THE RISK OF WATER EROSION INDICATOR FOR CANADA: INTEGRATING SCIENCE AND POLICY

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Abstract
Canada has been developing and using relevant Agri-Environmental Indicators for national assessments of the environmental sustainability of Canadian agriculture. Under the recently adopted Agricultural Policy Framework, the Risk of Water Erosion is one of many indicators used to assess farm management strategies in the areas of soil, water, and air quality, and biodiversity.

This paper shows results on national and provincial historical trends in water erosion and predicted impacts for various erosion control strategies. Between 1981 and 1996, water erosion risk in Canada improved by 22%. The Risk of Water Erosion Indicator integrated with an economic model (Canadian Regional Agricultural Model) was applied to several environmental management scenarios such as conservation tillage, reduced summer fallow, increased permanent cover, and improved grazing management, each having three levels of adoption rates.

Results from the quantitative analyses based on the integrated models were compared with a business as usual baseline extrapolated to 2008. The analytical results may assist federal, provincial and territorial decision-makers in establishing targets and monitoring environmental goals. Targeting soil conservation practices to cropland in the other than lowest (tolerable) risk class will help to move the sector towards the long-term goal of having all cropland in the tolerable risk class for the water erosion indicator.

Additional Keywords: soil erosion, agri-environmental indicators, economic models

Introduction
Agriculture interacts with and is influenced by a wide array of social, economic and environmental factors. These factors are inextricably linked to one another, interacting and giving rise to various driving forces that influence the nature and direction of agricultural production. In order to improve our understanding of these relationships, quantitative analyses were conducted through the integration of an economic model with seven existing Agi-Environmental Indicators (AEI) including the Risk of Water Erosion (RWE) Indicator. The AEI were used to estimate how various agricultural management strategies impact the Canadian environment.

Since the early 1980's, Canada has been developing and using relevant Agri-Environmental Indicators in national assessments of the environmental sustainability of Canadian agriculture. In the most recent national assessment, 14 indicators, including the Risk of Water Erosion indicator, were used to evaluate the degree to which Canada's agricultural land was affected by management practices (McRae *et al*., 2000).

Under the recently adopted long-term Agriculture Policy Framework (APF), Ministers of Agriculture agreed to work towards a comprehensive plan for accelerated environmental action, fully covering all Canadian farms, that will help achieve measurable, and meaningful environmental goals in the areas of water, air and soil quality, and bio-diversity. Ministers agreed to seek agreement on indicators, targets, timetables and approaches. Implementation of the APF points to the need for an analytical capacity to help set goals and targets for the environment and for indicators to measure progress toward these objectives. While AEI are useful for tracking environmental performance over historical periods, predictive models are needed to objectively estimate what the future might look like given the changes in policy today. This predictive capacity has been developed by linking the economic (CRAM) and science-based AEI models to support the policy development and evaluation process. Regional effects are estimated with the model based on comparisons between scenarios and a baseline (Heigh *et al*., pending)

Materials and Methods
The Risk of Water Erosion indicator
RWE was developed to monitor the extent of cultivated land at risk of water erosion. It uses information from Soil Landscapes of Canada maps (1:1M) and other data sources to tabulate rainfall, soil, and landscape (slope) factors for each mapping area. The change in erosion risk over time was calculated by considering the effects of

fluctuations in cropland areas, shifts in the type of crops grown, reduction in summer-fallow, and the use of conservation tillage and no-till. This information was obtained from the Census of Agriculture for 1981, 1991, 1996 and 2001. Scientific based models (Wall *et al*., 2002) were used to estimate the rate of water erosion.

The risk is expressed in the following five classes: tolerable (less than 6 t ha^{-1} yr^{-1}), low (6 -11 t ha^{-1} yr^{-1}), moderate (11 - 22 t ha^{-1} yr^{-1}), high (22 - 33 t ha^{-1} yr^{-1}), and severe (greater than 33 t ha^{-1} yr^{-1}). Areas in the lowest class are generally considered at tolerable risk of soil erosion and able to sustain long-term crop production. The other four classes represent the risk of conditions that are unsustainable and for which soil conservation practices are needed to support crop production over the long term. The indicator can be viewed as an indirect measure of soil quality. Because erosion is a process of soil degradation that results in decreased soil quality, a declining erosion risk is considered positive in terms of soil quality. The performance objective for the erosion indicators is to have all cropland in the lowest risk class.

