Integration of Economic and Biophysical Models for Assessing Agricultural Policy Impacts on Water Quality at a Regional Scale

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Abstract: Evaluation of the policy environments and market signals that influence choices in agricultural cropping systems and land management practices are usually conducted from a socioeconomic perspective on broad macroscales. The environmental impacts of these systems and practices, however, need to be assessed from a biophysical perspective at much finer microscales. Agriculture and Agri-Food Canada (AAFC) currently makes use of two models that respectively serve policy analysis and environmental water quality assessments. The Canadian Regional Agricultural Model (CRAM) is a macro-scale analytical tool for determining the likely agricultural production decisions resulting from policy initiatives and formulations. The water quality model, Indicator of Risk of Water Contamination (IROWC), determines the likely impact of specific agricultural management practices on given landscapes. Integration of these two models requires the development of a suitable land use allocation model (LUAM) that can scale down and parse macro-scale policy and market signals to landscapes based on a combination of land suitability/capability and cropping history information. This paper presents a framework and methodology being implemented to develop an integrated model that addresses policy and biophysical concerns for the determination of interactions between agricultural policy making and water quality.

Keywords: Integrated policy-environmental modelling; Land use allocation model

1. INTRODUCTION

Modern agriculture has been very effective in increasing crop yields and animal output, in some cases by as much as threefold over the last fifty years. However, some of these increases in productivity have been achieved at a high environmental cost. In Canada, the adverse impacts of agricultural practices on water quality has become a serious concern, and has led to considerations of policy instruments for mitigating these impacts. In order to establish effective policy instruments, the capacity to evaluate the potential outcome of a range of policy scenarios on producer response and resulting environmental impacts is required. This is best achieved through an integration of socioeconomic and biophysical analytical capacity. Individually, socioeconomic models provide an important indication of producer responses to policy signals, while biophysical models assess agricultural production practices and their potential impacts on the environment. To date, the integration of models from these two domains has not been extensively developed [Attwood et al., 2000], a major factor for this lack of integration being the disparity in the temporal and spatial scales at which theses two types of model function [Veldcamp and Lambin, 2001]. Socioeconomic or policy models usually function at an aggregate, regional or supra-regional spatial scale, and provide analysis for equilibrium or long-term temporal conditions. Conversely, biophysical models function at a detailed or micro-level spatial scale and provide responses ranging from daily to seasonal temporal scales. This paper reports on the framework and methodology for integrating a socioeconomic and a biophysical model for assessing the impacts of policies on water quality at a regional scale.

2. MODELLING FRAMEWORK

Agriculture and Agri-Food Canada (AAFC), the country's department of agriculture, has developed a socioeconomic model, the Canadian Regional Agriculture Model (CRAM), and a biophysical model, Indicator of Risk Of Water Contamination by Nitrogen (IROWC-N), to aid it in its analysis of policy response and water quality impacts, respectively, at national and regional levels.

CRAM is a socioeconomic model that determines the optimal use for agricultural land and levels of livestock production, based on a given set of economic and market conditions. It is a sector equilibrium model for Canadian agriculture which is disaggregated across both commodities and space [Horner at al., 1992]. CRAM is a non-linear optimization model based on profit maximization, and is sensitive to changes in commodity prices and input costs. It is applicable to commodities ranging across grains and oilseeds, forage, beef, hogs, dairy and poultry. Grains, oilseeds, and hay responses are determined by changes in the relative profitability of alternatives. Government policies are incorporated through direct payments, and indirectly through policies such as supply management and subsidized input costs. In the past, CRAM has been linked with the EPIC biophysical model to determine the impact of changes to government policies on soil degradation and land use change in the Canadian Prairies [Bouzaher et al., 1994; Izaurralde et al., 1996].

