in order to find agreement of extreme risk of water erosion. He commented that EPIC is overestimating the erosion risk for a wheat-fallow rotation in these polygons, for reasons for that are currently unclear. However, it is stressed that EPIC is still capturing the fact that risk of erosion will be much higher in this region as compared to most other areas in Alberta.

---

[7]The summary output is rotation-based ouput as described in section III.C. Table 3 should be consulted for a description of the continuous barley (rotation 1) and wheat-fallow (rotation 8) rotations.

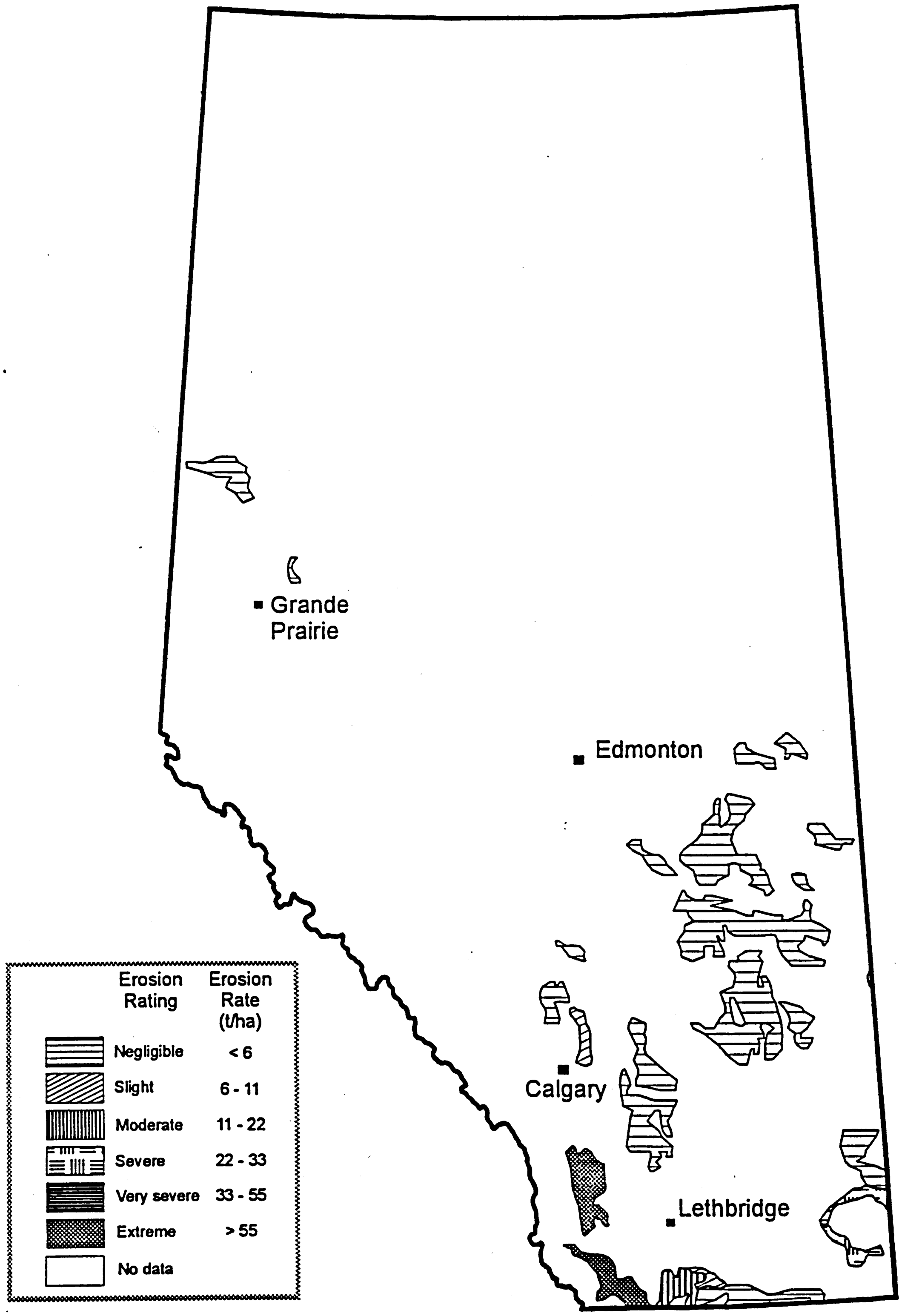

Figure 16. Comparison of annual EPIC erosion rate predictions over 31 years for selected landscape polygons in Alberta for the following categories: negligible (< 6 t/ha), slight (6-11 t/ha), moderate (11-22 t/ha), severe (22-33 t/ha), very severe (33-55 t/ha), and extreme (> 55 t/ha) (from Tajek 1994)

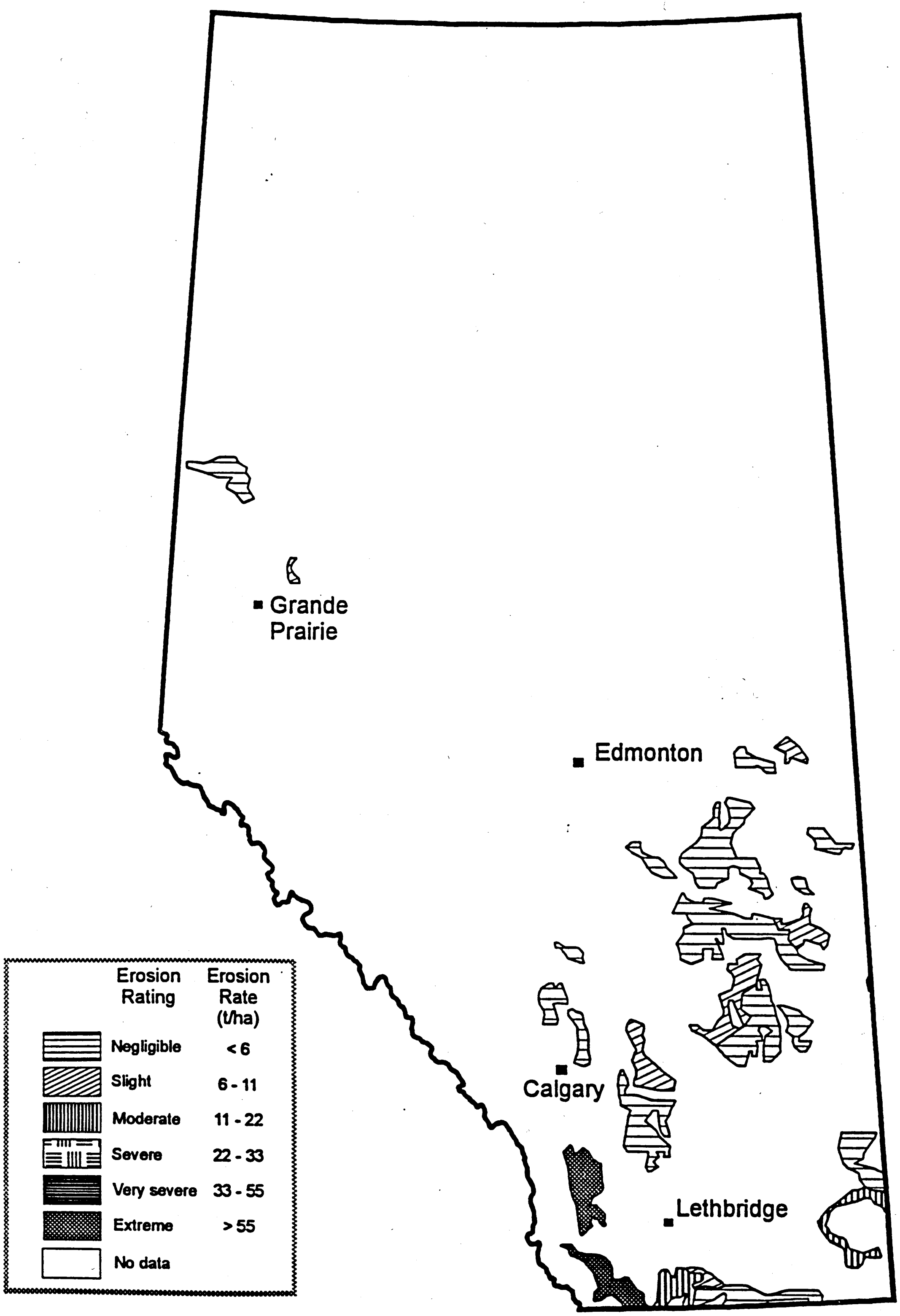

Figure 17. Classification of USLE potential erosion rates for selected landscape polygons in Alberta for the following categories: negligible (< 6 t/ha), slight (6-11 t/ha), moderate (11-22 t/ha), severe (22-33 t/ha), very severe (33-55 t/ha), and extreme (> 55 t/ha) (Tajek 1994)

This comparison shows the utility of estimating erosion rates for specific landscapes, crop rotations, tillage levels, and other factors. It is clear from this comparison that the trends of the EPIC water erosion results are consistent with previous efforts to estimate potential landscape-specific erosion levels with the USLE in Alberta. Similar comparisons can not be made at this time for Manitoba and Saskatchewan. However, the comparisons made for Alberta lend support that the trends of the Saskatchewan and Manitoba erosion estimates are also accurate.

Coote (1984) estimated wind erosion rates for cropland, pasture, and rangeland in the Prairie Provinces (Table 19) by extrapolating from previous estimates made by Chepil et al. (1962) for northern U.S. states that border Western Canada. Again, there is a reversal in the Alberta and Manitoba erosion levels between the values shown in Table 18 and the cropland erosion rates given in Table 19. However, it is difficult to attach much meaning to this comparison. Based on his estimates, Coote calculated that close to 90 percent of the total wind erosion would occur in Alberta and Saskatchewan. The EPIC results are in general agreement with this calculation, indicating that the majority of the wind erosion occurs in southern Alberta and southern Saskatchewan.

Table 19. Wind erosion rates estimated in adjacent U.S. states and adjusted for Canadian climatic conditions[a]

State/Province	Wind and Moisture Correction Factor	Cropland	($t\ ha^{-1}yr^{-1}$) Pasture	Rangeland
North Dakota	--	4.0	0.050	0.027
Montana	--	8.5	0.010	<0.010
Washington	--	<0.01	<0.01	<0.010
Manitoba	0.9 (N. Dakota)	3.6	0.045	0.024
Saskatchewan	0.6 (*)	4.2	0.014	0.009
Alberta	0.5 (Montana)	4.3	0.005	<0.005
Peace River Region	0.08 (Montana)	0.7	0.001	<0.001

[a]From Coote (1984).

A.5. Summary of erosion results

Based on the comparisons of the EPIC erosion results with measured data and previous estimates, it is concluded that the model is performing rationally in its predictions of wind and water erosion in the Prairie Provinces. It is clear that the application of EPIC provides a robust way of accounting for variation in landscapes, climate, soil types, tillage levels, crop rotations, and other management and environmental factors. Mermut et al. (1983) stated that there should be a greater emphasis on landscapes in erosion studies in the Prairies. Coote (1984) stressed that erosion assessments and mitigation efforts in Western Canada should focus on landscape productivity rather than off-site sediment loss, because 95 percent of the eroded sediment stays within the original watersheds. The application of EPIC for specific landscapes is consistent with these viewpoints.

However, it must be remembered that the data sets developed to represent western Canadian conditions were constructed on the basis of several assumptions. These assumptions can potentially result in large errors. For example, Coote (1984) states that wrong assumptions for the average values of slope and slope length factors for a landscape can lead to errors exceeding 100 percent. The comparisons of the EPIC erosion results with measured data and previous estimates also reveals that there is a need to further test the erosion submodels with site-specific measured data. Thus, the emphasis on the results of these EPIC simulations and the subsequent applications of the environmental metamodels should be for relative comparisons rather than to predict absolute magnitudes, as previously stated in Agriculture Canada (1993b).

B. Crop Yield Results

Tables D.7-D.9 list the average yields predicted by EPIC for the different crop and crop sequence combinations for Alberta, Saskatchewan, and Manitoba, respectively. The results indicate little yield variation across tillage types. A review of field experiments by Larney et al. (1993) reveals that this lack of yield variation between management systems is not inconsistent with measured observations. They state that "if rainfall received during the growing season is adequate and timely for crop growth then there will be little or no difference between yields under no-, minimum, or conventional tillage." They also emphasize that climatic variability in Western Canada make crop yield comparisons between conservation and conventional tillage systems difficult. While conventional tillage may outyield no-till in some years, the reverse occurs in other years.

The primary use of the EPIC yields is in the risk component of RS-CRAM. An important aspect of this application is the magnitude and variability of wheat and canola yields grown on stubble and fallow[8]. Tables 20-22 show the mean and standard deviations of EPIC-simulated wheat and canola yields by CRAM region for Alberta, Saskatchewan, and Manitoba, respectively. The standard deviations are shown as indicators of yield variability. The model indicates that fallowing provides a definite benefit in the Brown soil zone (Alberta CRAM regions 1 and 2, and Saskatchewan CRAM regions 3 and 4), correctly predicting that the average yields of wheat and canola on fallow would be higher than on stubble. Also, the model predicts that less yield variability would occur when crops are grown on fallow, which is also correct for this region.

The average yield relationships between stubble and fallow predicted by the model for the CRAM regions that lie within the Dark Brown, Black, and Gray soil zones were the reverse of those estimated for the Brown soil zone (Tables 20-22). The standard deviations of the wheat and canola yields simulated on fallow were also often higher than the wheat and canola yields predicted for stubble cropping. This was a clear indicator that the model was responding to differences in productivity and climate between the different soil zones. However, the response is inconsistent with expectations, especially for the Dark Brown soil zone.

The Dark Brown soil zone covers major portions of Saskatchewan CRAM regions 2, 6 and 7 and Alberta CRAM regions 3 and 4. Campbell et al. (1990) document that fallowing is very beneficial in the Dark Brown soil zone, which was not captured by EPIC. This is a clear weakness in the current application of the model that should be corrected for future applications.

---

[8]Lentils was also simulated as following stubble and fallow. However, wheat and canola are the principle crops grown on fallow and thus are emphasized here.

Table 20. Mean and standard deviations of EPIC-simulated crop yields (t/ha) by CRAM regions of Alberta

Crop	Tillage	Sequence	Statistic	CR1	CR2	CR3	CR4	CR5	CR6	CR7
Canola	conv.	stubble	mean	1.987	2.161	2.440	2.922	2.839	2.863	2.426
Canola	conv.	stubble	st. dev.	0.377	0.357	0.263	0.127	0.154	0.298	0.146
Canola	conv.	fallow	mean	2.450			2.757	2.663	2.227	2.162
Canola	conv.	fallow	std. dev.	0.347			0.171	0.235	0.287	0.235
Wheat	conv.	stubble	mean	2.017	2.314	2.937	3.499	3.491	3.248	2.837
Wheat	conv.	stubble	std. dev.	0.564	0.548	0.495	0.184	0.132	0.132	0.172
Wheat	conv.	fallow	mean	2.576	2.645	2.793	3.086	2.981		2.440
Wheat	conv.	fallow	std. dev.	0.427	0.50	0.416	0.340	0.30		0.261

Table 21. Mean and standard deviations of EPIC-simulated crop yields (t/ha) by CRAM regions of Saskatchewan

Crop	Tillage	Sequence	Statistic	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9
Canola	conv.	stubble	mean	2.67				2.59	2.47	2.45	2.60	2.69
Canola	conv.	stubble	st. dev.	0.15				0.26	0.32	0.35	0.15	0.19
Canola	conv.	fallow	mean	2.50	2.41			2.33	2.46	2.61	2.36	2.39
Canola	conv.	fallow	std. dev.	0.08	0.32			0.34	0.31	0.19	0.24	0.28
Wheat	conv.	stubble	mean	2.92	2.59	2.18	1.87	3.11	2.79	2.78	3.13	3.10
Wheat	conv.	stubble	std. dev.	0.22	0.42	0.43	0.21	0.33	0.49	0.51	0.24	0.27
Wheat	conv.	fallow	mean	2.57	2.50	2.53	2.38	2.42	2.61	2.78		2.59
Wheat	conv.	fallow	std. dev.	0.10	0.41	0.39	0.22	0.37	0.41	0.27		0.37

Table 22. Mean and standard deviations of EPIC-simulated crop yields (t/ha) by CRAM regions of Manitoba

Crop	Tillage	Sequence	Statistic	CR1	CR2	CR3	CR4	CR5	CR6
Wheat	conv.	stubble	mean	3.13	3.17	3.18	3.27	3.27	3.48
Wheat	conv.	stubble	std. dev.	0.38	0.24	0.44	0.36	0.45	0.09
Wheat	conv.	fallow	mean	2.48	2.55				
Wheat	conv.	fallow	std. dev.	0.42	0.22				

However, according to Dumanski (1994), the Dark Brown soil zone is a transition between the Brown and Black/Gray soil zones and fallowing will not always result in a positive yield response, depending on the interaction between soil types and growing season precipitation. He also points out that there are specific ARAs within the Dark Brown soil zone for which fallowing provides little benefit.

The Black and Gray soil zones cover all of the Manitoba CRAM regions; most of regions 5, 8 and 9, and part of region 1, in Saskatchewan; and all of regions 5, 6, and 7, and part of 4, in Alberta. In every one of these regions, EPIC is predicting that the average yields of wheat and canola on stubble will be higher than on fallow. According to Campbell et al. (1990), summer-fallowing to store moisture has no beneficial effect on crop yields in the Black and Gray soil zones. They state that the practice is only justified in these soil zones to control otherwise unmanageable pests or to protect against the possibility of drought. Dumanski (1994) further states that fallowing is not as important in modern cropping systems as it used to be, and it cannot be safely assumed that crops grown on fallow in the Black and Gray soil zones will always have higher yields and less variability. An example of this is reported by Juma et al. (1994), who found that wheat grown within in a five-year crop rotation outyielded wheat grown on fallow over a 60-year period at Breton, Alberta on a soil classified as a Gray Luvisol.

Other data sources present a somewhat conflicting view of the benefits of fallow in the Black and Gray soil zones. A review of the 10-year average census yields currently used in CRAM shows that in every CRAM region the wheat and canola yields grown on fallow were higher than those grown on stubble. Also, analysis of crop insurance data for six ARAs in Manitoba (representing each of the six CRAM regions) revealed that wheat and canola yields grown on fallow were also higher than those grown on stubble (however, the yield variability was greater for the crops grown on fallow as compared to being grown on stubble in three of the six ARAs). At best, it is concluded that while EPIC is logically responding to the climatic and productivity differences of the Black and Gray soil zones, it appears to be going "too far in the other direction" (i.e., reflecting too strong of yield response for stubble cropping as compared to fallow cropping).

An important overall trend noted for the predicted EPIC yields is that they are higher than the 10-year average census yields used previously in CRAM. There are at least two key reasons for this. The first is that regional variations in management practices were not accounted for in the EPIC simulations. This is especially important regarding the nitrogen application rates, which are typically much lower than those simulated in many areas of the Prairies. Second, the impact of pests and diseases upon crop yields were not incorporated in the EPIC simulations. This may be one reason that EPIC is predicting lower crop yields on fallow as compared to predicted stubble cropped yields in the more humid regions of the Prairies, where fallow can serve as an effective weed control practice.