To estimate the rate of water erosion, the universally accepted and scientifically credible water erosion prediction technology (Wischmeier and Smith, 1978; Renard *et al*., 1997), based on empirical models (USLE and RUSLE respectively), was used in the risk of water erosion indicator, as described by Wall *et al.* (2002).

The Canadian regional economic model

The economic model used for this study is the Canadian Regional Agricultural Model (CRAM), which has been used for many years in Canada as a policy analysis tool. CRAM is a sector equilibrium model for Canadian agriculture that is disaggregated across both commodities and space (Horner *at al*., 1992). CRAM is a static, non-linear optimization model that maximizes producer plus consumer surplus. The basic commodity coverage is grains and oilseeds, forage, beef, hogs, dairy and poultry (horticulture is excluded). Spatial features of the model include provincial-level livestock and crop production, with the exception of the Prairie Provinces, where crop production is divided into 22 regions based on the Census of Agriculture boundaries. Supply response is determined by the relative profitability of alternative crops. The model allows for both inter-provincial and international trade in primary and processed products. Government policies are incorporated directly through payments and indirectly through policies such as supply management and subsidized input costs. CRAM is capable of estimating the change in resource allocation into various enterprises in response to changes in technology, government programs and policies or market conditions. Analysis is carried out by comparing activity levels for a scenario versus a baseline version of CRAM.

The integrated model

While AEI models are useful for tracking environmental performance over historical periods, predictive models are needed to objectively estimate what the future might look like given the changes in policy today. This predictive capacity has been developed by linking the economic (CRAM) and seven AEI models including RWE. There are substantial spatial implications in doing this type of analysis since environmental impacts vary with local conditions such as climate, soil type and landscape. Policy scenarios are run by linking the crop and livestock activity levels generated by CRAM to the AEIs and assessing changes in the environmental indicators from the baseline.

Analysis

The first step in analyzing the environmental impacts due to changes in on-farm management practices over the next 5 years was to establish a business as usual (BAU) baseline case for 2008. The year 2008 was chosen since it marks the end of the first APF period for which achievable outcomes must be established. The 2008 BAU baseline for CRAM assumes no increase or decrease in the agricultural land base, with land management practices (e.g. conservation tillage, summerfallow and fertilizer use) continuing to be adopted at rates consistent with historical trends and physical constraints. Growth in various crop and livestock enterprises for 2008 were based on 2001 census information projections provided by AAFC's Medium Term Policy Baseline. Once the CRAM BAU was established, the data were used as input for establishing 2008 baselines for the AEIs (including RWE). Baseline numbers for 1996, 2001 and 2008 (not shown) reveal an increasing trend in cropland, hayland, beef cows and breeding sows whereas summerfallow and native pasture area are declining.

AAFC experts determined the package of environmental management scenarios to be used as potential strategies to meet the environmental goals outlined by the APF agreement. The choice of environmental management scenarios was based on the following criteria:

- Relevance to the established environmental goals for the APF
- Measurability – application and suitability to existing models
- Level of priority within agriculture
- Feasibility

Based on the above criteria, nine scenarios were chosen for quantitative analysis, from which five had significant impacts on the RWE indicator. For each scenario the following set of information was required as input into the economic model (CRAM): applicable regions, current adoption rates, potential future adoption rates, changes in input costs and output. Table 1 provides an overview of the environmental management scenarios included in this analysis and adoption rates applied to each scenario.

Table 1. Environmental management scenarios and adoption rates used in the analysis [1]

Scenario	Business As Usual (BAU)	Low Adoption	Medium Adoption	High Adoption	Units
Conservation Tillage	32	42	57	69	%
Reduced Summerfallow	3.9	3.2	2.4	1.5	M ha
Permanent Cover	--	0.4	0.6	1.0	M ha
Grazing Management:					
Complementary Grazing	40	45	50	60	%
Rotational Grazing	50	55	60	70	%

[1] Numbers reflect national levels but provincial differences are accounted for in the analysis.

The impact of the management scenarios on environmental indicators is dependent on the assumed adoption rates. Three adoption rates, low, medium and high, were developed for each scenario based on expert opinion. Low adoption rates are slightly above baseline levels. Medium adoption is reasonably achievable with some promotion of management practices. High adoption rates represent achievable adoption under aggressive promotion of management strategies (Table 1).