IROWC [MacDonald and Spaling 1995] measures the risk of water contamination from agricultural activities, including both crop- and livestock operations. The model follows a budgeting approach in estimating the N balance and the soil water balance. Nitrogen inputs arise from mineral fertilizer, animal manure, legume fixation and, in semi-arid regions, from N tied up in crop residues and mineralized soil N during periods of summerfallow. Outputs include N removed in the harvested portion of the crop and N lost via denitrification. The difference between inputs and outputs gives a value for residual N which is potentially available for transport to surface and/or ground water. The amount of water potentially available to move the residual N is calculated from a 30-year mean water budget with precipitation as input and potential evapotranspiration as output. An annual water deficit, or an annual water surplus less than the soil water-holding capacity would indicate that there is no risk of water contamination; otherwise the risk indicator is calculated by dividing the amount of residual N by the excess water.

Current IROWC-N research [MacDonald, 2000] has focussed on the spatial resolution of Soil Landscapes of Canada (SLC) polygons at a scale of 1:1 million. This level of resolution is detailed enough to show regional differences within a province, and is an appropriate scale at which to show changes occurring over 5 - 10 year periods. Evaluations at the more detailed scale (1:250,000) of the Canada Land Inventory (CLI) can be conducted if sufficient input data are available, or if data from coarser scales can be reliably disaggregated.

The integration of CRAM and IROWC-N requires the capacity to downscale predicted policy responses at large politically delineated areas to smaller biophysically-based soil or landscape polygons in order to carry out impact assessments. This is accomplished through the proposed land use allocation model (LUAM).

2.1 Land Use Allocation Model (LUAM)

The translation of policy responses, such as "a 10% increase in cattle numbers" or " a 20% reduction in nitrogen fertilizer use" determined for large, heterogeneous regions into the detailed and specific local impacts required for biophysical modelling is the task of a land use allocation model. For example, unless the soil, climate and current land use practices are uniform for all farms within a region, it is unrealistic to assume that the impacts of a policy will be felt uniformly across the region. The land use impacts will vary depending on the distribution of soil types, weather patterns, current production practices and range of socioeconomic conditions.

Standard spatial allocation models have two distinct components that combine to determine what uses are to be allocated, namely the 'objective' function, which chooses the solution that optimizes a given objective, and the 'constraint' function, which reduces the number of choices according to a given set of limitations. A prototype LUAM for use in Canada, with absolute constraints based on land capability, and constraints to be imposed based on energy inputs, urban growth needs, forest production levels and agricultural commodity production, was developed and tested for several scenarios by the University of Guelph in the 1980's [Smit, 1981; Land Evaluation Group, 1985]. This model was modified and showed good results in a more recent evaluation of the impact of production and use of maize-based ethanol fuel on greenhouse gas emissions [Vandergaast, 1999].

The analytical process of the integrated economic and biophysical assessment involves several stages: (i) Interpretation of policy response to specific changes in production systems (crops grown, input levels, tillage practices, livestock production); (ii) Determination of the likely locations of these changes on the landscape in a given region; (iii) Determination of impacts on water quality; and (iv) Aggregation of biophysical impacts to the policy scale and determination of new/changed mix of production systems. This process can be conducted for a range of policy scenarios in order to determine the optimal mix of policies with minimal impact on water quality.

CRAM provides production level response to policy and economic signals in terms of total areas within a region under different production regimes, or as shifts from current proportions of crops, land management practices and livestock production systems. However, this information is not provided in terms of actual locations within the physical landscape. Consequently, output from CRAM needs to be disaggregated such that crops and management practices are assigned to specific locations within the landscape according to a reliable set of criteria and methodologies incorporated in the land use allocation model (Figure 1). Land use allocation would be achieved through a linear programming approach where the LUAM would optimize land use subject to a range of soil, landscape, land suitability or capability and cropping history constraints.

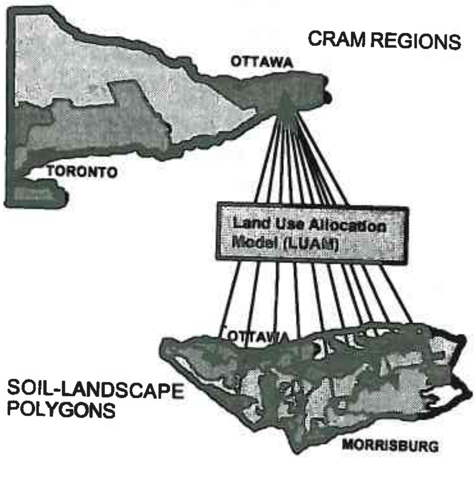

Figure 1. Land use allocation model for scaling from CRAM to SLC polygons.