These results underscore the need for further testing of the model to improve its accuracy in simulating crop growth and yield for the Prairie Provinces. Dumanski (1994) states that to date the only simulation method that has worked well for simulating moisture balance in the Prairies from the time of seeding is the "Variable Moisture Budget" routine. Thus, it would be beneficial to test and calibrate the EPIC moisture balance submodel with this routine. Also, previous experience shows that using static seeding dates introduces more variability into the final yield predictions (Dumanski 1994). Changing EPIC planting dates from static dates to those available from census data could improve the results. Finally, additional EPIC tests revealed that the model may be overestimating the amount of nutrient stress that normally occurs in fallow cropping systems. Therefore, additional testing and calibration of the nitrogen subroutine should be performed in future work.

B.1. The use of EPIC yields in RS-CRAM

In order to apply the generated EPIC yields in RS-CRAM, one set of 30-year annual yield distributions were used for each crop, crop sequence (fallow or stubble), and tillage combination in a given CRAM region, using the same weighting procedure described for the metamodel interface in section II.B. It was recognized that there are some inconsistencies between the magnitude and standard deviations of wheat and canola yields grown on stubble and fallow outside of the Brown soil zone, particularly in the Dark Brown soil zone. This could introduce some error into the risk analysis by providing "misleading" information that fallow cropping is riskier than stubble cropping. However, the impact of this error should be mitigated in part by the fact that the amount of fallow performed outside of the Brown soil zone (Alberta CRAM regions 1 and 2, and Saskatchewan CRAM regions 3 and 4) is relatively small for the majority of CRAM regions (Table 23).

The magnitude of the EPIC yields were adjusted downward to the levels of the 10-year average census yields used in CRAM to prevent any distortions from occurring within RS-CRAM. This was especially important for the predicted canola and lentil yields, which were very high for some of the CRAM regions. The EPIC predicted effects of fallow, stubble and different tillage levels were preserved in the adjustment process, resulting in RS-CRAM yields that are not the same as the census yields but much closer in magnitude[9]. Adjusted EPIC yields were also extrapolated to other CRAM regions for which wheat on fallow, canola on fallow and stubble, and flax activities were not simulated in EPIC. It was a necessary step to include these activity/region combinations for accounting purposes in RS-CRAM (the model assumes a small minimum number of hectares per activity). In most cases, these crop and crop sequence activities will have limited impact on any policy analysis.

Insurance payments (premiums) by producers and payouts (indemnities) are simulated in RS-CRAM for the period 1980-92. Both a 13-year distribution of yields, as well as a 10-year moving-average yield for each year of the 1980-92 time period, were required to perform the

---

[9]A more detailed description of the yield adjustment process is provided in Report 4 that covers the policy evaluations.

Table 23. Portion (percent) of the total cropped area that is planted to crops

Province	CRAM Region	Percent of cropped area planted to crops[a]
Alberta	1	0.6133
	2	0.7103
	3	0.9108
	4	0.8612
	5	0.9357
	6	0.8767
	7	0.8534
Saskatchewan	1	0.7009
	2	0.6483
	3	0.5756
	4	0.5571
	5	0.7684
	6	0.6778
	7	0.6162
	8	0.8316
	9	0.8294
Manitoba	1	0.9105
	2	0.8824
	3	0.9732
	4	0.9868
	5	0.9493
	6	0.9147

[a]The total precentage of cropped area in fallow is 1 minus the fraction given for each CRAM region.

risk calculations[10]. Ideally, the ten-year moving average yields would be computed by calculating the average yield over 1970-79 for 1980, 1971-1980 for 1981, and so forth. However, the EPIC yields were computed for those years that were available from climatic data in the ARA database (Kirkwood et al. 1993), which cover the 31-year time period 1955-85.

[10]The ten-year moving averages are used in the RS-CRAM variance-covariance matrix to compute the risk term of the objective function while the 13-year yield distributions are used in the optimization component of RS-CRAM.

A pairwise t-test performed on the EPIC yield distributions revealed that there was no statistical difference between the average yields calculated for the first ten years as compared to the third ten years, between the first 10 years and the second ten years, etc. Thus, the 23-year 1963-85 EPIC yield distributions were assumed representative of the 1970-92 RS-CRAM time period and were used to compute the ten-year moving averages. Likewise, the 13-year 1973-85 EPIC yield distributions were assumed representative of the 1980-92 yield distribution period required for the optimization component of RS-CRAM.

V. Structure and Validation of the Environmental Metamodels

In the metamodeling literature, the most commonly used models are the general linear and nonlinear models, which are often referred to as "regression metamodels" (Bouzaher et al. 1993). For the EPIC generated wind and water erosion estimates, an ordinary least squares (OLS) regression model was fitted separately for each crop and crop sequence (crop following stubble or fallow). Let Y be a n $\times$ 1 vector of observations of the response variable; X be a known full-rank n $\times$ p matrix of observations on the explanatory variables (regressors); and β be a p $\times$ 1 vector of unknown, fixed parameters. The OLS model then is

$$Y = X\beta + u;\ E(u_i) = 0,\ E(u_i^2) = \sigma_i^2,\ cov(u_i,u_j) = 0 \qquad (10)$$

Diagnostics of the wind and water erosion data indicated heterogeneity (nonconstant variance), implying that fitting an OLS model for the untransformed data would have violated classical assumptions of normality. A test for the null hypothesis that the untransformed data values are a random sample from a normal distribution was invariably rejected, implying nonnormal distribution of the untransformed data (Table 24). The usual Kolomogorov D statistic was used to test for normality, except for lentils in Saskatchewan. A simple Shapiro-Wilk statistic (Shapiro and Wilk 1965) was used to test lentils in Saskatchewan because the number of observations was less than 50[11]. Given that the response variable is nonnormal with nonconstant variance, the parameter vector $\hat{\beta} = (X^TX)^{-1}X^TY$, and the corresponding predictions $\hat{Y} = X\hat{\beta}$ are inefficient (in the minimum variance sense). An examination of the OLS residuals from the model fitted to the untransformed data confirmed the violation of the homogeneity assumption[12]. The adjusted R-squares of the OLS model fitted to the untransformed data are shown in Table 24.

Therefore, a simple transformation proposed by Lin and Vonesh (1989) was used to assure that the data satisfied normality. An estimated regression of the transformed data should have an error structure that is normally distributed with constant variance. When untransformed data are positively skewed (to the right), with a wide range, it is common to take a contracting type of transformation, such as the square-root, cube-root, fourth-root, and so forth. A fourth-root transformation was performed on both the wind and water erosion data generated by EPIC. The results of the normality checks for the fourth-root transformed data are shown in Table 24, together with the adjusted R-squares of the OLS model fitted to the transformed data. These results confirm that the OLS model fitted to the transformed data are much more robust than the OLS model fitted to the untransformed data.

---

[11]The Kolomogorov D statistic sets the mean and variance equal to the sample mean and variance while the Shapiro-Wilk statistic computes best estimates of the variance based on linear combinations of the order statistics.

[12]The residual plots exhibited a clear wedge-shaped pattern.

Table 24. Normality: Test Statistics from Untransformed Data (UD) and Transformed Data (TD)

Crop\a	N	Wind Erosion				Water Erosion			
		Dstat-UD\b	Dstat-TD	Rsqr-UD	Rsqr-TD	Dstat-UD	Dstat-TD	Rsqr-UD	Rsqr-TD
Saskatchewan									
Canola	294	0.53	0.96	0.49	0.88	0.57	0.95	0.58	0.88
S_Fallow	453	0.56	0.92	0.54	0.90	0.56	0.96	0.55	0.89
Flax	333	0.59	0.96	0.54	0.88	0.52	0.95	0.54	0.87
Field_Peas	294	0.46	0.95	0.43	0.87	0.55	0.95	0.53	0.87
Barley	453	0.53	0.94	0.49	0.82	0.44	0.94	0.43	0.80
Wheat	453	0.55	0.95	0.48	0.80	0.44	0.93	0.42	0.82
Fall_Rye	186	0.55	0.90	0.56	0.90	0.56	0.96	0.63	0.90
Alfalfa	183	0.68	0.94	0.58	0.80	0.60	0.91	0.62	0.88
Lentils\c	45	0.60	0.92	0.57	0.83	0.68	0.95	0.85	0.97
Alberta									
Canola	315	0.36	0.94	0.32	0.80	0.34	0.92	0.59	0.90
S_Fallow	315	0.29	0.90	0.26	0.77	0.41	0.94	0.59	0.89
Flax	291	0.28	0.92	0.25	0.76	0.43	0.94	0.67	0.91
Field_Peas	159	0.59	0.97	0.39	0.75	0.64	0.97	0.63	0.84
Barley	315	0.25	0.94	0.20	0.76	0.26	0.88	0.47	0.90
Wheat	315	0.32	0.94	0.27	0.79	0.27	0.90	0.44	0.89
Fall_Rye	102	0.69	0.94	0.47	0.81	0.46	0.88	0.79	0.96
Alfalfa	159	0.70	0.94	0.48	0.76	0.65	0.97	0.65	0.87
Lentils	156	0.34	0.90	0.39	0.88	0.52	0.96	0.73	0.90
Manitoba									
Canola	186	0.44	0.94	0.43	0.86	0.83	0.95	0.66	0.92
S_Fallow	102	0.42	0.91	0.48	0.80	0.75	0.97	0.62	0.92
Flax	63	0.47	0.92	0.53	0.87	0.84	0.90	0.88	0.95
Field_Peas	186	0.39	0.92	0.40	0.80	0.81	0.95	0.53	0.86
Barley	186	0.43	0.93	0.44	0.84	0.79	0.96	0.66	0.94
Wheat	186	0.48	0.93	0.50	0.85	0.81	0.96	0.63	0.90
Fall_Rye	69	0.67	0.85	0.71	0.81	0.82	0.92	0.76	0.96
Sunflower	114	0.48	0.92	0.49	0.90	0.80	0.96	0.73	0.96
Alfalfa	186	0.50	0.90	0.55	0.83	0.85	0.90	0.75	0.96
Lentils	138	0.49	0.93	0.46	0.86	0.79	0.95	0.73	0.94

a) Results are based on crop-stubble data, similar results were obtained for crop-fallow.
b) Dstat is the usual Kolomogorov D statistic for the null hypothesis that the data values are a random sample from a normal distribution. The statistic is between zero and one, with small values leading to rejection of the null hypothesis.
c) Shapiro-Wilks statistic (instead of the Kolmogorov D statistic) is calculated since $N < 50$.

The final estimated metamodel for wind erosion is

$$(Y_{wind})^{\lambda}_{j,\,seq} = a_0 + a_1(RAIN) + a_2(UAV) + a_3(LATI) + a_4(SAND) + a_5(OMBD) + a_6(DRTIL) + a_7(DNTIL) + \mu_{1i} \qquad (11)$$

where Y_{wind} is wind erosion (t/ha), j is the crop, seq is the stubble/fallow sequence, λ is the optimal transformation parameter equal to 1/4, the a_i's are the regression coefficients, RAIN is the average annual rainfall (mm), UAV is the average annual wind speed (m/s), LATI is a proxy variable for weather station location (degrees), SAND is the soil sand content (%), OMBD is an interaction term of organic matter (%) and bulk density (t/m^3), DRTIL and DNTIL are dummy variables which measure the erosion rates relative to conventional tillage, and u_{1i} is the unknown error term. Similarly, the final estimated metamodel for water erosion is

$$(Y_{water})^{\lambda}_{j,\,seq} = b_0 + b_1(RAIN) + b_2(LATI) + b_3(SLOPE) + b_4(OMBD) + b_5(RCN) + b_6(DRTIL) + b_7(DNTIL) + \mu_{2i} \qquad (12)$$

where Y_{water} is water erosion (t/ha), the b_i's are the regression coefficients, SLOPE is the landform slope gradient (%), and RCN is the runoff curve number that is used as a proxy to capture the hydrologic effects (i.e., partitioning of precipitation between runoff and infiltration) on water erosion.

The results of the estimated metamodels for wind and water erosion for crops following stubble are shown for Alberta, Saskatchewan, and Manitoba respectively in Tables 25-30. Similar results are shown for the wind and water erosion metamodels for the crops following fallow in Tables 31 and 32. The adjusted R-squares and the Root Mean Square Error (RMSE) values all suggest a "good-fit" of the EPIC generated data, with the majority of the adjusted R-square values falling within the range of 0.80-0.95. As well, most of the coefficients were significant at the 5 percent level of confidence. Care was taken to avoid multi-collinearity among the regressors by judging the degree of collinearity indicated by the variance inflation factor associated with each regressor.

Over 90 percent of the variation of the wind erosion metamodels are described with only two variables: UAV and SAND. The positive signs of these two variables indicate that increasing wind erosion would occur with increasing wind speed and higher soil sand content. According to Padbury (1993), it would be expected that the highest rates of wind erosion would occur for sandy soils. As well, greater rates of wind erosion would be expected for higher wind speeds. Negative signs for the RAIN, DRTIL, and DNTIL coefficients of the wind erosion metamodels are also consistent with expectations, because increased soil moisture and lower levels of tillage should lead to reduced wind erosion rates.

The negative sign for the organic matter and bulk density interaction (OMBD) coefficient is consistent with theory, in which it would be expected that erosion would decrease with increasing levels of organic matter and greater soil compaction. Initially, a separate bulk denisty term was attempted for the wind erosion metamodel that provided little improvement and was often insignificant. The explanatory power of the wind erosion metamodel improved greatly by re-estimating it with the OMBD interaction term.

The sign for the weather station location variable LATI was somewhat ambiguous. This variable was included to further delineate the spatial variability of weather impacts. Because LATI is a proxy for weather station location, it captures all weather variables including wind velocity. Therefore, it is difficult to indicate a sign for the LATI coefficient. Overall, the

Table 25. Metamodel Parameters for Wind Erosion (t/ha) in Alberta by Crops on Stubble

CROP	R-Sqr	N	INTER	RAIN	UAV	LATI	SAND	OMBD	DRTIL	DNTIL
Canola	0.82	315	-1.694	-0.002	0.388	0.028	0.005	-0.037	-0.186	-0.276
S_Fallow	0.81	315	-3.164	-0.001	0.685	0.034	0.008	-0.083	-0.118	-0.317
Flax	0.79	291	-2.620	-0.001	0.418	0.039	0.005	-0.047	-0.180	-0.264
Field_Peas	0.77	159	-4.200	**0.000**	0.374	0.059	0.004	-0.023	-0.098	-0.149
Barley	0.78	315	-3.173	-0.001	0.391	0.046	0.005	-0.038	-0.165	-0.232
Wheat	0.81	315	-2.806	-0.001	0.415	0.045	0.006	-0.040	-0.232	-0.272
Fall_Rye	0.82	102	**-0.267**	-0.001	0.281	**0.001**	0.002	-0.028	-0.066	-0.073
Alfalfa	0.78	159	-3.282	**0.000**	0.347	0.042	0.004	-0.022	**0.005**	**0.003**
Lentils	0.88	156	3.721	**0.001**	0.377	-0.098	0.009	-0.035	-0.198	-0.287

Note: The highlighted coefficients are not significant at 5% level.
The dependent variable is a fourth-root of EPIC simulated erosion estimates.

Table 26. Metamodel Parameters for Water Erosion (t/ha) in Alberta by Crops on Stubble

CROP	R-Sqr	N	INTER	RAIN	LATI	SLOPE	OMBD	RCN	DRTIL	DNTIL
Canola	0.90	315	-2.548	0.002	**0.005**	0.061	**-0.003**	0.023	-0.076	-0.100
S_Fallow	0.89	315	-2.877	0.002	**0.005**	0.075	-0.006	0.031	-0.140	-0.369
Flax	0.91	291	-3.490	0.003	0.019	0.066	**-0.006**	0.025	-0.077	-0.126
Field_Peas	0.84	159	-1.307	**0.000**	**0.001**	0.065	-0.015	0.023	-0.081	-0.098
Barley	0.90	315	-1.796	0.002	**-0.005**	0.053	**-0.003**	0.019	-0.102	-0.125
Wheat	0.89	315	-2.193	0.002	**0.003**	0.062	**-0.004**	0.023	-0.153	-0.167
Fall_Rye	0.96	102	-1.799	0.003	-0.026	0.057	-0.016	0.030	**-0.029**	**-0.029**
Alfalfa	0.87	159	-2.669	**0.000**	0.027	0.058	-0.011	0.020	**-0.002**	**-0.003**
Lentils	0.90	156	-3.284	0.003	**0.018**	0.058	**-0.011**	0.022	**-0.033**	-0.084

Note: The highlighted coefficients are not significant at 5% level.
The dependent variable is a fourth-root of EPIC simulated erosion estimates.

Table 27. Metamodel Parameters for Wind Erosion (t/ha) in Saskatchewan by Crops on Stubble

CROP	R-Sqr	N	INTER	RAIN	UAV	LATI	SAND	OMBD	DRTIL	DNTIL
Canola	0.89	294	-3.775	-0.001	0.343	0.068	0.006	-0.069	-0.179	-0.296
S_Fallow	0.93	453	-2.234	-0.002	0.618	0.022	0.013	-0.175	-0.143	-0.327
Flax	0.89	333	-2.383	0.000	0.317	0.038	0.008	-0.073	-0.210	-0.341
Field_Peas	0.89	294	-4.580	-0.001	0.418	0.077	0.008	-0.107	-0.165	-0.240
Barley	0.84	453	-3.872	-0.001	0.287	0.070	0.008	-0.085	-0.199	-0.293
Wheat	0.81	453	-3.720	**0.000**	0.344	0.058	0.008	-0.073	-0.274	-0.316
Fall_Rye	0.91	186	-3.157	-0.001	0.374	0.049	0.008	-0.101	-0.062	-0.062
Alfalfa	0.80	183	-6.221	-0.001	0.326	0.112	0.006	-0.043	**-0.009**	**-0.009**
Lentils	0.83	45	-0.810	**0.002**	0.627	**-0.042**	0.008	**-0.018**	-0.147	-0.251

Note: The highlighted coefficients are not significant at 5% level.
The dependent variable is a fourth-root of EPIC simulated erosion estimates.

Table 28. Metamodel Parameters for Water Erosion (t/ha) in Saskatchewan by Crops on Stubbl

CROP	R-Sqr	N	INTER	RAIN	LATI	SLOPE	OMBD	RCN	DRTIL	DNTIL
Canola	0.88	294	-3.481	0.003	0.017	0.062	-0.030	0.023	-0.060	-0.079
S_Fallow	0.89	453	-2.589	0.004	-0.013	0.083	-0.040	0.031	-0.090	-0.192
Flax	0.87	333	-2.505	0.004	**-0.009**	0.073	-0.032	0.025	-0.091	-0.131
Field_Peas	0.87	294	-3.132	0.003	**0.010**	0.061	-0.031	0.024	-0.071	-0.092
Barley	0.80	453	-2.297	0.003	**0.004**	0.056	-0.018	0.018	-0.082	-0.112
Wheat	0.82	453	-2.441	0.004	**-0.004**	0.065	-0.020	0.022	-0.142	-0.155
Fall_Rye	0.90	186	-2.909	0.004	**0.004**	0.054	-0.023	0.023	**-0.022**	**-0.020**
Alfalfa	0.88	183	-4.223	0.003	0.029	0.055	**-0.013**	0.024	**0.001**	**-0.001**
Lentils	0.97	45	**-1.384**	0.003	**-0.037**	0.048	-0.096	0.040	-0.044	-0.066

Note: The highlighted coefficients are not significant at 5% level.
The dependent variable is a fourth-root of EPIC simulated erosion estimates.