Results and Discussion

The Risk of Water Erosion indicator

For Canada, the risk of water erosion under prevailing management practices is presented in Table 2, which shows the share of cropland in the various risk classes.

Table 2. Risk of water erosion on Canadian cropland under prevailing management practices

Cropland Area (million ha)	Share (%) of Cropland in Various Risk Classes									
	Tolerable 1981	Tolerable 1996	Low 1981	Low 1996	Moderate 1981	Moderate 1996	High 1981	High 1996	Severe 1981	Severe 1996
40	70	85	19	9	7	5	3	2	2	1
	Change in Risk (%)									
	+22		-53		-26		-49		-39	

[1] Numbers reflect national levels but provincial differences are accounted for in the analysis.

In 1996, Canada had 85% of its cropland area in the tolerable water erosion risk. This is an improvement (see Change in Risk in Table 2) of 22% in water erosion risk since 1981, because of a shift of its cropland into the tolerable risk class from higher risk classes. The general trend of decreasing risk of erosion between 1981 and 1996 in Canada reflects the degree to which changes have been made in cropping systems and tillage practices. A combination of reduced tillage, less intensive crop production, decreased summer fallow, and removal of marginal land from production all contribute to lower erosion rates. From an agricultural policy perspective, it is obvious that soil conservation practices should be targeted to cropland in the other than tolerable erosion risk classes.

On a provincial basis, reduction in the RWE between 1981 and 1996 showed Saskatchewan with the most improvement of all provinces, with a shift of 26% of its cropland into the tolerable risk class from the higher risk classes, followed by Alberta (8% improvement) and Ontario (7% improvement). Saskatchewan and Alberta combined have approximately three-quarters of the total Canadian area in cropland.

The integrated model

The following results and discussion concentrate on provincial impacts estimated by the integrated model for medium adoption rates. Results in the figures are reported as a percentage change from the 2008 BAU baseline for medium adoption rates, and the range of impacts for low and high adoption are also provided. Changes for medium adoption rates of less than 0.5% are not presented.

Conservation tillage

The conservation tillage scenario was characterized by increased no-till (zero tillage). Adoption of conservation tillage in Canada was assumed to increase to 57% of cropland compared to 32% in the baseline. This represents an increase of 7.1 million hectares over baseline levels with corresponding decreases in minimum and conventional tillage. It is expected that increased no-till will result in a decrease in water erosion.

Although this scenario is applicable to all provinces, it should be noted that the current structure of CRAM contains tillage distributions for the Prairie Provinces only. Hence, the information that is fed from CRAM to the AEI models is limited for the non-prairie provinces, and may not be sensitive enough to reflect changes due to improved tillage practices.

In the prairie provinces, there is an approximate 10% reduction in the RWE indicator (Figure 1). Sensitivity analysis suggests the impact on the RWE indicator may vary considerably depending on the assumed adoption rate.

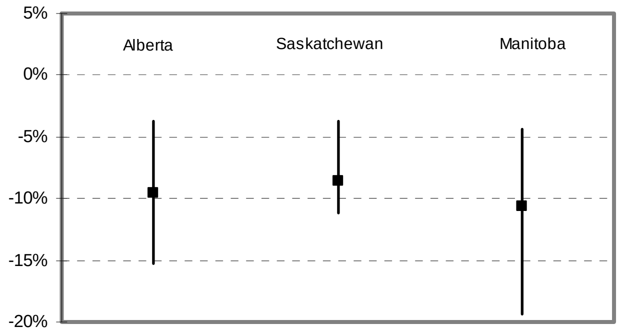

Figure 1. Percentage change in the RWE indicator as a result of increased conservation tillage

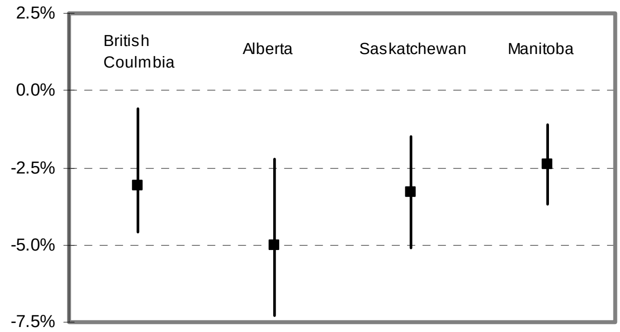

Figure 2. Percentage change in the RWE indicator as a result of reduced summer fallow