Once the location of each production system is assigned to a given landscape, water quality impacts can be assessed at this disaggregated level by means of the IROWC-N models. The model runs would identify areas where the combination of actual land use and long-term precipitation characteristics would result in an elevated risk of water contamination. The outcome from these assessments would then be reaggregated to provide a response at the CRAM region level (Figure 2).

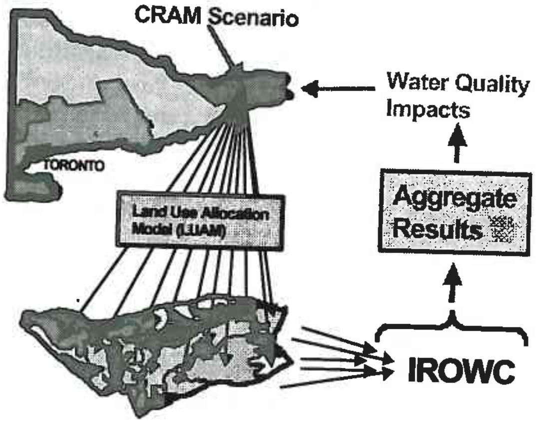

Figure 2. Schematic of water quality impact assessment from IROWC model output

This series of analytical processes can be repeated for different scenarios, e.g. new crops, shifts in crop/livestock mixtures, climate change, incentive programs. These analyses can serve in evaluating possible outcomes of different policy scenarios and in choosing the most appropriate policy signals for mitigating adverse water quality impacts.

3. SCALE AND DATA CHARACTERISTICS

Data and information provided by CRAM is generally on a very coarse scale based on political boundaries. For crop production assessment, there are a total of 38 CRAM regions for all of Canada, with 22 of these in the three Prairie provinces, ten in Ontario, and provincial boundaries of the remaining six provinces serving as the CRAM region boundaries. Provincial boundaries for all ten provinces serve as CRAM region boundaries for livestock production assessment, although work is underway to disaggregate these to the regional level. In contrast, there are over 1500 SLC polygons across Canada.

CRAM model outputs can be disaggregated by means of the LUAM to a scale of 1:1M for use with the SLC database, or to that of 1:250,000 for the CLI database. Additionally, rescaling of soils and climate data between the two biophysical databases may be required depending on the level of detail required. The reliance of IROWC-N on a budgeting approach allows its use at either the CLI or SLC scale provided that sufficient data is available.

Data for the parameters required for the constraint functions (soils, landscape, land suitability, etc.) are available from a number of national databases compiled and maintained by AAFC. Land suitability ratings are available from the CLI database. Soils, landscape, climate and similar data are available from the SLC database. Cropping history can be obtained from annual and census-year agricultural management and production data which have been recompiled into SLC polygons.

4. SUMMARY

Producer behaviour is affected by policies, markets, resources and technology. It is necessary to link regional, national and international issues and concerns to landscape-level environmental impacts of producer decisions. The impacts of a particular policy scenario on land use and livestock production needs to be translated for evaluation in biophysical models to determine environmental impacts. The challenge is to relate the landscape specific nature of biophysical models to the national, provincial and regional impacts of interest to policy makers. The spatial aggregation issues associated with this task are complicated by the fact that economic/political and ecological boundaries are disparate.

A LUAM is being developed to bridge the scaling gap between socioeconomic and biophysical modelling in order to provide an integrated framework for assessing the impact of policy scenarios on water quality at the regional level. The capacity of the LUAM to make use of a range of soil, landscape, cropping history and related information to disaggregate policy response to specific soil polygons will facilitate the development of sound policies for improved productivity and environmental stewardship.

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