Table 29. Metamodel Parameters for Wind Erosion (t/ha) in Manitoba by Crops on Stubble

CROP	R-Sqr	N	INTER	RAIN	UAV	LATI	SAND	OMBD	DRTIL	DNTIL
Canola	0.90	186	**1.153**	-0.001	0.459	-0.036	0.009	-0.079	-0.279	-0.401
S_Fallow	0.88	102	5.127	-0.003	0.524	-0.093	0.013	-0.148	-0.148	-0.319
Flax	0.92	63	-2.985	**0.000**	0.385	**0.045**	0.009	-0.080	-0.182	-0.286
Field_Peas	0.84	186	**0.598**	**0.001**	0.470	**-0.045**	0.012	-0.087	-0.189	-0.242
Barley	0.90	186	**-1.396**	-0.001	0.479	**0.011**	0.009	-0.084	-0.189	-0.265
Wheat	0.90	186	-2.755	0.001	0.542	**0.019**	0.009	-0.080	-0.219	-0.251
Fall_Rye	0.87	69	**-3.361**	**0.000**	0.439	**0.050**	0.008	-0.096	-0.065	-0.066
Sunflower	0.91	114	4.127	-0.002	0.450	-0.079	0.010	-0.089	-0.331	-0.464
Alfalfa	0.91	186	-2.737	**0.000**	0.470	0.030	0.007	-0.083	**-0.010**	**-0.008**
Lentils	0.86	138	**2.379**	-0.006	0.401	**0.002**	0.010	-0.108	-0.140	-0.203

Note: The highlighted coefficients are not significant at 5% level.
The dependent variable is a fourth-root of EPIC simulated erosion estimates.

Table 30. Metamodel Parameters for Water Erosion (t/ha) in Manitoba by Crops on Stubble

CROP	R-Sqr	N	INTER	RAIN	LATI	SLOPE	OMBD	RCN	DRTIL	DNTIL
Canola	0.92	186	**-0.362**	0.001	-0.028	0.073	-0.022	0.028	-0.136	-0.163
S_Fallow	0.92	102	**-0.952**	0.001	**-0.023**	0.105	**-0.011**	0.030	-0.127	-0.250
Flax	0.96	63	**-1.033**	**0.000**	**-0.008**	0.105	-0.031	0.031	-0.062	-0.096
Field_Peas	0.86	186	**1.089**	0.001	-0.061	0.066	**-0.011**	0.028	-0.097	-0.117
Barley	0.95	186	**-0.175**	0.001	-0.030	0.066	-0.016	0.027	-0.152	-0.186
Wheat	0.90	186	1.784	**0.000**	-0.071	0.080	-0.016	0.030	-0.178	-0.189
Fall_Rye	0.96	69	3.246	**-0.001**	-0.092	0.074	-0.024	0.030	-0.035	-0.035
Sunflower	0.96	114	**1.274**	0.002	-0.070	0.093	-0.023	0.028	-0.086	-0.106
Alfalfa	0.96	186	**-0.006**	0.000	-0.034	0.064	-0.010	0.026	**0.000**	**-0.001**
Lentils	0.95	138	**-0.031**	0.001	-0.044	0.112	-0.024	0.029	-0.040	-0.060

Note: The highlighted coefficients are not significant at 5% level.
The dependent variable is a fourth-root of EPIC simulated erosion estimates.

Table 31. Metamodel Parameters for Wind Erosion (t/ha) by Province: Crops on Fallow

CROP	R-Sqr	N	INTER	RAIN	UAV	LATI	SAND	OMBD	DRTIL	DNTIL
Saskatchewan										
Canola	0.88	294	-5.896	-0.001	0.548	0.096	0.009	-0.112	**0.000**	**-0.011**
Wheat	0.92	453	-4.063	-0.001	0.514	0.063	0.010	-0.114	**0.013**	**0.006**
Lentils	0.91	333	-2.939	-0.002	0.543	0.046	0.012	-0.114	-0.055	**-0.045**
Alberta										
Canola	0.83	453	-3.331	-0.001	0.582	0.043	0.006	-0.040	**-0.006**	**-0.018**
Wheat	0.81	453	-3.309	-0.001	0.552	0.045	0.007	-0.056	**-0.009**	**-0.017**
Manitoba										
Wheat	0.89	186	5.789	-0.003	0.594	-0.114	0.008	-0.082	**0.013**	**0.014**
Lentils	0.84	183	**-0.470**	**-0.002**	0.586	**-0.002**	0.011	-0.104	**-0.013**	**-0.001**

Note: The highlighted coefficients are not significant at 5% level.
The dependent variable is a fourth-root of EPIC simulated erosion estimates.

Table 32. Metamodel Parameters for Water Erosion (t/ha) by Province: Crops on Fallow

CROP	R-Sqr	N	INTER	RAIN	LATI	SLOPE	OMBD	RCN	DRTIL	DNTIL
Saskatchewan										
Canola	0.90	294	-4.266	0.004	0.012	0.093	-0.038	0.038	**-0.007**	**-0.018**
Wheat	0.89	453	-2.903	0.003	**-0.006**	0.089	-0.020	0.034	**-0.006**	-0.028
Lentils	0.90	333	**0.512**	0.002	-0.059	0.102	**0.028**	0.029	**-0.014**	**-0.022**
Alberta										
Canola	0.90	294	-4.082	0.001	0.027	0.090	-0.012	0.037	**-0.001**	**-0.026**
Wheat	0.91	453	-2.355	0.003	-0.016	0.085	-0.013	0.035	**-0.011**	**-0.027**
Manitoba										
Wheat	0.97	186	**-0.089**	0.002	-0.055	0.118	**0.007**	0.035	**-0.022**	-0.044
Lentils	0.99	183	9.316	-0.003	-0.205	0.108	-0.028	0.041	**0.001**	-0.029

Note: The highlighted coefficients are not significant at 5% level.
The dependent variable is a fourth-root of EPIC simulated erosion estimates.

explanatory power provided by LATI is very low, especially for Manitoba where the LATI coefficient is insignificant for most crops.

Three variables, RAIN, SLOPE, and RCN, capture the majority of the variation explained by the water erosion metamodels. The signs of these variables are all positive, which is consistent with known theory that increasing rain, slope gradient, and runoff curve numbers will result in higher erosion rates (the higher the runoff curve number, the greater the amount of surface runoff). The signs for DRTIL and DNTIL are again negative, implying that water erosion will decrease with decreasing tillage as expected.

The negative signs on the OMBD coefficients indicate that water erosion rates decrease as soil organic matter and bulk density increases, which was consistent with expectations. Originally, a single organic matter term was tried for the water erosion metamodels that was often insignificant and yielded very little improvement in explanatory power. Similar to the wind erosion metamodels, however, an increase in the explanatory ability of the water erosion metamodel was seen by incorporating the OMBD term.

The previous comments regarding the sign of the LATI coefficient also hold true for the water erosion metamodels as well. The explanatory power of LATI is again very low, particularly for the Alberta and Saskatchewan water erosion metamodels where the LATI coefficients are insignificant for the majority of crops.

Almost all DRTIL and DNTIL coefficients estimated for crops following fallow for the wind and water erosion metamodels lacked statistical significance. As discussed previously for the EPIC results, this may be a function of the majority of the erosion occurring in the months preceding the seeding of the crops of a given year. The tillage variables were always insignificant for alfalfa. This reflects the fact that while three different tillage systems were simulated for barely in rotation 2 (see Tables 3 and 10), only conventional systems were simulated for alfalfa within the same rotation (i.e., the predicted erosion rates for alfalfa were not significantly affected by the different tillage systems simulated for barley within rotation 2). The tillage variables were insignificant for half of the fall rye erosion metamodels. This is related to the fact that only two tillage levels being simulated for fall rye, with a "conventional" system similar to the reduced tillage systems simulated for the other crops.

A. Validation of the Metamodels

Metamodel "validation" refers to testing the robustness and predictive ability of the estimated models. Metamodel validation often differs from the usual sense of validation in which statistical and process models are compared with actual (observed) data, because the metamodels are built with simulated data. Validating the metamodels is important because they are two steps away from the underlying real processes. Greater confidence can be placed in the regression metamodels, and their estimated parameters and predictions, when they are statistically validated before being integrated into the unified modeling system. The possible statistical validation methods include (1) comparison of metamodel predictions with observed (measured data) soil erosion rates, (2) comparison of metamodel predictions with simulated data, (3) validation with new data, and (4) cross-validation (split-half validation) in which the original data set is randomly split into two halves, a metamodel is fitted for each half separately, and the fitted metamodels are used to predict the other half of the data (Snee 1977; McCarthy, 1976; Friedman and Friedman, 1985).

As described in section IV, only qualitative comparisons were possible between the EPIC results and the limited measured erosion data that exists for conditions in the Prairies. Thus, the validation of the metamodels must be confined to the other three methods listed above. In the absence of any limitations to obtaining new data, model validation with new data is the best method. However, generation of additional EPIC data was not possible due to time and cost constraints. Snee (1977) regards data splitting using either a random split-half, or splitting the data based on the underlying structural makeup, as alternative procedures when the preferred method of evaluation on new data is not feasible. Therefore, the validations were performed by comparing the metamodel predictions with the EPIC simulated values and by using a random split-half validation (cross-validation) technique.

Tables 33 and 34 summarize several important statistics, by province and crops on stubble, that judge the predictive power of the estimated wind and water erosion metamodels. The error between the predicted metamodel outputs and the simulated data were small, as shown by the values of the mean absolute errors and root mean squared errors (RMSE). In confirmation, the prediction R-squares (R^2) and the Pearson correlation ($\hat{p}$) between simulated and predicted erosion rates were high, generally ranging from 0.80 to 0.95. As an additional measure of accuracy, predicted metamodel mean values were compared with the simulated EPIC means. The majority of the predicted mean values were in good agreement with the simulated data. The results of testing the erosion metamodels for crops grown on fallow were similar to those shown in Tables 33 and 34.

Stone (1974) and Snee (1977) offer a good review and discussion of cross-validation and alternative data-splitting methods. According to Snee, cross-validation by data splitting is a method to test the in-use prediction accuracy of the model and simulate the complete or partial

Table 33. Summary statistics to judge the predictive power of the wind erosion metamodels by province and crop

Province/Crop	Mean Absolute Error	RMS Error	Prediction R^2	$\hat{\rho}$ [a]	Mean Erosion Rates (t/ha) Simulated[b]	Predicted[b]
Alberta						
Canola	0.1102	0.1458	0.82	0.87	0.70	0.49
S-Fallow	0.1929	0.2551	0.81	0.87	3.32	1.78
Flax	0.1181	0.1541	0.80	0.84	0.66	0.41
Field Peas	0.0801	0.1031	0.78	0.76	0.10	0.08
Barley	0.1047	0.1394	0.79	0.80	0.41	0.26
Wheat	0.1130	0.1473	0.82	0.87	0.73	0.51
Fall Rye	0.0616	0.0786	0.83	0.85	0.16	0.14
Alfalfa	0.0735	0.0926	0.79	0.81	0.09	0.08
Lentils	0.1057	0.1398	0.88	0.88	1.20	0.86
Saskatchewan						
Canola	0.0770	0.0970	0.89	0.91	0.85	0.76
S-Fallow	0.1394	0.1758	0.93	0.94	7.99	6.72
Flax	0.0937	0.1192	0.89	0.92	1.38	1.20
Field Peas	0.0927	0.1180	0.89	0.92	1.33	1.13
Barley	0.0969	0.1244	0.84	0.90	1.00	0.84
Wheat	0.1269	0.1587	0.81	0.88	2.06	1.73
Fall Rye	0.0733	0.0963	0.91	0.92	1.04	0.94
Alfalfa	0.0837	0.1027	0.81	0.89	0.47	0.42
Lentils	0.0880	0.1027	0.86	0.95	0.43	0.36
Manitoba						
Canola	0.0945	0.1211	0.91	0.94	1.89	1.61
S-Fallow	0.1406	0.1665	0.89	0.97	3.98	3.30
Flax	0.0623	0.0870	0.92	0.95	0.76	0.68
Field Peas	0.1470	0.1770	0.84	0.93	2.60	2.17
Barley	0.0904	0.1173	0.90	0.93	1.44	1.22
Wheat	0.0974	0.1254	0.90	0.95	2.40	2.11
Fall Rye	0.0926	0.1062	0.88	0.96	1.35	1.23
Alfalfa	0.0720	0.0955	0.91	0.95	1.11	1.01
Lentils	0.1323	0.1645	0.86	0.97	2.85	2.42
Sunflower	0.0964	0.1167	0.92	0.97	2.41	2.11

[a] $\hat{\rho}$ is the Pearson correlation coefficient—between simulated and predicted wind erosion.

[b] "Simulated" mean wind erosion rates were predicted by EPIC and "predicted" mean wind erosion rates are metamodel results.

Table 34. Summary statistics to judge the predictive power of the water erosion metamodels by province and crop

Province/Crop	Mean Absolute Error	RMS Error	Prediction R^2	$\hat{\rho}$ [a]	Mean Erosion Rates(t/ha) Simulated[b]	Predicted[b]
Alberta Canola	0.0845	0.1071	0.90	0.94	1.01	0.93
S-Fallow	0.1114	0.1434	0.90	0.94	2.97	2.74
Flax	0.0890	0.1162	0.91	0.96	1.72	1.66
Field Peas	0.0736	0.0953	0.84	0.90	0.38	0.35
Barley	0.0769	0.0978	0.90	0.89	0.52	0.43
Wheat	0.0885	0.1129	0.89	0.84	0.91	0.77
Fall Rye	0.0651	0.0831	0.96	0.98	1.47	1.50
Alfalfa	0.0563	0.0729	0.87	0.91	0.25	0.23
Lentils	0.0769	0.0957	0.90	0.95	0.66	0.64
Saskatchewan Canola	0.0750	0.0960	0.89	0.88	0.38	0.33
S-Fallow	0.0899	0.1150	0.89	0.86	1.02	0.90
Flax	0.0899	0.1144	0.87	0.87	0.64	0.54
Field Peas	0.0753	0.0985	0.88	0.85	0.35	0.30
Barley	0.0811	0.1077	0.81	0.81	0.22	0.17
Wheat	0.0947	0.1231	0.82	0.80	0.42	0.32
Fall Rye	0.0637	0.0805	0.90	0.89	0.27	0.24
Alfalfa	0.0694	0.0897	0.89	0.87	0.29	0.25
Lentils	0.0420	0.0513	0.98	0.99	0.80	0.77
Manitoba Canola	0.0535	0.0710	0.93	0.93	0.56	0.53
S-Fallow	0.0769	0.0955	0.92	0.94	1.60	1.49
Flax	0.0372	0.0461	0.97	0.97	1.10	1.09
Field Peas	0.0754	0.0962	0.86	0.83	0.46	0.42
Barley	0.0428	0.0567	0.95	0.96	0.35	0.33
Wheat	0.0709	0.0878	0.90	0.93	0.63	0.58
Fall Rye	0.0378	0.0529	0.96	0.90	0.42	0.41
Alfalfa	0.0331	0.0436	0.96	0.97	0.27	0.26
Lentils	0.0480	0.0647	0.95	0.94	0.82	0.79
Sunflower	0.0433	0.0529	0.96	0.96	0.60	0.58

[a] $\hat{\rho}$ is the Pearson correlation coefficient—between simulated and predicted wind erosion.

[b] "Simulated" mean water erosion rates were predicted by EPIC while "predicted" mean water erosion rates are metamodel results.

replication of the study. For purposes of cross-validation, the data were split randomly into two approximately equal halves. The first subset, ss1, was used to estimate the model, while the second subset, ss2, was used to measure the predictive ability of the model. The same procedure was then used to estimate a model with ss2 and test the predictive ability with ss1. The cross-validation results shown for wind and water erosion in Tables 35 and 36, respectively, demonstrate the robustness and predictive power of the estimated metamodels for crops grown on stubble. The sign and magnitude of the estimated coefficients from the two split-half models were also compared. The signs of the coefficients were the same in both samples, and the estimated coefficients were comparable in their magnitude. The cross-validation test for the crops grown on fallow indicated the same trends.

B. Strengths and Weaknesses of the Environmental Metamodels

The results discussed in section IV confirm that metamodeling is a statistically sound and robust technique. For several reasons, metamodels (reduced form response functions) are very effective within integrated modeling systems requiring multidisciplinary interaction, because of the underlying sampling design combined with good econometric estimation procedures used in building them. First, the constructed metamodels are relatively easy to understand and simple to operate. Second, they allow natural and scientific aggregation to any regional level of interest from the usual field-specific results of EPIC and similar simulation models. Finally, impacts of new policy scenarios can be evaluated without having to perform an entire new set of EPIC simulations.

However, there are limitations as to how the metamodels can be used. For example, the wind and water erosion metamodels constructed for this study can only be used to assess long-

Table 35. Cross-validation results for wind erosion metamodels

	Number of Objectives		SSI-Model[b] R^2	SSII-Pred.[b] R^2	SSII-Model[b] R^2	SSI-Pred.[b] R^2
	SSI[a]	SSII[a]				
Alberta						
Canola	164	151	.79	.83	.84	.77
S-Fallow	164	143	.78	.81	.83	.76
Flax	151	132	.81	.77	.78	.80
Field peas	95	74	.76	.76	.80	.73
Barley	164	151	.76	.79	.80	.75
Wheat	164	151	.80	.81	.82	.79
Fall rye	55	47	.84	.76	.80	.76
Alfalfa	85	74	.73	.81	.82	.73
Lentils	84	72	.90	.84	.85	.88
Saskatchewan						
Canola	153	141	.89	.88	.89	.88
S-fallow	232	221	.94	.92	.93	.93
Flax	174	159	.89	.88	.89	.89
Field peas	153	141	.89	.88	.88	.88
Barley	232	221	.85	.82	.83	.84
Wheat	232	221	.81	.80	.81	.80
Fall rye	98	88	.92	.89	.90	.91
Alfalfa	97	86	.77	.80	.82	.74
Lentils	20	25	.87	.69	.83	.83
Manitoba						
Canola	98	88	.90	.90	.90	.89
S-fallow	55	47	.90	.83	.83	.89
Flax	33	30	.92	.89	.89	.89
Field peas	98	88	.82	.84	.86	.77
Barley	98	88	.89	.89	.89	.88
Wheat	98	88	.90	.88	.89	.89
Fall rye	36	33	.91	.77	.79	.87
Alfalfa	98	88	.90	.90	.91	.89
Lentils	72	66	.83	.82	.88	.75
Sunflower	64	50	.92	.87	.87	.91

[a]SSI is sub-sample one and SSII is sub-sample two.

[b]Predicted results (SSII-Pred.) estimated with sub-sample two for the metamodel (SSI-Model) constructed with sub-sample one and vice-versa.