Reduced summer fallow

Summer fallow is traditionally used in cropping rotations as a method of replenishing moisture in the soil in the prairie regions. The summer fallow scenario, applied to western Canada only, assumes reduction in the frequency of summer fallow within a cropping rotation. Adoption rates vary by soil zone and province. A medium adoption rate is assumed to translate into a 1.5 million hectare reduction in summer fallow relative to baseline levels. A reduction in summer fallow is expected to cause a decrease in RWE. Improvements in the RWE (2 to5%) occur in all western provinces (Figure 2). Sensitivity analysis shows adoption rates have some effect on the RWE indicator.

Permanent cover

Assumptions for this scenario were adapted from the existing permanent cover programs. This scenario involves a shift of an additional 600000 ha of marginal cropland to permanent cover with perennial crops. Most of the marginal land is converted to improved pasture, with the remainder converted to hay land. Distribution of land converted to improved pasture or hay land varies by region, soil type, actual cultivated marginal lands and the distribution of grazing/hay to support beef animals. The scenario assumes a 2% increase in beef cattle numbers as an outlet for the increased forage production. Increased permanent cover is expected to reduce soil erosion.

The permanent cover scenario is applicable to all provinces. The impact of this scenario on water erosion is small, except in British Columbia where the risk of water erosion is reduced by approximately 5% (Figure 3). These results may be explained by the high concentration of hay land versus cropland in the British Columbia BAU case. Therefore, shifting small amounts of cropland into forage results in a relatively large percentage decrease in cropland, which is more susceptible to erosion than hay land. Sensitivity analysis indicates that adoption rates have little effect on RWE except in BC.

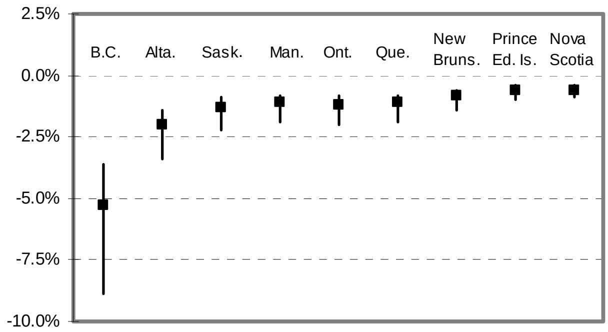

Figure 3. Percentage change in the RWE indicator as a result of increased permanent cover

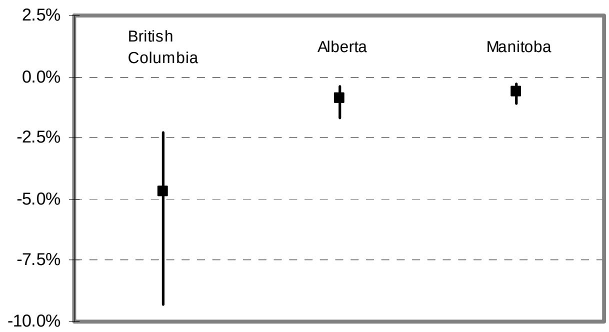

Figure 4. Percentage change in the RWE indicator as a result of grazing management strategies

Grazing management - rotational and complementary grazing
Rotational and complementary grazing systems decrease grazing intensity on native pastureland by supplementing tame pasture land. This results in an increase in forage quality on native pastureland and a decrease in feed requirements due to higher calf weaning weights. Rotational grazing is applied to moist tame pasture areas in western Canada and tame and native pasture lands in eastern Canada. Complementary grazing is applied to British Columbia, western Manitoba, northern Saskatchewan and northern and western Alberta. Assumed adoption rates for rotational and complementary grazing are 10% above BAU levels

The grazing management scenario is applied to relevant areas across all provinces. Model results show that the impact on RWE is greatest in British Columbia due to a relatively large shift in crop and summer fallow area to tame pasture (Figure 4). Similar to the permanent cover scenario, the high proportion of hay land to cropland mix may explain this result.

Combined scenario
Previous results were an estimation of the impacts of individual scenarios. To gain a clearer understanding of the overall impact of the suite of management scenarios, a combined scenario analysis was conducted. In the combined scenario, the CRAM optimization model is solved simultaneously for all scenarios, accounting for possible interaction among scenarios. A comparison of the individual and combined scenario results suggests that the impacts on the AEIs are essentially additive across scenarios.