Table 36. Cross-validation results for water erosion metamodels

	Number of Objectives		SSI-Model[b] R^2	SSII-Pred.[b] R^2	SSII-Model[b] R^2	SSI-Pred.[b] R^2
	SSI[a]	SSII[a]				
Alberta						
Canola	164	151	.92	.87	.88	.91
S-Fallow	164	143	.90	.88	.88	.90
Flax	151	132	.90	.92	.93	.89
Field peas	95	74	.84	.81	.84	.79
Barley	164	151	.91	.84	.87	.89
Wheat	164	151	.90	.85	.89	.87
Fall rye	55	47	.96	.93	.95	.94
Alfalfa	85	74	.88	.83	.86	.82
Lentils	84	72	.90	.88	.89	.89
Saskatchewan						
Canola	153	141	.88	.88	.88	.88
S-fallow	232	221	.89	.88	.89	.88
Flax	174	159	.88	.85	.87	.86
Field peas	153	141	.87	.87	.88	.86
Barley	232	221	.80	.79	.81	.78
Wheat	232	221	.82	.80	.82	.80
Fall rye	98	88	.90	.89	.90	.89
Alfalfa	97	86	.87	.89	.90	.85
Lentils	20	25	.98	.95	.97	.93
Manitoba	98					
Canola		88	.91	.91	.93	.90
S-fallow	55	47	.90	.93	.93	.89
Flax	33	30	.96	.96	.97	.93
Field peas	98	88	.87	.83	.85	.84
Barley	98	88	.94	.94	.94	.94
Wheat	98	88	.90	.90	.90	.89
Fall rye	36	33	.97	.94	.93	.96
Alfalfa	98	88	.96	.95	.96	.95
Lentils	72	66	.92	.96	.92	.96
Sunflower	64	50	.96	.94	.96	.96

[a]SSI is sub-sample one and SSII is sub-sample two.

[b]Predicted results (SSII-Pred.) estimated with sub-sample two for the metamodel (SSI-Model) constructed with sub-sample one and vice-versa.

term average erosion impacts. They can not be applied to assess the erosion impacts over shorter time durations, such as weekly cumulative amounts or specific storm-events. Likewise, these metamodels are not portable to other regions, unless it is demonstrated that the soil, weather, management, and other characteristics of the "new" region fall within the ranges of the sampled parameters used to construct the metamodels. Another important constraint is that the metamodels should be used for making relative comparisons between scenarios, rather than being used to predict absolute erosion rates.

It is also emphasized that wind and water erosion are modelled (metamodeled) as separate processes. If there is strong evidence that the two processes are not independent, then the wind and water metamodels would need to be estimated simultaneously (jointly) using the simultaneous or Seemingly Unrelated Regression (SUR) procedures to account for interprocess correlations. This could be considered for future improvements.

However, the best way to improve the wind and water erosion metamodels is to improve the accuracy of EPIC itself. As shown in section IV the explanatory power of the metamodels for describing EPIC output is very high, leaving little room for improvement of the actual statistical procedures themselves. Thus, the next step is to refine EPIC's ability to estimate crop yields, wind and water erosion, and other processes for Prairie Province conditions. Some specific suggestions are given here for further testing and potential modifications of EPIC, building on the recommendations given in Agriculture Canada (1993b):

1) Available data sets with measured erosion data should be identified and obtained to further test the EPIC wind and water erosion submodels. Expert opinion should be sought out to "fill in the gaps" as much as possible where validation data are lacking.

2) Additional calibration of the EPIC crop growth model and yield estimates is needed. Regional variation in planting dates and management systems should be incorporated into the modelling system. Crop response to nitrogen and soil moisture should be examined in more detail for Prairie Province conditions. The effect of overestimates of nitrogen stress for fallow-cropping systems should be further examined. The possibility of underprediction of moisture stress for continuous cropping systems should be examined as well.
3) Further testing of the residue decomposition routine should be performed to make sure it is performing within expected bounds.
4) Better estimates of the BW parameters for the different crops grown in Western Canada could be obtained from more quantitative research on the effects of growing crops and crop residues on erosion.
5) In general, continued testing of the EPIC crop growth model and other components should be performed with long-term rotation data sets available for different sites in the Prairie Provinces and with crop insurance data.

VI. Aggregation of Environmental Indicators

In order to compare environmental indicators with economic indicators in a consistent manner for each policy scenario, the environmental indicators must be aggregated from the landscape polygon level to the CRAM production region level. This is a multiple step process that begins with inputting predicted RS-CRAM cropping patterns and tillage distributions to the metamodels, and then aggregating the environmental indicators back up to the production regions. The necessary steps are described by using the example shown in Figure 18, which shows how the ARA boundaries overlay the landscape polygons in Alberta CRAM region 4. The overlays of

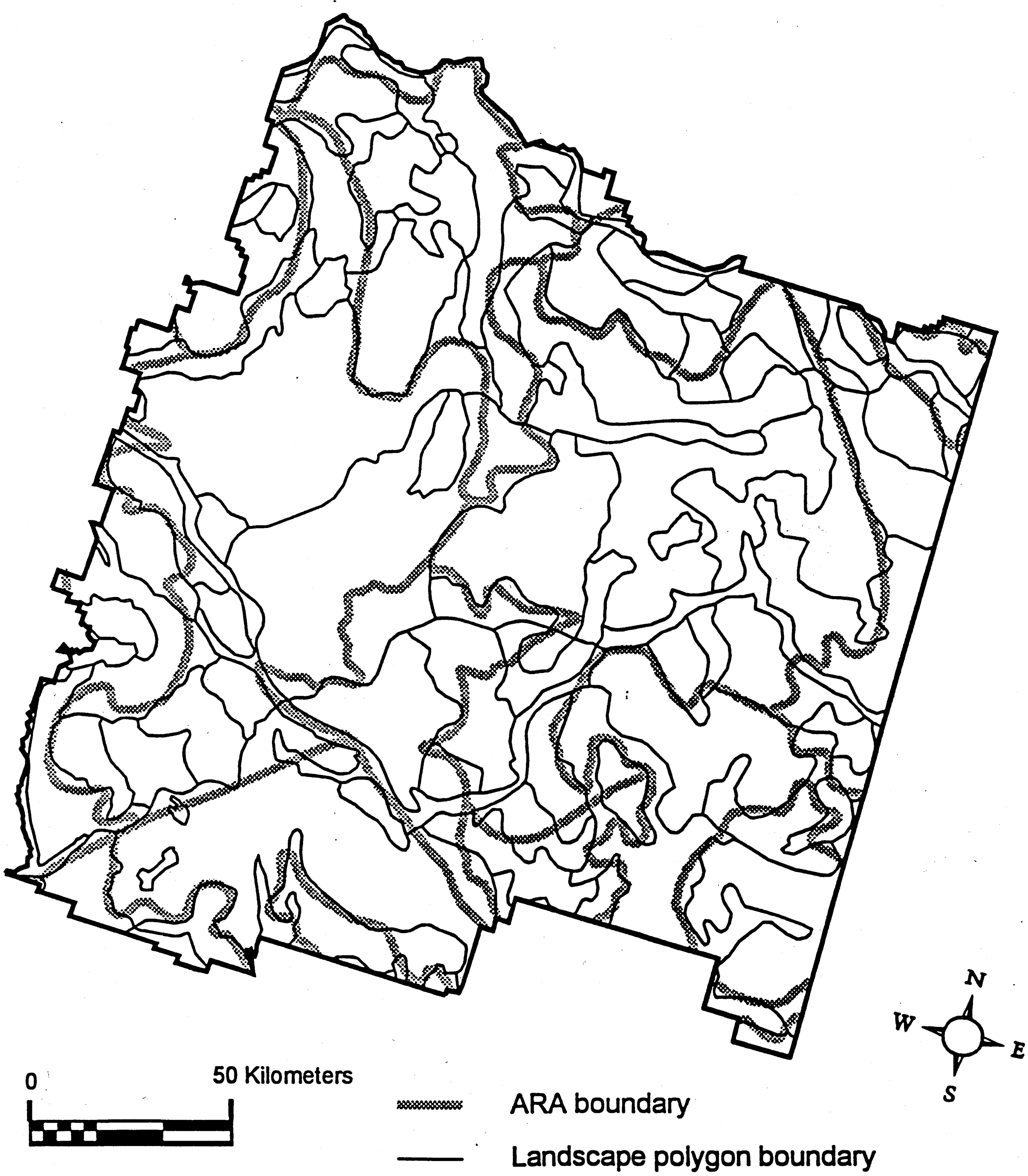

Figure 18. Overlay of ARA boundaries on landscape polygon boundaries for CRAM region 4 in Alberta

the RS-CRAM, ARA, and landscape polygon boundaries were performed in the ARC/INFO geographic information software package, which provided a consistent format for constructing the area weights between the different spatial units.

The initial step in estimating environmental outcomes for a given policy scenario is to input the predicted RS-CRAM cropping patterns and tillage distributions into the metamodel of interest for every ARA, landscape polygon, and soil combination available in the environmental database that exists within the CRAM production region. This underscores the ability of the metamodels to be extrapolated to other soil layer and landform conditions besides those that were originally used to construct the metamodels, providing the "new" conditions fall within the ranges of the original sample population data. In this step, it is assumed that the cropping and tillage practices are evenly distributed across all soils and landscape polygons within the RS-CRAM region. In reality, cropping patterns and management systems are not evenly distributed within individual CRAM regions, due to differences in soil zones and other environmental features. However, it is not currently possible to account for these differences with the integrated modeling system.

Once the RS-CRAM estimates have been input to the metamodels, erosion rates are estimated for each landscape polygon-soil type combination available in the total population of the environmental database. The next step is to aggregate the indicators to the ARA level using weights based on the total cropped acres of each soil type in each landscape polygon. As can be seen from Figure 18, greater weight would be placed on those landscape polygon-soil combinations that occupy the most area. It is also important to point out that some landscape polygons are not included in agriculturally important ARAs (the dropped polygons noted in Table 15). In these situations the weights are adjusted (normalized) based on the remaining cropped acreages of the other landscape polygons within the ARA.

Two additional problems had to be corrected. The first was the fact that landscape polygon boundaries could cross ARA boundaries in Alberta, as shown for Alberta CRAM region 4 in Figure 18. This resulted in many situations where multiple pieces of polygons existed independently within an ARA. This problem was dealt with by aggregating the pieces of different landscape polygons within ARAs in Alberta into one polygon as described in Agriculture Canada (1993b). For example, two unique landscape polygons were created if pieces of a landscape polygon existed in two different ARAs in Alberta. This allowed environmental indicators to be directly aggregated from landscape polygons to the ARA level in Alberta.

A similar weighting procedure was employed to ensure consistent aggregation of the environmental indicators from the landscape polygon and ARA levels to the CRAM production region level. Landscape polygon and ARA boundaries often cross CRAM production region boundaries in all three provinces. In these cases, the acreages of each part of a landscape polygon and a ARA lying within a single CRAM region were computed, providing a consistent set of area weights to allow aggregation of environmental indicators to the CRAM region level.

VII. Summary

The interface between RS-CRAM and the environmental component of the integrated modelling system has been described for crops, crop sequences, and management systems representative of Western Canada. An experimentally designed set of EPIC simulations were performed to generate erosion output that was used to construct wind and water erosion metamodels (response functions). The results of the EPIC simulations indicated that wind erosion would be the dominant erosion problem over most of Saskatchewan and Manitoba. For Alberta, water erosion was predicted to be the dominant problem, except for southern portion of the province. Erosion impacts were sensitive to tillage and cropping patterns. EPIC predicted yields did not vary much across tillage, a result consistent with measured observations. However, the EPIC yield estimates tended to be higher than previous average census yields used in CRAM. Also, the model appears to underpredict yields of crops grown on fallow in the more humid regions of the Prairie Provinces.

Fourth-root transformations of the EPIC output were required to construct the erosion metamodels in order to satisfy the normality criteria. The wind and water erosion metamodels estimated for the three provinces were very robust, with the majority possessing r^2 values in the range of 0.80-0.97. The predictive power of the metamodels was confirmed in validation tests comparing metamodel output with the original simulation data. These validation tests included a comparison with the entire set of simulated data and two cross-validation tests. The efficiency of the metamodels in facilitating the integration of the complete policy modeling system was described. Finally, the process of aggregating environmental indicators, estimated with the metamodels, from the landscape polygon level to ARAs and ultimately to the CRAM region level was also described.

It was emphasized that the environmental metamodels should be used to provide estimates of relative differences rather than absolute prediction of wind and water erosion when comparing between different management systems and environmental conditions for policy scenarios. Continued calibration and code modifications based on further testing of EPIC should produce more reliable estimates of crop yields and wind and water erosion for Alberta, Saskatchewan, and Manitoba, that can be incorporated into improved metamodels in the future.

References

Agriculture Canada. 1993a. "Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment (Report 1: Conceptual Framework)." Technical Report 2/93, Policy Branch, Ottawa, Ontario.

Agriculture Canada. 1993b. "Agricultural Policies and Soil Degradation in Western Canada: An Agro-Ecological Economic Assessment (Report 2: The Environmental Modelling System)." Technical Report 5/93, Policy Branch, Ottawa, Ontario.

Bouzaher, A., J.B. Braden, and G.V. Johnson. 1990. "A Dynamic Programming Approach to a Class of Nonpoint Source Pollution Control Problems." *Management Science* 66(1):1-15.

Bouzaher, A. and J.F. Shogren. 1992. "Modeling Nonpoint Source Pollution in an Integrated System." Presented at The International Workshop on Environmental Policy Modeling, Steamboat Springs, Colorado.

Bouzaher, A., P.G. Lakshminarayan, R. Cabe, A. Carriquiry, P.W. Gassman, and J.F. Shogren. 1993. "Metamodels and Nonpoint Pollution Policy in Agriculture." *Water Resources Research* 29(6): 1579-1587.

Brower, F. 1987. *Integrated Environmental Modeling: Design and Tools*. Dordrecht: Kluwer Academic Publishers.

Campbell, C.A., R.P. Zentner, H.H. Janzen, and K.E. Bowren. 1990. *Crop Rotation Studies on the Canadian Prairies*. Publication 1841/E, Research Branch, Agriculture Canada, Ottawa, Ontario.

Chanasyk, D.S. and C.P. Woytowich. 1987a. "Sediment Yield as a Result of Snowmelt Runoff in the Peace River Region." *Can. Agrc. Engr.* 29(1):1-6.

Chanasyk, D.S. and C.P. Woytowich. 1987b. "A study of water erosion in the Peace River Region." Farming for the Future, Project # 83-0145. Department of Soil Science, University of Alberta, Edmonton, Alberta.

Chepil, W.S., F.H. Siddoway, and D.V. Armbrust. 1962. "Climatic Factor for Estimating Wind Erodibility of Farm Fields". *J. Soil and Water Cons.* 63:607-617.

Cochran, W. 1977. *Sampling Techniques*. Wiley, New York, New York.

Cole, G.V., and B.C. English. 1990. "The Micro Oriented Agricultural Production System (MOAPS): A Documentation." Research Report, 90-03. Department of Agricultural Economics and Rural Sociology, University of Tennessee, Knoxville.

Coote, D.R. 1984. "The Extent of Soil Erosion in Western Canada". Proceedings of the @nd Annual Western Provincial Conference on Rationalization of Water and Soil Research and Management, Saskatoon, Saskatchewan.

Coy, G. 1993. Personal Communication. Alberta Agriculture, Fairview, Alberta.

de Jong, E. 1993. Personal Communication. Soil Science Department, University of Saskatchewan, Saskatoon, Saskatchewan.

de Jong, E., C.B.M. Begg, and R.G. Kachanoski. 1983. "Estimates of Soil Erosion and Deposition for some Saskatchewan Soils." *Can J. Soil Sci.* 63:607-617.

de Jong, E., H. Villar, and J.R. Bettany. 1982. "Preliminary Investigations on the use of ^{137}Cs to Estimate Erosion in Saskatchewan". *Can. J. Soil Sci. 62:673-683.*

de Jong. E. and R.G. Kachanoski. 1988. "The Importance of Erosion in the Carbon Balance of Prairie Soils." *Can. J. Soil Sci.* 68:111-119.

Dickinson, W.T. and G.J. Wall. 1983. "Soil Erosion by Water - Nature and Extent." Notes on Agriculture, University of Guelph, December, pp. 4-7.

Dumanski, J. 1993. Personal Communication. Land Resource Research Centre, Research Branch, Agriculture Canada, Ottawa, Ontario.

EMA. 1993. "Environmental Assessment of GRIP Volume II: Main Technical Report." Environmental Management Associates, Calgary, Alberta.

Entz, P. 1993. Personal Communication. Manitoba Agriculture, Carman, Manitoba.

Friedman, L. W., and H. H. Friedman. 1985 "Validating the simulation metamodel: Some practical approaches." *Simulation*, 45(3):144-146.

Gameda, S. 1993. Personal Communication. Land Resource Research Centre, Research Branch, Agriculture Canada, Ottawa, Ontario.

Hiley, J.C. and R.L. Wehrhahn. 1991. "Evaluation of the Sustainability of Extensive Annual Cultivation within Selected Agroecological Resource Areas of Alberta." Agriculture Canada, Land Resource Research Centre Contribution No. 91-18. Edmonton: Alberta Institute of Pedology. 88 pp.

Horner, G.L., J. Corman, R.E. Howitt, C.A. Carter, R.J. MacGregor. 1992. "The Canadian Regional Agriculture Model Structure, Operation and Development." Ottawa: Agriculture Canada.

Izaurralde, R.C., D.S. Chanasyk, R.F. Grant, M.C. Quiroga Jakas, and H. Puurveen. 1993. "Simulation of Changes in Soil Productivity: Final Report submitted to the National Soil Conservation Program of Canada." Department of Soil Science, University of Alberta, Edmonton, Alberta.

Jenkins, C. 1982. "What Cost Erosion?" Unpublished Report, Manitoba Department of Agriculture, Winnipeg, Manitoba.

Jensen, T. 1993. Personal Communication. Alberta Agriculture, Edmonton, Alberta.

Johnston, A. 1993. Personal Communication. Agriculture Canada Research Station, Melfort, Saskatchewan.

Juma, N.G., R.C. Izaurralde, J.A. Robertson, and W.B. McGill. 1994. "Crop Yield and Soil Organic Matter Trends over 60 Years in a Typic Cryoboralf at Breton, Alberta." In: Soil Organic Matter in Temperate Regions: Driving Variables across a Site network. Proceedings of a Workshop held Feb. 18-21, 1992 at the Kellogg Biological Station, Hickory Corners, MI.

Kirkwood, V., A. Bootsma, R. de Jong, J. Dumanski, J.C. Hiley, E.C. Huffman, A. Moore, C. Onofrei, W.W. Pettapiece, B. Vigier. 1993. "Documentation of the Database Files Associated with the Agroecological Resource Area Maps for Alberta, Saskatchewan, and Manitoba (Draft)." Centre for Land and Biological Resources Research, Agriculture Canada, Ottawa, Ontario.

Kiss, J.J., E. de Jong, and H.P.W. Rostad. 1986. "An Assessment of Soil Erosion in West-Central Saskatchewan using Cesium-137." *Can. J. Soil Sci.* 66:591-600.

Lakshminarayan, P.G., J.D. Atwood, S.R. Johnson, and V.A. Sposito. 1991. "Compromise Solution for Economic-Environmental Decisions in Agriculture." *Journal of Environmental Management* 33:51-64.

Lafond, G.P., R.P. Zentner, R. Geremia, and D.A. Derksen. 1993. "The Effects of Tillage Systems on the Economic Performance of Spring Wheat, Winter Wheat, Flax and Field Pea Production in East-Central Saskatchewan." *Can. J. Plant Sci.* 73: 47-54.

Larney, F.J. 1993. Personal communication. Agricultural Canada Research Station, Lethbridge, Alberta.