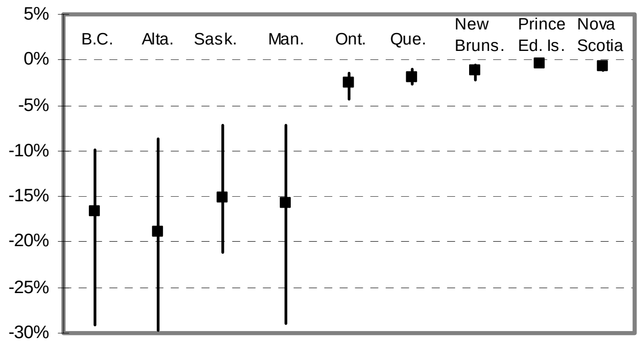

Figure 5. Percentage change in the RWE indicator for the combined scenario

The RWE indicator is relevant in all provinces except Newfoundland. The impact on the indicator is larger in the western provinces (15 to 19%) than eastern provinces (0.5 to 3%) (Figure 5). This is likely explained by the additional impact in western provinces resulting from the conservation tillage, reduced summer fallow, and grazing management scenarios.

Conclusions

- The reduced risk of water erosion between 1981 and 1996 in Canada (22%) shown by the indicator is a positive trend resulting from shifts in farming practices (tillage and cropping), attitudes towards land stewardship, and management strategies.
- A proportion (15% or 6 million ha) of Canadian cropland is still subject to the unsustainable loss of soil resulting from water erosion, needing improvements in farming practices, management strategies and policies.
- For 2008, the integrated model predicted substantial provincial reductions in RWE from the BAU case as a result of several environmental management scenarios and adoption rates, with the greatest impact by increased conservation tillage on the Canadian prairies (Alberta, Saskatchewan and Manitoba).
- The overall impact of a suite of management scenarios showed an improvement in RWE between 15-20% for the Western provinces (British Columbia, Alberta, Saskatchewan and Manitoba) for the medium adoption rates, and varying between 7 and 30% reduction for the full range of adoption rates.
- The integrated model proved to be a useful tool in assist federal, provincial and territorial decision-makers in establishing targets and monitoring environmental goals.
- Targeting soil conservation practices to cropland in the other than lowest (tolerable) risk class will help to move the sector towards the long-term goal of having all cropland in the tolerable risk class for water erosion.

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Any policy views, whether explicitly stated, inferred or interpreted from the contents of this paper, should not be represented as reflecting the views of Agriculture and Agri-Food Canada.

References

Heigh, L., Junkins, B, MacGregor, R.J., Gill, R., Heigh, J., Huffman, T., Yang, J., van Vliet, L., Padbury, G., and Boehm, M. (publication pending). “Quantitative Analysis of the Impact of Agricultural Management Strategies on Environmental Indicators”. Agriculture and Agri-Food Canada, Ottawa, Ont.

Horner, G.L., Corman, J., Howitt, R.E., Carter, C.A., and MacGregor, R.J. (1992). “The Canadian Regional Agricultural Model: Structure, Operations and Development.” Technical Report 1/92. Policy Branch, Agriculture and Agri-Food Canada, Ottawa, Ont.

McRae, T., Smith, C.A.S. and Gregorich, L.J. (editors). (2000). “Environmental Sustainability of Canadian Agriculture: Report of the Agri-Environmental Indicator Project”. Agriculture and Agri-Food Canada, Ottawa, Ont.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, D.C. 1997. “Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)”. Agriculture Handbook No.703, U.S. Department of Agriculture, Agricultural Research Service, Greenbelt, MD.

Wall, G.J., Coote. D.R., Pringle, E.A. and Shelton, I.J. (editors) (2002). “RUSLEFAC – Revised Universal Soil Loss Equation for Application in Canada: A Handbook for estimating Soil Loss from Water Erosion in Canada”. Research Branch, Agriculture and Agri-Food Canada, Ottawa, Ont.

Wischmeier, W.H. and Smith, D.D. (1978). “Predicting Rainfall Erosion Losses – A Guide to Conservation Planning”. Agriculture Handbook No.537, U.S. Department of Agriculture, Washington, DC.