Larney, F.J., C.W. Lindwall, R.C. Izaurralde, and A.P. Moulin. 1993. "Tillage Systems for Soil and Water Conservation in Western Canada." In: *Conservation Tillage in Temperate Regions; Development and Adaptation to Soil, Climatic, and Biological Constraints* (M.R. Carter, ed.), Lewis Publishers, CRC Press, Boca Raton, Florida.

Lin, L. and E. F. Vonesh. 1989. "An Empirical Nonlinear Data-Fitting Approach for Transforming Data to Normality." *Am. Stat.* 43(4): 237-243.

Martz, L.W. and E. de Jong. 1987. "Using Cesium-137 to assess the Variability of Net Soil Erosion and its Association with Topography in a Canadian Prairie Landscape." *Catena* 14: 439-451.

McCarthy, P. J. 1976. "The use of balanced half-sample replication in cross-validation studies." *J. American Statistical Association*, 71(355):596-604.

MacGregor, R.J. 1994. Personal Communication. Economic Analysis and Innovation Division, Industry Performance and Analysis Directorate, Agriculture Canada, Ottawa, Ontario.

McKenzie, R. 1993. Personal Communication. Alberta Agriculture, Lethbridge, Alberta.

Mermut, A.R., D.F. Acton, and W.D. Eilers. 1983. "Estimation of Soil Erosion and Deposition by a Landscape Analysis Technique on Clay Soils in Southwestern Saskatchewan." *Can. J. Soil Sci.* 63:727-739.

Milon, J.W. June 1987. "Optimizing Nonpoint Source Controls in Water Quality Regulation." *Water Resources Bulletin* 23:387-396.

Nicholaichuk, W. 1967. "Comparative Watershed Studies in Southern Saskatchewan." *Trans. ASAE.* 10:502-504.

Nicholaichuk, W. and D.W.L. Read. 1978. "Nutrient Runoff from Fertilized and Unfertilized Fields in Western Canada." *J. Environ. Qual.* 7:542-544.

Nijkamp, P. 1980. *Environmental Policy Analysis.* Chichester: Wiley.

Nolan, S., T. Goddard, and L.J.P. van Vliet. 1992. "Soil Erosion from Selected Conservation and Conventional Management Practices." In: Proceedings of the 29th Alberta Soil Science Workshop, Lethbridge, Alberta.

Padbury, G. 1993. Personal communication. Agriculture Canada Research Branch, Saskatoon, Saskatchewan.

Potter, J.R. 1993. Personal Communication. U.S. Department of Agriculture, Agricultural Research Service, Grassland Research Laboratory, Temple, Texas.

Setia, P. and S. Piper. January 1992. "Effects of Soil and Agricultural Chemicals Management on Farm Returns and Ground Water Quality." *Rev. of Agr. Econ.* 14:65-80.

Shapiro, S.S. and M.B. Wilk. 1965. "An Analysis of Variance Test for Normality (Complete Samples)." *Biometrika* 52: 591-611.

Shaykewich, C.F. 1993. Personal Communication. Department of Soil Science, University of Manitoba, Winnipeg, Manitoba.

Shields, J.A., C. Tarnocai, K.W.G. Valentine, and K.B. MacDonald. 1991. "Soil Landscapes of Canada - Procedures Manual and User's Handbook." Agriculture Canada Publication 1868/E, Land Resource Research Centre, Ottawa, Ontario.

Shoney, R.A. 1993. Personal Communication. Department of Agricultural Economics, University of Saskatchewan, Saskatoon, Saskatchewan.

Skidmore, E.L. 1993. Personal Communication. U.S. Department of Agriculture, Agricultural Research Service, Kansas State University, Manhattan, Kansas.

Skidmore, E.L. and R.G. Nelson. 1992. "Small-Grain Equivalent of Mixed Vegetation for Wind Erosion Control and Prediction." *Agron. J.* 84: 98-101.

Skidmore, E.L. and J.R. Williams. 1991. "Modified EPIC Wind Erosion Model." In: *Modeling Plant and Soil Systems* (J. Hanks and J.T. Ritchie, eds.). Agronomy Monograph No. 31, American Society of Agronomy, Madison, Wisconsin.

Snee, R. D. 1977. "Validation of regression models: Methods and examples." *Technometrics*, 19(4):415-428.

Stone, M. 1974. "Cross-validatory choice and assessment of statistical predictions." *Journal of the Royal Statistical Society*, Series B, 36(2):111-147.

Tajek, J. 1994. Personal Communication. Centre for Land and Biological Resources Research, Agriculture Canada, Edmonton, Alberta.

Tajek, J., W.W. Pettapiece, and K.E. Toogood. 1985. "Water Erosion Potential of Soils in Alberta: Estimates using a Modified USLE." Agric. Can. Tech. Bull. No. 1985-29, Ottawa, Ontario. 35p.

Taylor, M.L. 1990. *Farm-level response to agricultural effluent control strategies: The case of the Willamette Valley*. Ph.D. dissertation. Corvallis: Oregon State University.

Togood, J.A. 1963. "Water Erosion in Alberta." *J. Soil Water Cons.* Nov.-Dec.:238-240.

Troeh, F.R., J.A. Hobbs, and R.L. Donahue. 1991. *Soil and Water Conservation, Second Edition*. Prentice Hall, Englewood Cliffs, New Jersey.

van Vliet, L.J.P. and J.W. Hall. 1991. "Effects of Two Crop Rotations on Seasonal Runoff and Soil Loss in the Peace River Region." *Can. J. Soil Sci.* 71:533-544.

Voroney, R.P., J.A. Van Veen, and E.A. Paul. 1981. "Organic Dynamics in Grassland Soils. 2. Model Validation and Simulation of the Long-Term Effects of Cultivation and Rainfall Erosion." *Can. J. Soil Sci.* 61:211-224.

Webber, R.J., J.D. Graham, and K.K. Klein. 1986. "The Structure of CRAM: A Canadian Regional Agricultural Model." Department of Agricultural Economics, University of British Columbia, Vancouver, British Columbia.

Williams, J.R. 1993. Personal Communication. U.S. Department of Agriculture, Agricultural Research Service, Grassland Research Laboratory, Temple, Texas.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1984. "A Modeling Approach to Determining the Relationship Between Erosion and Soil Productivity." *Trans. ASAE* 27(1):129-144.

Wossink, G.A.A., T.J. de Koeijer, and J.A. Renkema. 1992. "Environmental-Economic Policy Assessment: A Farm Economic Approach." *Agrc. Systems* 39:421-438.

Appendix A

Tables of Sampled Soils and

Tables of Sample and Population Statistics

Table A.1. List of Sampled Soils for the Province of Alberta

Soil	Slope	Slope Length(m)	Soil_Acres	Clay%	Bulk Density	Sand%	Organic Matter	CEC	ARA	Polygon Number
DVS	A	60	38171	12.0	1.30	25.0	2.00	20.0	78	749
KLM	A	60	142262	18.0	1.30	42.0	4.00	25.0	45	969
WWT	A	60	43255	13.0	1.40	80.0	1.50	18.0	28	575
BVH	B	70	26925	20.0	1.20	42.0	4.00	27.0	39	516
IRM	A	60	5104	8.0	1.40	73.0	3.00	12.0	38	545
DVS	B	50	2017	12.0	1.30	25.0	2.00	20.0	69	74
BVH	C	35	15598	20.0	1.20	42.0	4.00	27.0	39	515
HAN	B	70	12093	23.0	1.30	45.0	3.40	20.0	24	576
DEL	A	60	185931	24.0	1.30	24.0	5.50	17.0	26	659
TOM	A	60	8439	20.0	1.30	25.0	2.00	15.0	49	317
CHN	A	60	47753	21.0	1.30	35.0	3.30	24.0	6	643
HBM	A	60	16324	24.0	1.20	32.0	4.00	33.0	40	557
ABC	A	60	24178	25.0	1.30	45.0	2.00	24.0	51	240
EOR	B	70	116564	21.0	1.30	40.0	5.00	25.0	36	374
DVG	D	90	58394	35.0	1.20	35.0	4.00	30.0	13	572
MYW	A	60	1638	65.0	1.40	10.0	2.00	35.0	60	198
PRV	A	60	79139	33.0	1.25	9.0	6.30	36.0	73	110
MAB	B	50	24255	28.0	1.40	32.0	1.80	23.0	5	954
MCO	A	60	10928	40.0	1.30	10.0	3.00	31.0	54	417
AGS	A	60	6958	30.0	1.30	40.0	4.90	33.0	43	521
CTE	A	60	1614	36.0	1.30	7.0	8.50	42.0	63	110
BVL	A	60	5615	8.0	1.30	76.0	1.50	10.0	7	648
LAD	A	60	52644	14.0	1.25	33.0	4.50	26.0	67	52
ATL	A	60	22155	30.0	1.10	25.0	4.00	30.0	26	553
FLU	B	50	13730	22.0	1.20	46.0	3.00	25.0	39	551
ESH	A	60	20110	48.0	1.00	12.0	3.50	35.0	69	72
CMO	A	60	123437	25.0	1.10	40.0	4.00	28.0	45	539
GDB	A	60	26985	20.0	1.20	25.0	4.00	20.0	45	531
HKR	B	70	6214	16.0	1.30	35.0	3.00	20.0	24	581
HDY	B	50	6861	25.0	1.30	25.0	2.00	24.0	8	477
HKR	A	60	88210	16.0	1.30	35.0	3.00	20.0	30	532
DEL	B	100	31520	24.0	1.30	24.0	5.50	17.0	26	656
LET	A	60	148229	23.0	1.30	32.0	2.50	22.0	15	956
HKR	A	60	8738	16.0	1.30	35.0	3.00	20.0	45	532
EOR	A	60	43976	21.0	1.30	40.0	5.00	25.0	31	364
HND	C	35	17146	25.0	1.40	45.0	2.50	25.0	32	425
TNW	A	60	9498	10.0	1.40	65.0	2.00	3.0	51	236
CRD	A	60	39670	26.0	1.40	38.0	2.30	22.0	14	667
PUR	C	35	4052	30.0	1.40	35.0	3.00	26.0	10	640
TAG	B	50	5222	9.0	1.30	39.0	3.00	21.0	79	76
CFD	A	60	10395	23.0	1.40	19.0	2.10	19.0	5	954
MSN	B	50	26478	20.0	1.40	50.0	2.00	19.0	6	637
FAL	A	60	8244	33.0	1.20	15.0	3.50	30.0	79	101
BTN	A	60	15756	12.0	1.30	26.0	2.00	15.0	55	696
ATL	B	100	22728	30.0	1.10	25.0	4.00	30.0	27	561
FAL	A	60	1089	33.0	1.20	15.0	3.50	30.0	65	55
WTB	A	60	23794	25.0	1.30	15.0	3.00	34.0	54	442
ATL	A	60	35306	30.0	1.10	25.0	4.00	30.0	40	553
CTN	B	100	6459	43.0	1.30	22.0	4.30	40.0	12	914
LET	B	100	61304	23.0	1.30	32.0	2.50	22.0	25	579
CHN	A	60	21678	21.0	1.30	35.0	3.30	24.0	4	618
POK	A	60	22644	24.0	1.20	32.0	3.50	27.0	44	521
FMT	B	70	18000	20.0	1.30	35.0	2.00	19.0	4	619

Table A.1. Continued

Soil	Slope	Slope Length(m)	Soil_Acres	Clay%	Bulk Density	Sand%	Organic Matter	CEC	ARA	Polygon Number
POK	A	60	32681	24.0	1.20	32.0	3.50	27.0	54	437
HKR	B	30	4706	16.0	1.30	35.0	3.00	20.0	37	533
DVG	C	90	45051	35.0	1.20	35.0	4.00	30.0	11	907
CVD	B	50	4314	8.0	1.40	87.0	1.50	17.0	4	593
MGS	B	70	552	6.0	1.40	85.0	4.00	9.0	49	337
HAN	B	70	33124	23.0	1.30	45.0	3.40	20.0	29	576
FLU	A	60	14040	22.0	1.20	46.0	3.00	25.0	52	271
IRM	A	60	2911	8.0	1.40	73.0	3.00	12.0	45	530
FRY	C	35	12195	18.0	1.30	43.0	4.50	27.0	36	343
HND	A	60	24926	25.0	1.40	45.0	2.50	25.0	34	423
COA	B	100	56677	19.0	1.30	44.0	2.00	22.0	60	711
HUK	A	60	39531	20.0	1.30	40.0	2.00	22.0	8	605
MAB	D	40	28387	28.0	1.40	32.0	1.80	23.0	2	620
FMT	C	55	22960	20.0	1.30	35.0	2.00	19.0	5	598
BVL	B	60	7467	8.0	1.30	76.0	1.50	10.0	4	591
HUB	C	90	1104	30.0	1.40	25.0	2.00	15.0	43	683
HUK	A	60	17883	20.0	1.30	40.0	2.00	22.0	23	489
HND	B	70	25182	25.0	1.40	45.0	2.50	25.0	20	473
CFD	A	60	39218	23.0	1.40	19.0	2.10	19.0	18	650
LET	B	50	3986	23.0	1.30	32.0	2.50	22.0	32	452
CFD	B	70	27852	23.0	1.40	19.0	2.10	19.0	6	617
LET	A	60	16822	23.0	1.30	32.0	2.50	22.0	25	574
HND	B	70	23412	25.0	1.40	45.0	2.50	25.0	36	370
TAG	B	60	6854	9.0	1.30	39.0	3.00	21.0	66	49
KLM	A	60	6798	18.0	1.30	42.0	4.00	25.0	36	969
AGS	A	60	30859	30.0	1.30	40.0	4.90	33.0	45	513
AGS	A	60	11539	30.0	1.30	40.0	4.90	33.0	39	516
PED	A	60	10595	18.0	1.20	43.0	4.00	26.0	40	672
ATL	B	100	24722	30.0	1.10	25.0	4.00	30.0	40	561
ESH	A	60	6841	48.0	1.00	12.0	3.50	35.0	80	6
LTA	B	100	7880	24.0	1.00	33.0	4.00	38.0	26	565
BTN	B	100	9000	12.0	1.30	26.0	2.00	15.0	56	692
HKR	B	70	16138	16.0	1.30	35.0	3.00	20.0	8	581
MGS	B	50	1855	6.0	1.40	85.0	4.00	9.0	44	436
CCL	A	60	384	25.0	1.30	50.0	2.00	15.0	62	611
HKR	B	70	8472	16.0	1.30	35.0	3.00	20.0	30	581
FMT	B	50	17011	20.0	1.30	35.0	2.00	19.0	5	599
DEL	B	100	14842	24.0	1.30	24.0	5.50	17.0	40	565
MAB	B	70	11050	28.0	1.40	32.0	1.80	23.0	1	635
HND	B	70	20372	25.0	1.40	45.0	2.50	25.0	31	365
FLU	A	60	48590	22.0	1.20	46.0	3.00	25.0	51	271
LET	A	60	51634	23.0	1.30	32.0	2.50	22.0	14	956
LET	B	100	83812	23.0	1.30	32.0	2.50	22.0	16	653
FLU	B	50	591	22.0	1.20	46.0	3.00	25.0	43	551
SDN	B	70	25955	25.0	1.30	30.0	2.00	20.0	47	347
PUR	B	100	21096	30.0	1.40	35.0	3.00	26.0	10	639
SPS	B	100	7949	49.0	1.40	9.0	1.00	34.0	6	631
BZR	C	90	25835	27.0	1.20	37.0	4.00	30.0	10	918
CYG	A	60	5184	24.0	1.30	36.0	4.00	28.0	43	555
BZR	A	60	9577	27.0	1.20	37.0	4.00	30.0	12	913
MLA	B	70	3556	40.0	1.20	15.0	2.00	35.0	55	708
AGS	B	70	20248	30.0	1.30	40.0	4.90	33.0	45	508

Table A.2. List of Sampled Soils for the Province of Saskatchewan

Soil	Slope	Slope Length(m)	Soil_Acres	Clay%	Bulk Density	Sand%	Organic Matter	CEC	ARA	Polygon Number
HMA	A	80	4378	18.0	1.30	53.0	2.80	21.0	96	1700
SYA	A	80	20026	9.0	1.30	65.0	2.00	14.0	31	4000
WVA	B	110	16348	18.0	1.40	44.0	1.30	16.0	31	1734
AQA	A	80	14625	10.0	1.40	77.0	1.50	13.0	15	2209
MEA	C	60	9680	10.0	1.40	81.0	2.00	15.0	99	1662
OXA	A	40	225106	21.0	1.30	47.0	3.20	24.0	2	2242
OXA	B	50	18787	21.0	1.30	47.0	3.20	24.0	26	1840
MFA	C	60	4530	20.0	1.30	48.0	2.80	22.0	88	1626
HRA	B	50	1139	19.0	1.30	52.0	1.70	19.0	59	2327
WRA	B	50	247747	22.0	1.30	44.0	2.40	22.0	17	1956
WWA	A	80	19856	37.0	1.40	20.0	1.80	27.0	51	2268
STA	A	80	38500	25.0	1.30	33.0	2.60	24.0	81	1835
ADA	B	110	98732	26.0	1.40	38.0	1.70	22.0	64	2153
PYA	A	90	12138	26.0	1.20	29.0	4.00	29.0	22	1877
ECC	B	110	46040	40.0	1.40	21.0	1.80	29.0	57	2333
FXA	B	50	13590	24.0	1.30	33.0	1.80	21.0	66	1827
ETA	A	80	30492	29.0	1.20	27.0	3.00	29.0	28	1710
YKA	A	40	220263	20.0	1.20	46.0	4.00	26.0	10	1987
AMA	B	50	20218	29.0	1.30	39.0	2.20	25.0	12	2350
HMA	B	97	13712	18.0	1.30	53.0	2.80	21.0	88	1518
OXA	B	50	188928	21.0	1.30	47.0	3.20	24.0	18	2016
SUA	A	80	65356	40.0	1.30	16.0	2.30	30.0	75	1983
OXA	B	50	40786	21.0	1.30	47.0	3.20	24.0	17	2055
SCD	A	80	66552	59.0	1.30	5.0	1.60	37.0	68	2078
TRC	A	80	138179	26.0	1.30	35.0	1.90	22.0	11	2236
ADA	B	50	70891	26.0	1.40	38.0	1.70	22.0	13	2337
WRA	B	50	153130	22.0	1.30	44.0	2.40	22.0	8	3006
RAD	A	80	439085	62.0	1.40	8.0	2.00	40.0	15	2129
BYA	B	97	7232	16.0	1.40	51.0	1.50	16.0	63	2222
WRA	B	110	2600	22.0	1.30	44.0	2.40	22.0	81	1834
RAD	A	80	130712	62.0	1.40	8.0	2.00	40.0	75	1983
MRA	A	90	107163	50.0	1.20	10.0	4.50	43.0	32	1674
CFA	B	50	6467	25.0	1.20	26.0	3.50	27.0	100	1568
CFA	B	97	18054	25.0	1.20	26.0	3.50	27.0	85	1791
EWA	B	50	41040	27.0	1.30	30.0	2.50	25.0	23	1858
WKA	A	80	13411	20.0	1.30	35.0	2.20	20.0	49	2317
ESA	B	50	98626	23.0	1.30	42.0	2.50	23.0	4	2228
OXA	A	80	50578	21.0	1.30	47.0	3.20	24.0	2	2342
EGA	B	50	20959	32.0	1.30	36.0	3.00	29.0	9	2115
WHA	C	60	13078	21.0	1.30	42.0	2.80	23.0	31	1759
BRA	A	80	30035	18.0	1.30	50.0	2.20	19.0	78	3019
HRA	B	97	19836	19.0	1.30	52.0	1.70	19.0	55	2324
HTA	C	60	1380	10.0	1.40	74.0	1.20	12.0	71	2010
AQA	A	80	5821	10.0	1.40	77.0	1.50	13.0	24	2002
BYA	A	80	17203	16.0	1.40	51.0	1.50	16.0	77	2074
SCD	A	80	6458	59.0	1.30	5.0	1.60	37.0	74	1971
BGA	A	80	9678	12.0	1.40	76.0	1.50	13.0	15	2159
SCD	B	97	96931	59.0	1.30	5.0	1.60	37.0	68	2095

Table A.2. Continued

Soil	Slope	Slope Length(m)	Soil_Acres	Clay%	Bulk Density	Sand%	Organic Matter	CEC	ARA	Polygon Number
WVA	B	50	2933	18.0	1.40	44.0	1.30	16.0	45	4002
EDA	A	90	17008	26.0	1.30	17.0	1.60	21.0	33	1714
ROA	A	80	29754	27.0	1.30	33.0	2.00	23.0	55	2324
MEA	A	80	18565	10.0	1.40	81.0	2.00	15.0	22	1923
WRA	B	50	50803	22.0	1.30	44.0	2.40	22.0	76	2050
ECC	B	97	17416	40.0	1.40	21.0	1.80	29.0	68	2024
HYC	A	80	17748	28.0	1.30	28.0	2.40	26.0	26	1982
CRG	A	80	4622	6.0	1.30	84.0	2.60	15.0	36	1553
EWA	A	80	11748	27.0	1.30	30.0	2.50	25.0	15	2209
YKA	A	40	245700	20.0	1.20	46.0	4.00	26.0	23	1809
MAA	A	80	30656	21.0	1.30	42.0	2.80	23.0	108	1386
EWA	A	80	76577	27.0	1.30	30.0	2.50	25.0	78	1980
AQA	A	80	9764	10.0	1.40	77.0	1.50	13.0	26	1920
LNA	B	50	8088	8.0	1.30	39.0	1.60	13.0	120	1465
HRA	B	50	31710	19.0	1.30	52.0	1.70	19.0	66	2134
WSA	A	100	3422	10.0	1.30	72.0	2.10	14.0	22	1891
MEA	B	97	26701	10.0	1.40	81.0	2.00	15.0	88	1609
WRA	C	60	33835	22.0	1.30	44.0	2.40	22.0	25	1968
WKA	B	110	68250	20.0	1.30	35.0	2.20	20.0	50	2273
FXA	A	80	10406	24.0	1.30	33.0	1.80	21.0	62	2184
MFA	B	50	11117	20.0	1.30	48.0	2.80	22.0	88	1757
MFA	C	60	14226	20.0	1.30	48.0	2.80	22.0	100	1568
STA	B	97	12940	25.0	1.30	33.0	2.60	24.0	84	1785
OXA	B	50	157596	21.0	1.30	47.0	3.20	24.0	7	2178
CFA	A	80	46284	25.0	1.20	26.0	3.50	27.0	85	1690
SCD	A	80	13292	59.0	1.30	5.0	1.60	37.0	13	2306
OXA	C	60	1302	21.0	1.30	47.0	3.20	24.0	31	1759

Table A.3. List of Sampled Soils for the Province of Manitoba

Soil	Slope	Slope Length(m)	Soil_Acres	Clay%	Bulk Density	Sand%	Organic Matter	CEC	ARA	Polygon Number
PMG	A	308	108504	16.0	1.27	53.0	3.70	23.0	29	103
GDH	A	308	60750	20.0	1.30	55.0	3.10	28.0	34	74
CLN	B	92	92502	24.0	1.27	39.0	4.00	28.0	12	111
RYS	A	92	49224	24.0	1.26	35.0	3.10	27.0	2	321
RIV	A	308	18927	56.0	1.00	8.0	4.50	50.0	36	75
DGF	A	185	58239	33.0	1.23	26.0	5.00	44.0	7	67
RIV	A	308	261090	56.0	1.00	8.0	4.50	50.0	35	89
KVL	A	308	33588	26.0	1.00	46.0	6.10	45.0	19	186
MRQ	A	308	31374	57.0	1.30	23.0	4.70	42.0	35	98
ASS	A	308	7944	8.0	1.30	85.0	2.30	14.0	29	104
WWD	A	308	19278	27.0	1.30	28.0	5.10	33.0	9	52
NDL	B	154	19494	30.0	1.44	34.0	4.40	39.0	3	5
HRY	A	308	42444	17.0	1.20	24.0	3.70	18.0	5	36
OBO	A	308	73953	59.0	1.20	4.0	4.30	51.0	35	90
NDL	A	92	182952	30.0	1.44	34.0	4.40	39.0	12	324
ECK	B	92	48810	23.0	1.27	41.0	2.70	29.0	14	116
PMG	A	308	14445	16.0	1.27	53.0	3.70	23.0	35	97
ASS	A	308	38304	8.0	1.30	85.0	2.30	14.0	30	100
RLD	A	308	36240	9.0	1.40	84.0	1.90	15.0	34	73
SOU	A	308	29820	6.0	1.60	86.0	1.30	8.0	1	35
RYS	B	154	178686	24.0	1.26	35.0	3.10	27.0	5	37
FMS	A	308	51936	51.0	1.30	13.0	3.00	50.0	39	51
NDL	B	92	10098	30.0	1.44	34.0	4.40	39.0	3	4
MRQ	A	308	111672	57.0	1.30	23.0	4.70	42.0	26	81
HIT	B	92	49049	25.0	1.10	41.0	3.60	28.0	6	44
SDI	B	154	5370	2.0	1.60	95.0	2.00	5.0	38	188
ABG	A	308	29856	53.0	1.10	11.0	3.00	38.0	26	148
MEH	A	185	73170	11.0	1.25	71.0	4.40	29.0	17	126
CXF	B	62	23004	31.0	1.20	11.0	4.10	43.0	12	29
PGU	A	308	20016	51.0	1.10	5.0	2.60	40.0	26	149

Table A.4. Average attribute values for soils in Alberta

Attribute	Mean	Standard Deviation	Minimum	Maximum
Population, N = 957				
Clay	24.10	11.21	3.00	70.00
Bulk Density	1.30	0.09	1.00	1.50
Sand	36.90	18.98	2.00	95.00
Organic Matter	2.93	1.16	1.00	8.50
CEC	23.45	7.75	3.00	53.00
Sample, N = 105				
Clay	23.49	9.59	6.00	65.00
Bulk Density	1.29	0.09	1.00	1.40
Sand	36.33	16.34	7.00	87.00
Organic Matter	3.15	1.21	1.00	8.50
CEC	23.87	7.04	3.00	42.00

Table A.5. Average attribute values for soils in Saskatchewan

Attribute	Mean	Standard Deviation	Minimum	Maximum
Population, N = 725				
Clay	22.30	10.75	4.00	75.00
Bulk Density	1.31	0.06	1.10	1.50
Sand	43.45	19.27	2.00	90.00
Organic Matter	2.26	0.77	1.00	4.50
CEC	21.74	6.52	8.00	47.00
Sample, N = 75				
Clay	24.69	13.09	6.00	62.00
Bulk Density	1.311	0.06	1.20	1.40
Sand	41.48	19.66	5.00	84.00
Organic Matter	2.35	0.74	1.20	4.50
CEC	23.09	6.83	12.00	43.00

Table A.6. Average attribute values for soils in Manitoba

Attribute	Mean	Standard Deviation	Minimum	Maximum
Population, N = 96				
Clay	25.56	14.42	2.00	60.00
Bulk Density	1.27	0.24	0.00	1.60
Sand	40.83	24.25	4.00	95.00
Organic Matter	3.51	1.16	1.30	7.10
CEC	30.57	12.46	1.20	55.00
Sample, N = 30				
Clay	29.33	17.67	2.00	59.00
Bulk Density	1.27	0.15	1.00	1.60
Sand	39.67	26.91	4.00	95.00
Organic Matter	3.66	1.10	1.30	6.10
CEC	32.03	13.04	5.00	51.00

Appendix B

Comparisons of Wheat Yields for Two Rotations at Swift Current, Saskatchewan before and after Residue Code Changes

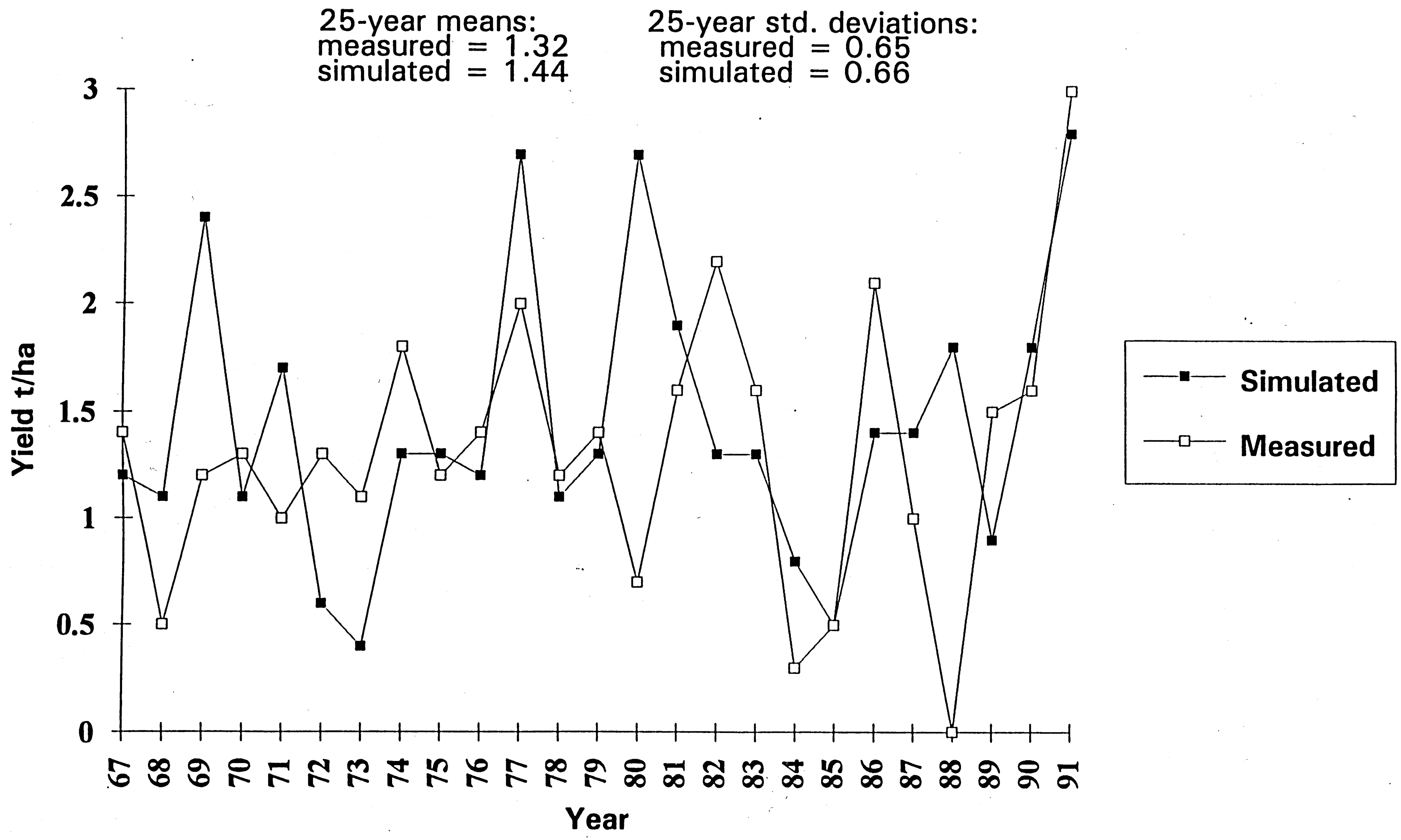

Figure B.1. Comparison of simulated (EPIC) and measured wheat yields for a 25-year continuous wheat rotation for plot 38 at the Swift Current, Saskatchewan Agriculture Canada Research Station, before residue code changes were implemented

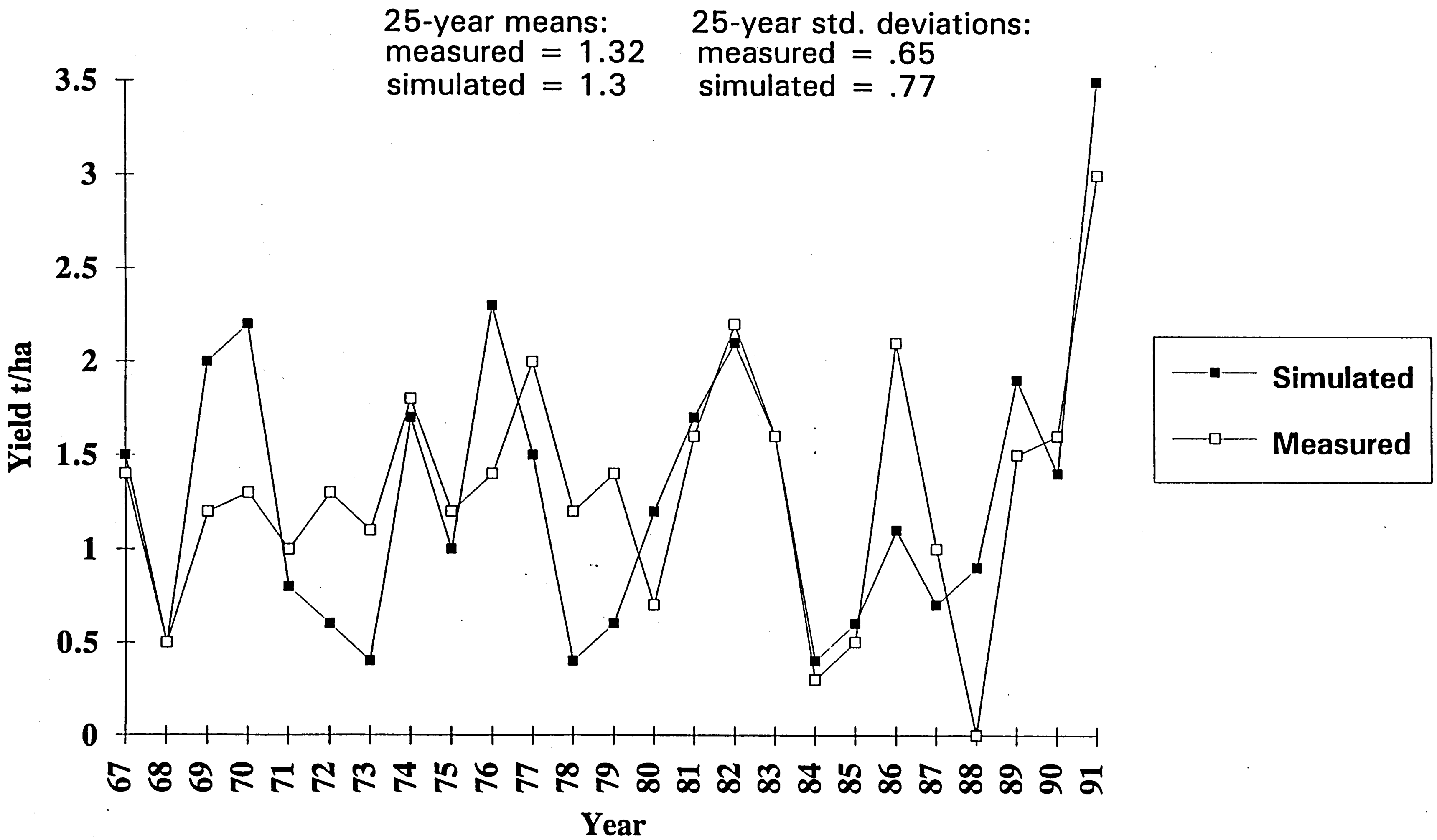

Figure B.2. Comparison of simulated (EPIC) and measured wheat yields for a 25-year continuous wheat rotation for plot 38 at the Swift Current, Saskatchewan Agriculture Canada Research Station, after residue code changes were implemented

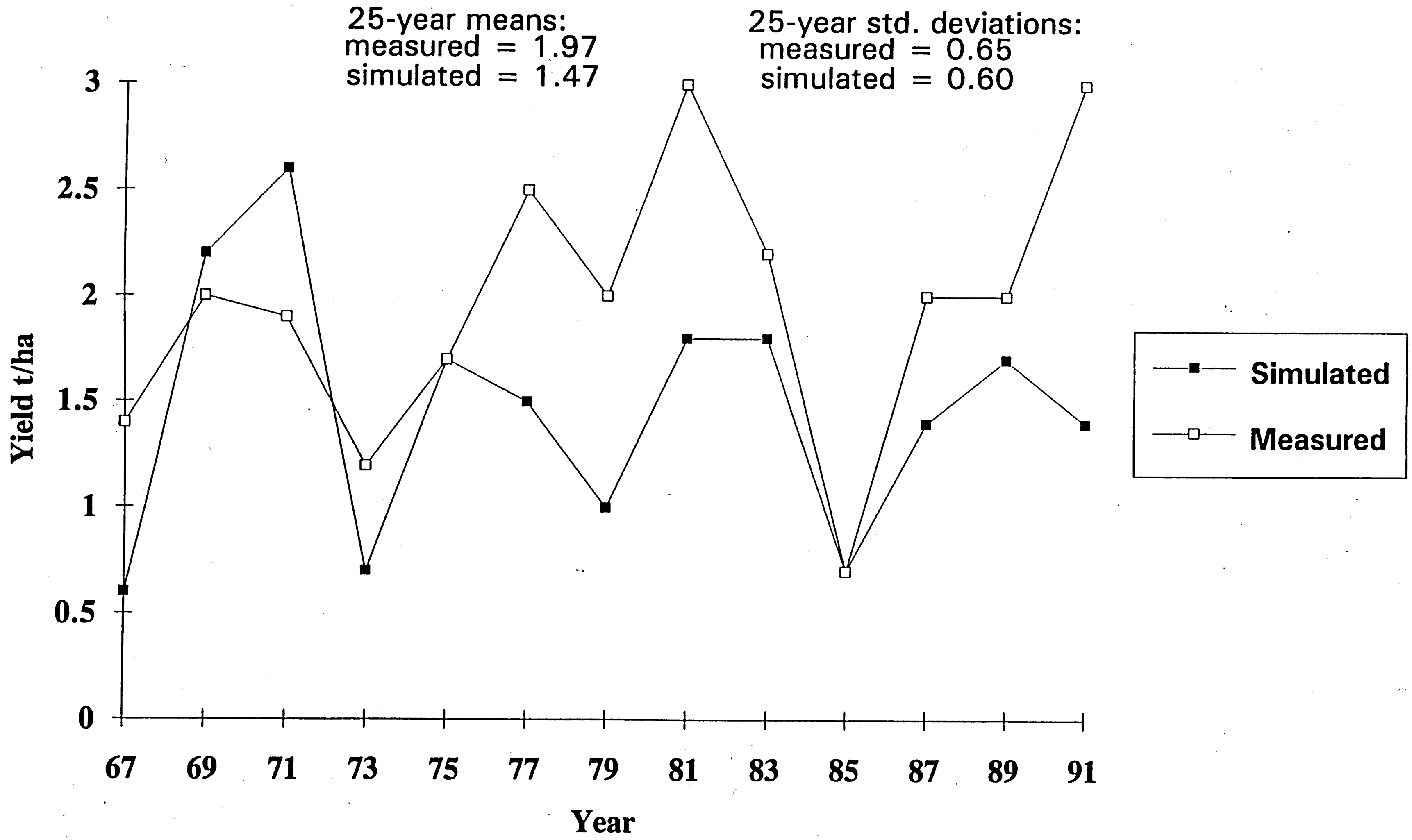

Figure B.3. Comparison of simulated (EPIC) and measured wheat yields for a 25-year wheat-fallow rotation for plot 25 at the Swift Current, Saskatchewan Agriculture Canada Research Station, before residue code changes were implemented

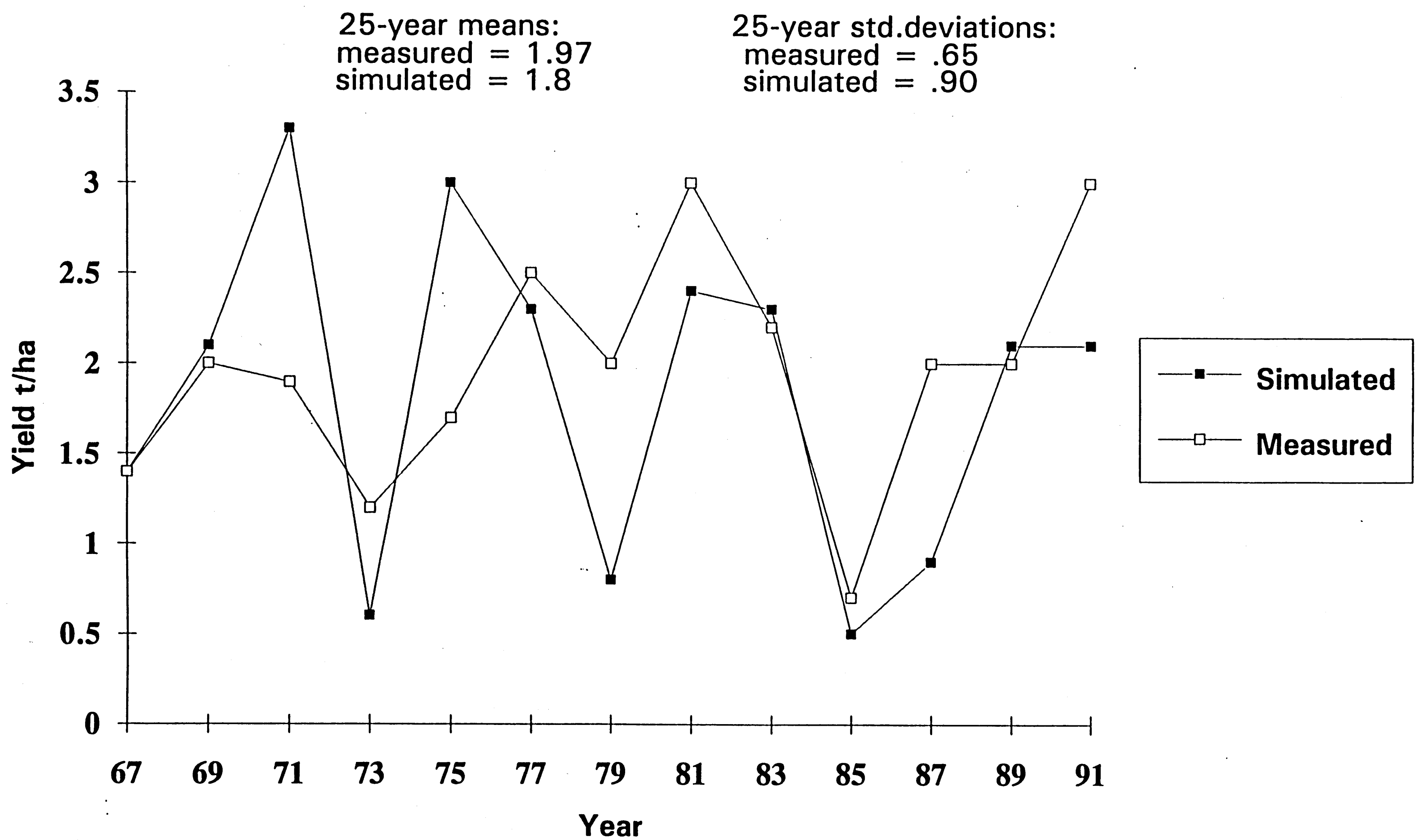

Figure B4. Comparison of simulated (EPIC) and measured wheat yields for a 25-year wheat-fallow rotation for plot 38 at the Swift Current, Saskatchewan Agriculture Canada Research Station, after residue codes were implemented

Appendix C

Table of Revised EPIC Crop Parameters

and Table of EPIC Default Values

Table C.1. Revised crop parameters selected for the EPIC simulations[a]

	Crop								
Variable	Spring Wheat	Barley	Fall Rye[b]	Canola	Sunflower	Alfalfa[c]	Flax	Lentils	Field Pea
WA	28.0	30.0	30.0	34.0	35.0	20.0	25.0	25.0	25.0
HI	0.42	0.47	0.42	0.3	0.4	0.25	0,35	0.46	0.32
TB	18.0	15.0	15.0	21.0	25.0	20.0	15.0	15.0	15.0
TG	0.0	0.0	0.0	5.0	6.0	4.0	5.0	5.0	1.0
DMLA	5.0	5.0	3.0	4.5	5.0	5.0	1.0	5.0	5.0
DLAI	0.60	0.62	0.80	0.55	0.55	0.9	0.9	0.9	0.75
DLAP1	20.01	15.01	30.01	15.02	15.01	15.01	15.02	15.02	15.01
DLAP2	45.95	50.95	50.95	45.95	50.95	50.95	50.95	50.95	50.95
RLAD	1.0	1.0	1.0	0.3	1.0	2.0	1.0	1.0	2.0
RBMD	1.0	1.0	1.0	0.3	1.0	10.0	0.5	0.5	2.0
ALT	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	2.0
CAF	0.85	0.85	0.75	0.82	0.85	0.85	0.9	0.9	0.85
HMX	1.2	1.2	1.1	1.3	2.0	1.25	0.55	0.4	1.2
RDMX	1.3	2.0	2.0	0.9	2.2	2.0	2.0	2.0	2.0
CVM	0.03	0.01	0.03	0.1	0.2	0.01	0.2	0.2	0.01
CNY	0.025	0.021	0.023	0.038	0.028	0.025	0.04	0.45	0.37
CPY	0.0022	0.0017	0.0037	0.0079	0.061	0.0035	0.0033	0.0045	0.021
WSYF	0.15	0.15	0.05	0.18	0.3	0.01	0.01	0.01	0.1
PST	0.60	0.60	0.60	0.95	0.60	0.60	0.9	0.95	0.6
WCY	0.12	0.12	0.11	0.12	0.06	0.1	0.12	0.11	0.0
IDC	5	5	6	5	4	3	2	1	2
FIRST1	5.001	5.001	5.001	5.0	5.15	5.01	5.05	5.05	5.01
FRST2	15.01	15.01	15.01	15.01	15.95	15.95	15.10	15.10	15.1

Table C.1. (Continued)

	Crop								
Variable	Spring Wheat	Barley	Fall Rye[b]	Canola	Sunflower	Alfalfa[c]	Flax	Lentils	Field Pea
BN_1	0.0663	0.047	0.0226	0.044	0.05	0.0417	0.0482	0.0524	0.0515
BN_2	0.0255	0.0177	0.018	0.0164	0.023	0.0290	0.0294	0.032	0.0335
BN_3	0.0148	0.0138	0.0140	0.0128	0.0146	0.02	0.0263	0.0258	0.0296
BP_1	0.0053	0.0048	0.004	0.0074	0.0063	0.0035	0.0049	0.0074	0.0033
BP_2	0.002	0.0018	0.003	0.0037	0.0029	0.0028	0.0024	0.0037	0.0019
BP_3	0.0012	0.0014	0.0034	0.0023	0.0023	0.002	0.0023	0.0023	0.0014

[a]See Table 6 for definitions of each variable (values of SDW, COSD, and PRY are not of importance and are not given here).

[b]Values are for altai wild rye.

[c]Alfalfa and bromegrass are assumed representative of tame hay.

Table C.2. List of default values used for the EPIC simulations

Variables	Description	Value	Comments/Units
LET	Potential ET equation	1	Penman-Monteith
WSA	Watershed drainage area	5.00	hectares
CHL	Distance of watershed	0	not used
CHS	Mainstream channel slope	0	not used
CHN	Channel roughnes factor	.0250	earth, uniform
SN	Surface roughness factor	.2000	Manning's N
APM	Peak runoff rate - rainfall energy	1.0	
SNO	Water content of snow at beginning	10.0	mm
RCN	Average concentration of N in rainfall	.800	
RTN	Years of cultivation before beginning	50	
CO2	CO2 concentration in atmosphere	330.0	
CNO3i	CNO3 concentration in irrigation water	blank	not used
CHD	Channel depth	blank	
PEC	Erosion control practice factor	1.0	no practice used
DRV	Equation of water erosion	4	modified USLE (MUSLE)
FL	Field length for wind erosion	2.0	kilometers
FW	Field width for wind erosion	2.0	kilometers
ANG	Clockwise angle of length from north for wind erosion	90.0	degrees
DIAM	Soil practice diameter for erosion	0	defaults to 500 micrometers
ACW	Wind erosion adjustment factor for wind erosion	1	no acceleration
SALB	Soil albedo	.12	

Appendix D

Table of EPIC Average Wind Erosion Rates, Water Erosion Rates, and Crop Yields by Province and CRAM Regions

Table D.1. Mean of EPIC-Simulated Wind Erosion (tons/ha) by CRAM Regions of Alberta

CROP	TILLAGE	SEQUENCE	CR1	CR2	CR3	CR4	CR5	CR6	CR7
Alfalfa	INTL	Stubble				0.072	0.110	0.154	0.065
Alfalfa	MDTL	Stubble				0.077	0.108	0.161	0.060
Alfalfa	NOTL	Stubble				0.075	0.107	0.159	0.059
Canola	INTL	Stubble	3.651	2.895	0.701	0.230	0.214	0.224	0.233
Canola	INTL	Fallow	4.844			0.487	0.718	0.727	0.384
Canola	MDTL	Stubble	0.972	1.467	0.316	0.062	0.078	0.101	0.086
Canola	MDTL	Fallow	4.807			0.453	0.654	0.742	0.383
Canola	NOTL	Stubble	0.633	0.965	0.169	0.030	0.036	0.046	0.048
Canola	NOTL	Fallow	4.546			0.426	0.683	0.748	0.388
Fallow	INTL	Stubble	8.452	19.714	3.446	0.289	0.162	0.606	0.235
Fallow	MDTL	Stubble	6.661	11.786	2.284	0.162	0.108	0.475	0.199
Fallow	NOTL	Stubble	3.344	7.115	1.443	0.030	0.024	0.043	0.035
Flax	INTL	Stubble	2.340	4.298	0.874	0.092	0.141		0.184
Flax	MDTL	Stubble	0.733	1.350	0.233	0.037	0.048		0.067
Flax	NOTL	Stubble	0.492	0.926	0.126	0.017	0.022		0.036
Field_Peas	INTL	Stubble				0.117	0.164	0.321	0.203
Field_Peas	MDTL	Stubble				0.058	0.081	0.116	0.051
Field_Peas	NOTL	Stubble				0.036	0.050	0.067	0.025
Lentils	INTL	Stubble	2.564	5.108		0.110			
Lentils	MDTL	Stubble	0.832	1.600		0.043			
Lentils	NOTL	Stubble	0.548	1.100		0.019			
Barley	INTL	Stubble	0.975	3.353	0.647	0.075	0.196	0.268	0.111
Barley	MDTL	Stubble	0.386	0.973	0.179	0.030	0.059	0.115	0.063
Barley	NOTL	Stubble	0.208	0.674	0.107	0.014	0.035	0.083	0.045
Wheat	INTL	Stubble	2.500	5.223	1.024	0.237	0.349	0.396	0.174
Wheat	INTL	Fallow	3.525	7.731	1.539	0.278	0.479		0.241
Wheat	MDTL	Stubble	0.748	1.389	0.172	0.092	0.103	0.177	0.069
Wheat	MDTL	Fallow	3.613	7.408	1.536	0.284	0.413		0.256
Wheat	NOTL	Stubble	0.633	1.147	0.112	0.072	0.076	0.140	0.052
Wheat	NOTL	Fallow	3.462	6.866	1.444	0.288	0.403		0.270
Fall_Rye	INTL	Stubble			0.326		0.088		
Fall_Rye	MDTL	Stubble			0.199		0.058		
Fall_Rye	NOTL	Stubble			0.189		0.056		

Note: INTL is conventional tillage, MDTL is reduced tillage, and NOTL is no-till.

Table D.2. Mean of EPIC-Simulated Wind Erosion (tons/ha) by CRAM Regions of Saskatchewan

CROP	TILLAGE	SEQUENCE	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9
Alfalfa	INTL	Stubble					0.293		0.608	0.583	0.441
Alfalfa	MDTL	Stubble					0.280		0.590	0.541	0.444
Alfalfa	NOTL	Stubble					0.281		0.588	0.544	0.446
Canola	INTL	Stubble	1.877				0.693	2.355	1.365	1.141	0.869
Canola	INTL	Fallow	6.163	9.341			1.982	7.270	3.999	3.016	2.259
Canola	MDTL	Stubble	0.726				0.298	1.121	0.653	0.488	0.393
Canola	MDTL	Fallow	6.145	9.309			1.949	7.126	4.184	2.996	2.225
Canola	NOTL	Stubble	0.380				0.150	0.625	0.383	0.256	0.207
Canola	NOTL	Fallow	5.971	8.948			1.960	6.874	3.989	3.016	2.194
Fallow	INTL	Stubble	5.601	12.290	25.238	27.691	1.127	10.274	4.409	2.221	1.316
Fallow	MDTL	Stubble	4.380	8.835	18.601	20.743	0.793	6.858	2.905	1.632	0.901
Fallow	NOTL	Stubble	2.462	4.823	11.565	13.491	0.407	3.809	1.745	0.694	0.353
Flax	INTL	Stubble			4.123	4.044	1.114	2.239		1.782	0.684
Flax	MDTL	Stubble			1.926	1.870	0.304	1.065		0.495	0.331
Flax	NOTL	Stubble			0.972	0.917	0.166	0.570		0.271	0.172
Field_Peas	INTL	Stubble	2.302				0.747	3.707	2.216	1.661	0.960
Field_Peas	MDTL	Stubble	1.024				0.411	1.920	0.833	0.617	0.603
Field_Peas	NOTL	Stubble	0.738				0.286	1.452	0.615	0.410	0.417
Lentils	INTL	Stubble									0.759
Lentils	INTL	Fallow	5.974	9.659	16.925	18.145					
Lentils	MDTL	Stubble									0.355
Lentils	MDTL	Fallow	5.717	8.716	14.055	14.712					
Lentils	NOTL	Stubble									0.184
Lentils	NOTL	Fallow	5.903	8.962	14.374	15.153					
Barley	INTL	Stubble	1.006	2.326	3.239	3.041	0.526	1.812	1.326	1.241	0.906
Barley	MDTL	Stubble	0.390	0.951	1.103	0.951	0.312	0.736	0.614	0.639	0.370
Barley	NOTL	Stubble	0.202	0.541	0.610	0.525	0.214	0.406	0.499	0.507	0.249
Wheat	INTL	Stubble	3.569	5.527	6.450	6.354	1.214	4.066	2.062	1.889	1.206
Wheat	INTL	Fallow	4.614	6.885	11.341	12.037	1.353	5.287	2.893		1.529
Wheat	MDTL	Stubble	1.610	2.034	1.295	1.151	0.766	1.833	0.961	1.135	0.521
Wheat	MDTL	Fallow	4.982	7.359	11.641	12.100	1.387	5.550	3.081		1.641
Wheat	NOTL	Stubble	1.495	1.830	0.911	0.808	0.682	1.631	0.882	1.030	0.439
Wheat	NOTL	Fallow	4.772	7.092	11.361	12.129	1.394	5.451	3.044		1.692
Fall_Rye	INTL	Stubble						1.858	0.886		0.565
Fall_Rye	MDTL	Stubble						1.297	0.749		0.445
Fall_Rye	NOTL	Stubble						1.299	0.752		0.445

Note: INTL is conventional tillage, MDTL is reduced tillage, and NOTL is no-till

Table D.3. Mean of EPIC-Simulated Wind Erosion (tons/ha) by CRAM Regions of Manitoba

CROP	TILLAGE	SEQUENCE	CR1	CR2	CR3	CR4	CR5	CR6
Alfalfa	INTL	Stubble	1.411	0.706	1.323	0.892	1.511	0.459
Alfalfa	MDTL	Stubble	1.403	0.763	1.291	0.836	1.533	0.419
Alfalfa	NOTL	Stubble	1.427	0.762	1.287	0.840	1.580	0.438
Canola	INTL	Stubble	5.424	1.674	4.906	2.921	3.944	0.813
Canola	MDTL	Stubble	1.770	0.681	1.629	0.994	1.816	0.311
Canola	NOTL	Stubble	1.007	0.373	0.986	0.591	1.109	0.152
Fallow	INTL	Stubble	9.226	2.874		3.862		
Fallow	MDTL	Stubble	5.459	1.600		3.014		
Fallow	NOTL	Stubble	2.863	0.815		1.664		
Flax	INTL	Stubble				1.851		0.583
Flax	MDTL	Stubble				0.766		0.260
Flax	NOTL	Stubble				0.451		0.143
Field_Peas	INTL	Stubble	5.247	1.756	2.881	1.959	3.955	0.757
Field_Peas	MDTL	Stubble	1.478	0.687	1.142	0.875	2.265	0.341
Field_Peas	NOTL	Stubble	0.901	0.458	0.703	0.595	1.765	0.235
Lentils	INTL	Stubble	6.907		3.395	2.238		0.590
Lentils	INTL	Fallow				4.729		
Lentils	MDTL	Stubble	1.443		1.276	0.781		0.277
Lentils	MDTL	Fallow				4.362		
Lentils	NOTL	Stubble	5.723		0.933	0.763		0.142
Lentils	NOTL	Fallow				4.767		
Barley	INTL	Stubble	3.379	1.378	2.846	1.559	3.388	0.853
Barley	MDTL	Stubble	1.749	0.710	1.205	0.714	1.587	0.330
Barley	NOTL	Stubble	1.309	0.540	0.815	0.466	1.082	0.222
Wheat	INTL	Stubble	4.679	2.122	4.622	3.012	5.141	1.543
Wheat	INTL	Fallow	6.285	3.114				
Wheat	MDTL	Stubble	2.042	1.040	2.395	1.278	2.534	0.852
Wheat	MDTL	Fallow	6.342	3.211				
Wheat	NOTL	Stubble	1.611	0.914	2.173	1.112	2.280	0.748
Wheat	NOTL	Fallow	6.141	3.402				
Fall_Rye	INTL	Stubble			2.077	1.294		
Fall_Rye	MDTL	Stubble			1.538	0.971		
Fall_Rye	NOTL	Stubble			1.528	0.966		
Sunflower	INTL	Stubble	6.168		5.111	2.888		
Sunflower	MDTL	Stubble	1.835		1.612	1.140		
Sunflower	NOTL	Stubble	1.066		1.018	0.712		

Note: INTL is conventional tillage, MDTL is reduced tillage, and NOTL is no-till

Table D.4. Mean of EPIC-Simulated Water Erosion (tons/ha) by CRAM Regions of Alberta

CROP	TILLAGE	SEQUENCE	CR1	CR2	CR3	CR4	CR5	CR6	CR7
Alfalfa	INTL	Stubble				0.217	0.349	0.176	0.207
Alfalfa	MDTL	Stubble				0.220	0.344	0.170	0.203
Alfalfa	NOTL	Stubble				0.214	0.335	0.169	0.204
Canola	INTL	Stubble	1.086	0.178	4.197	0.777	1.136	0.596	0.789
Canola	INTL	Fallow	2.727			1.839	3.128	1.367	1.540
Canola	MDTL	Stubble	0.368	0.150	2.718	0.535	0.986	0.494	0.464
Canola	MDTL	Fallow	2.926			1.854	2.996	1.331	1.505
Canola	NOTL	Stubble	0.303	0.125	2.195	0.479	0.911	0.482	0.417
Canola	NOTL	Fallow	2.426			1.690	2.716	1.218	1.384
Fallow	INTL	Stubble	3.122	1.590	12.334	3.847	4.574	3.186	2.692
Fallow	MDTL	Stubble	1.970	0.584	6.311	2.180	3.456	2.501	2.141
Fallow	NOTL	Stubble	0.591	0.307	3.647	0.557	1.657	0.454	0.762
Flax	INTL	Stubble	1.212	0.411	5.416	1.522	2.544		1.380
Flax	MDTL	Stubble	0.752	0.323	4.283	1.084	2.061		0.879
Flax	NOTL	Stubble	0.565	0.230	3.272	0.923	1.853		0.794
Field_Peas	INTL	Stubble				0.394	0.673	0.364	0.525
Field_Peas	MDTL	Stubble				0.367	0.542	0.177	0.120
Field_Peas	NOTL	Stubble				0.345	0.519	0.150	0.085
Lentils	INTL	Stubble	0.945	0.298		1.009			
Lentils	MDTL	Stubble	0.704	0.266		0.900			
Lentils	NOTL	Stubble	0.483	0.187		0.777			
Barley	INTL	Stubble	0.328	0.089	3.150	0.285	0.718	0.319	0.354
Barley	MDTL	Stubble	0.199	0.050	1.461	0.175	0.308	0.122	0.154
Barley	NOTL	Stubble	0.167	0.045	1.208	0.137	0.270	0.097	0.123
Wheat	INTL	Stubble	1.048	0.214	5.601	0.767	1.188	0.560	0.705
Wheat	INTL	Fallow	2.500	0.678	10.200	1.486	2.464		1.262
Wheat	MDTL	Stubble	0.488	0.100	1.673	0.386	0.442	0.238	0.334
Wheat	MDTL	Fallow	2.404	0.623	10.016	1.428	2.327		1.212
Wheat	NOTL	Stubble	0.453	0.096	1.418	0.360	0.405	0.216	0.304
Wheat	NOTL	Fallow	2.184	0.568	8.966	1.354	2.197		1.156
Fall_Rye	INTL	Stubble			2.517		0.722		
Fall_Rye	MDTL	Stubble			2.046		0.636		
Fall_Rye	NOTL	Stubble			2.007		0.626		

Note: INTL is conventional tillage, MDTL is reduced tillage, and NOTL is no-till.

Table D.5. Mean of EPIC-Simulated Water Erosion (tons/ha) by CRAM Regions of Saskatchewan

CROP	TILLAGE	SEQUENCE	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9
Alfalfa	INTL	Stubble					0.377		0.075	0.416	0.333
Alfalfa	MDTL	Stubble					0.383		0.073	0.435	0.329
Alfalfa	NOTL	Stubble					0.372		0.074	0.418	0.329
Canola	INTL	Stubble	0.286				0.807	0.233	0.188	0.928	0.826
Canola	INTL	Fallow	1.407	1.308			3.249	1.073	1.060	3.542	2.629
Canola	MDTL	Stubble	0.204				0.536	0.173	0.139	0.579	0.549
Canola	MDTL	Fallow	1.413	1.311			3.169	1.039	1.023	3.419	2.653
Canola	NOTL	Stubble	0.182				0.454	0.152	0.131	0.480	0.472
Canola	NOTL	Fallow	1.361	1.232			2.909	0.995	0.960	3.169	2.542
Fallow	INTL	Stubble	1.299	1.308	0.633	1.115	2.866	1.064	0.945	2.548	2.375
Fallow	MDTL	Stubble	1.055	0.818	0.385	0.691	2.194	0.621	0.516	1.987	1.794
Fallow	NOTL	Stubble	0.608	0.473	0.230	0.405	1.347	0.356	0.297	1.171	1.087
Flax	INTL	Stubble			0.242	0.418	1.972	0.480		2.038	1.409
Flax	MDTL	Stubble			0.153	0.253	0.937	0.312		1.009	1.093
Flax	NOTL	Stubble			0.113	0.200	0.823	0.249		0.902	0.843
Field_Peas	INTL	Stubble	0.281				0.773	0.210	0.195	1.125	0.724
Field_Peas	MDTL	Stubble	0.212				0.525	0.171	0.091	0.411	0.518
Field_Peas	NOTL	Stubble	0.177				0.472	0.155	0.076	0.335	0.433
Lentils	INTL	Stubble									0.995
Lentils	INTL	Fallow	1.593	1.507	0.790	1.592					
Lentils	MDTL	Stubble									0.749
Lentils	MDTL	Fallow	1.674	1.520	0.749	1.429					
Lentils	NOTL	Stubble									0.651
Lentils	NOTL	Fallow	1.561	1.419	0.714	1.390					
Barley	INTL	Stubble	0.194	0.184	0.088	0.175	0.754	0.156	0.156	0.987	0.731
Barley	MDTL	Stubble	0.111	0.108	0.053	0.102	0.507	0.098	0.064	0.413	0.272
Barley	NOTL	Stubble	0.085	0.087	0.034	0.067	0.441	0.078	0.051	0.331	0.203
Wheat	INTL	Stubble	0.512	0.496	0.168	0.332	1.704	0.352	0.281	1.831	1.165
Wheat	INTL	Fallow	1.261	1.146	0.637	1.203	3.058	0.955	0.972		2.303
Wheat	MDTL	Stubble	0.209	0.255	0.062	0.127	0.849	0.124	0.097	0.902	0.413
Wheat	MDTL	Fallow	1.241	1.105	0.600	1.146	2.873	0.921	0.974		2.272
Wheat	NOTL	Stubble	0.203	0.248	0.051	0.107	0.823	0.110	0.093	0.869	0.358
Wheat	NOTL	Fallow	1.149	1.021	0.540	1.011	2.542	0.868	0.874		2.046
Fall_Rye	INTL	Stubble						0.192	0.168		0.657
Fall_Rye	MDTL	Stubble						0.175	0.146		0.543
Fall_Rye	NOTL	Stubble						0.174	0.145		0.524

Note: INTL is conventional tillage, MDTL is reduced tillage, and NOTL is no-till

Table D.6. Mean of EPIC-Simulated Water Erosion (tons/ha) by CRAM Regions of Manitoba

CROP	TILLAGE	SEQUENCE	CR1	CR2	CR3	CR4	CR5	CR6
Alfalfa	INTL	Stubble	0.258	0.299	0.152	0.262	0.329	0.353
Alfalfa	MDTL	Stubble	0.252	0.287	0.158	0.263	0.347	0.374
Alfalfa	NOTL	Stubble	0.253	0.289	0.157	0.264	0.342	0.367
Canola	INTL	Stubble	1.015	0.750	0.580	0.945	0.878	0.896
Canola	MDTL	Stubble	0.385	0.426	0.238	0.446	0.560	0.600
Canola	NOTL	Stubble	0.315	0.367	0.211	0.363	0.494	0.533
Fallow	INTL	Stubble	2.793	3.044		1.867		
Fallow	MDTL	Stubble	1.460	1.596		1.432		
Fallow	NOTL	Stubble	0.825	0.949		0.850		
Flax	INTL	Stubble				1.208		1.563
Flax	MDTL	Stubble				0.919		1.256
Flax	NOTL	Stubble				0.785		1.096
Field_Peas	INTL	Stubble	0.808	0.788	0.413	0.632	0.559	0.609
Field_Peas	MDTL	Stubble	0.179	0.313	0.342	0.535	0.462	0.489
Field_Peas	NOTL	Stubble	0.133	0.257	0.345	0.545	0.427	0.447
Lentils	INTL	Stubble	1.308		0.417	0.892		1.096
Lentils	INTL	Fallow				2.508		
Lentils	MDTL	Stubble	1.122		0.350	0.675		0.932
Lentils	MDTL	Fallow				2.525		
Lentils	NOTL	Stubble	1.000		0.314	0.599		0.838
Lentils	NOTL	Fallow				2.316		
Barley	INTL	Stubble	0.583	0.676	0.329	0.475	0.768	0.907
Barley	MDTL	Stubble	0.206	0.240	0.145	0.244	0.328	0.366
Barley	NOTL	Stubble	0.160	0.182	0.115	0.202	0.266	0.293
Wheat	INTL	Stubble	1.076	1.042	0.544	1.176	1.036	1.403
Wheat	INTL	Fallow	1.994	2.166				
Wheat	MDTL	Stubble	0.491	0.280	0.206	0.600	0.321	0.615
Wheat	MDTL	Fallow	1.934	2.149				
Wheat	NOTL	Stubble	0.482	0.236	0.189	0.608	0.285	0.564
Wheat	NOTL	Fallow	1.719	1.962				
Fall_Rye	INTL	Stubble			0.372	0.570		
Fall_Rye	MDTL	Stubble			0.301	0.464		
Fall_Rye	NOTL	Stubble			0.301	0.470		
Sunflower	INTL	Stubble	1.043		0.513	0.832		
Sunflower	MDTL	Stubble	0.572		0.311	0.603		
Sunflower	NOTL	Stubble	0.491		0.285	0.529		

Note: INTL is conventional tillage, MDTL is reduced tillage, and NOTL is no-till

Table D.7. Mean of EPIC-Simulated Crop Yields (tons/ha) by CRAM Regions of Alberta

CROP	TILLAGE	SEQUENCE	CR1	CR2	CR3	CR4	CR5	CR6	CR7
Alfalfa	INTL	Stubble				2.927	2.935	3.026	2.533
Alfalfa	MDTL	Stubble				2.928	2.935	3.024	2.533
Alfalfa	NOTL	Stubble				2.928	2.935	3.025	2.533
Canola	INTL	Stubble	1.987	2.161	2.440	2.922	2.839	2.863	2.426
Canola	INTL	Fallow	2.450			2.757	2.663	2.227	2.162
Canola	MDTL	Stubble	2.013	2.187	2.475	2.910	2.834	2.858	2.403
Canola	MDTL	Fallow	2.461			2.769	2.670	2.232	2.165
Canola	NOTL	Stubble	2.015	2.189	2.470	2.897	2.821	2.842	2.383
Canola	NOTL	Fallow	2.472			2.769	2.683	2.247	2.169
Flax	INTL	Stubble	1.093	1.293	1.556	1.628	1.662		1.568
Flax	MDTL	Stubble	1.098	1.301	1.561	1.627	1.660		1.561
Flax	NOTL	Stubble	1.100	1.301	1.563	1.624	1.657		1.554
Field_Peas	INTL	Stubble				2.557	2.588	2.608	2.328
Field_Peas	MDTL	Stubble				2.548	2.581	2.594	2.303
Field_Peas	NOTL	Stubble				2.536	2.571	2.580	2.289
Lentils	INTL	Stubble	1.899	2.282		4.290			
Lentils	MDTL	Stubble	1.921	2.317		4.292			
Lentils	NOTL	Stubble	1.928	2.333		4.282			
Barley	INTL	Stubble	2.601	2.851	3.388	4.049	3.983	4.027	3.644
Barley	MDTL	Stubble	2.664	2.986	3.713	4.193	4.206	4.173	3.760
Barley	NOTL	Stubble	2.674	2.995	3.720	4.188	4.201	4.168	3.743
Wheat	INTL	Stubble	2.017	2.314	2.937	3.499	3.491	3.248	2.837
Wheat	INTL	Fallow	2.576	2.645	2.793	3.086	2.981		2.440
Wheat	MDTL	Stubble	2.034	2.345	2.953	3.446	3.442	3.197	2.772
Wheat	MDTL	Fallow	2.619	2.700	2.812	3.093	2.965		2.445
Wheat	NOTL	Stubble	2.040	2.349	2.953	3.437	3.440	3.192	2.759
Wheat	NOTL	Fallow	2.628	2.719	2.825	3.102	2.981		2.460
Fall_Rye	INTL	Stubble			2.691		2.901		
Fall_Rye	MDTL	Stubble			2.685		2.826		
Fall_Rye	NOTL	Stubble			2.687		2.824		

Note: INTL is conventional tillage, MDTL is reduced tillage, and NOTL is no-till.

Table D.8. Mean of EPIC-Simulated Crop Yields (tons/ha) by CRAM Regions of Saskatchewan

CROP	TILLAGE	SEQUENCE	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9
Alfalfa	INTL	Stubble					2.525		2.296	2.540	2.635
Alfalfa	MDTL	Stubble					2.525		2.297	2.540	2.635
Alfalfa	NOTL	Stubble					2.525		2.298	2.541	2.636
Canola	INTL	Stubble	2.668				2.591	2.473	2.448	2.597	2.694
Canola	INTL	Fallow	2.499	2.408			2.328	2.463	2.610	2.360	2.386
Canola	MDTL	Stubble	2.667				2.593	2.477	2.457	2.597	2.683
Canola	MDTL	Fallow	2.495	2.407			2.333	2.461	2.606	2.364	2.378
Canola	NOTL	Stubble	2.658				2.580	2.468	2.449	2.582	2.663
Canola	NOTL	Fallow	2.500	2.416			2.338	2.468	2.609	2.372	2.386
Flax	INTL	Stubble			1.180	1.098	1.407	1.348		1.443	1.520
Flax	MDTL	Stubble			1.182	1.103	1.406	1.347		1.440	1.518
Flax	NOTL	Stubble			1.185	1.108	1.406	1.345		1.439	1.514
Field_Peas	INTL	Stubble	1.999				2.181	1.973	1.956	2.239	2.339
Field_Peas	MDTL	Stubble	2.008				2.177	1.977	1.965	2.233	2.325
Field_Peas	NOTL	Stubble	2.005				2.168	1.972	1.965	2.223	2.308
Lentils	INTL	Stubble									3.724
Lentils	INTL	Fallow	3.560	3.300	2.960	2.642					
Lentils	MDTL	Stubble									3.738
Lentils	MDTL	Fallow	3.562	3.307	2.978	2.661					
Lentils	NOTL	Stubble									3.731
Lentils	NOTL	Fallow	3.563	3.312	2.994	2.679					
Barley	INTL	Stubble	3.237	2.954	2.657	2.385	3.372	3.177	3.288	3.633	3.754
Barley	MDTL	Stubble	3.377	3.132	2.814	2.524	3.543	3.339	3.383	3.716	3.844
Barley	NOTL	Stubble	3.379	3.133	2.828	2.544	3.537	3.340	3.385	3.707	3.836
Wheat	INTL	Stubble	2.917	2.587	2.179	1.869	3.116	2.795	2.777	3.126	3.102
Wheat	INTL	Fallow	2.568	2.501	2.531	2.383	2.416	2.610	2.783		2.589
Wheat	MDTL	Stubble	2.896	2.567	2.183	1.887	3.101	2.779	2.773	3.103	3.053
Wheat	MDTL	Fallow	2.556	2.525	2.562	2.416	2.415	2.632	2.805		2.581
Wheat	NOTL	Stubble	2.898	2.568	2.194	1.900	3.098	2.778	2.774	3.098	3.046
Wheat	NOTL	Fallow	2.567	2.531	2.577	2.432	2.417	2.637	2.806		2.585
Fall_Rye	INTL	Stubble						2.447	2.443		2.712
Fall_Rye	MDTL	Stubble						2.429	2.434		2.664
Fall_Rye	NOTL	Stubble						2.433	2.443		2.667

Note: INTL is conventional tillage, MDTL is reduced tillage, and NOTL is no-till

Table D.9. Mean of EPIC-Simulated Crop Yields (tons/ha) by CRAM Regions of Manitoba

CROP	TILLAGE	SEQUENCE	CR1	CR2	CR3	CR4	CR5	CR6
Alfalfa	INTL	Stubble	2.690	2.647	2.661	2.724	2.650	2.688
Alfalfa	MDTL	Stubble	2.690	2.646	2.659	2.723	2.648	2.686
Alfalfa	NOTL	Stubble	2.689	2.645	2.659	2.723	2.648	2.686
Canola	INTL	Stubble	2.866	2.777	2.789	2.959	2.931	2.989
Canola	MDTL	Stubble	2.880	2.762	2.823	2.978	2.927	2.976
Canola	NOTL	Stubble	2.866	2.738	2.813	2.965	2.900	2.943
Flax	INTL	Stubble				1.209		1.215
Flax	MDTL	Stubble				1.210		1.215
Flax	NOTL	Stubble				1.208		1.210
Field_Peas	INTL	Stubble	2.224	2.288	2.079	2.131	2.074	2.120
Field_Peas	MDTL	Stubble	2.221	2.274	2.078	2.129	2.066	2.111
Field_Peas	NOTL	Stubble	2.216	2.259	2.074	2.124	2.054	2.098
Lentils	INTL	Stubble	3.616		3.421	3.535		3.607
Lentils	INTL	Fallow				3.574		
Lentils	MDTL	Stubble	3.623		3.418	3.533		3.601
Lentils	MDTL	Fallow				3.573		
Lentils	NOTL	Stubble	3.622		3.413	3.530		3.592
Lentils	NOTL	Fallow				3.571		
Barley	INTL	Stubble	3.490	3.619	3.278	3.351	3.364	3.482
Barley	MDTL	Stubble	3.653	3.708	3.465	3.539	3.518	3.616
Barley	NOTL	Stubble	3.653	3.698	3.461	3.534	3.512	3.610
Wheat	INTL	Stubble	3.128	3.168	3.181	3.268	3.274	3.485
Wheat	INTL	Fallow	2.481	2.550				
Wheat	MDTL	Stubble	3.092	3.129	3.166	3.222	3.233	3.450
Wheat	MDTL	Fallow	2.503	2.560				
Wheat	NOTL	Stubble	3.089	3.117	3.158	3.214	3.223	3.439
Wheat	NOTL	Fallow	2.514	2.564				
Fall_Rye	INTL	Stubble			1.915	2.053		
Fall_Rye	MDTL	Stubble			1.907	2.025		
Fall_Rye	NOTL	Stubble			1.903	2.023		
Sunflower	INTL	Stubble	2.671		2.718	2.835		
Sunflower	MDTL	Stubble	2.652		2.703	2.820		
Sunflower	NOTL	Stubble	2.631		2.677	2.794		

Note: INTL is conventional tillage, MDTL is reduced tillage, and NOTL is no-till