TWO ESSAYS ANALYSING POLLUTION FROM AGRICULTURE:

Alternatives for assessing indirect effects

By

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ABSTRACT

Given the importance of agricultural GHG mitigation strategies, this thesis addresses, both theoretically and empirically, the indirect effects of GHG mitigation in agriculture. The first Chapter is focused on the "ancillary" physical effects of GHG mitigation, specifically in the case of water quality. Chapter two provides an adaptation of a theoretical/graphical framework that can be used to analyze the indirect effects of GHG mitigation strategies.

The analysis in Chapter one develops watershed and provincial estimates of water quality co-effects of GHG mitigation strategies by linking a water quality model to a national level agricultural sector model. The Canadian Economic and Emissions Model of Agriculture (CEEMA) is used as the agricultural model. Its output is used as input for the Agricultural Non-Point Source Pollution Model (AGNPS). The output of AGNPS is then assessed using the British Columbia (BC) Water Quality Guidelines.

Results from Chapter one show that around 28% of the water in the Okanagan watershed is below desirable standards. The provincial results were obtained for the lower part of BC. They show that the basins along the main rivers contain water that is barely suitable for aquatic life. In the case of the Okanagan watershed under a $25/tonne carbon equivalent price scenario there is around a 4% decrease in the total pollutant loadings ending up in the water. The biggest decrease is in Nitrogen, around 7%, with TSS being around 6%, and Phosphorous being insignificantly under 1% change. The results show that the water quality ancillary effects of GHG mitigation strategies are existent and can be quantified and targeted accordingly.

The analysis done in Chapters two, although different from the analysis in Chapter one, presents an example of the possible microfoundations for some of the effects quantified in Chapter one and allows us to see how farmers react to different scenarios caused by the presence of a carbon equivalent price. The two assumed scenarios are: An overall increase of the prices of all inputs and an increase only on the N-based fertilizer price. I show how a farmer will react to these changes focusing on his risk attitudes.

Chapter two uses the state contingent approach with the case of a farmer that produces a certain crop and is faced with uncertainty caused by two states of the environment and by input use. Using state contingency I develop a diagrammatic framework to analyze input transformation and two scenarios assumed to be caused by the presence of a carbon equivalent price and the resulting effects on non point source pollution. This type of framework is relatively new in the literature and discusses intuition that has not been presented before to analyze GHG mitigation.

Both analyses done on this thesis, although radically different, show that when doing policy analysis on GHG mitigation they have to be targeted according to research done on their overall effects. Failing to do proper policy analysis could prove to be resource and time consuming not achieving the desired effects. Analyzing policies aimed to reduce GHG emissions must include both the direct and indirect effects caused by their adoption. These analyzes have to include the effects that geographic, climatic, and other aspects will have on their outcome. If these outcomes are not correctly assessed, they could lead to failed objectives in reducing GHG emissions and improving the environment.

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LIST OF ACRONYMS

AGNPS	**Agriculture Non-Point Source Pollution Model**
CEEMA 2.0	**Canadian Economic and Emissions Model for Agriculture**
CRAM	**Canadian Regional Agricultural Sector Model**
GHGSM	**Greenhouse Gas Emissions Sub-Model**
GHG	**Greenhouse Gases**
N	**Nitrogen**
P	**Phosphorous**
TSS	**Total Suspended Solids**
NPS	**Non Point Source**

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INTRODUCTION

Global warming is an issue important to every nation in the world. Greenhouse gas (GHG) emissions are the main cause for climate change. This is the reason why more than 80 countries signed the Kyoto Accord, a 1997 pact, which requires industrialized countries to cut greenhouse gas emissions by an average of 5.2 per cent by 2012 (Edwards, C., 2000). Agriculture can play an important role in mitigating greenhouse gas emissions, especially in Canada where agriculture contributes approximately 10% of total GHG emissions.

This thesis addresses, both theoretically and empirically, the indirect effects of GHG mitigation. The first Chapter of the analysis focuses on the ancillary effects, specifically in the case of water quality using computational models. Chapter two, although radically different from Chapter one, provides an example of the possible micro-foundations for some of the predictions presented in Chapter one. This Chapter presents an adaptation of a new theoretical/graphical framework that can be used to analyze the indirect effects of GHG mitigation strategies.

The first Chapter deals with the secondary effects of GHG mitigation strategies. Specifically, it focuses on the physical effects that these strategies can have on the quality of water. The analysis develops watershed and provincial estimates of water quality co-effects of GHG mitigation strategies by linking a national level water quality model to a national level agricultural sector model. The Canadian Economic and Emissions Model of Agriculture (CEEMA) is used as the agricultural model. The output obtained from CEEMA is used as part of the input for the Agricultural Non-Point Source Pollution Model (AGNPS). The output of AGNPS is assessed using the British Columbia (BC) Water Quality Guidelines.

The analysis for Chapter one was done in the Okanagan Watershed for two market prices for GHG reduction scenarios expressed as $ per tonne of carbon equivalent (CE). The two scenarios included a world with no carbon equivalent prices ($0/tonne), and a $25/tonne scenario. The changes from these scenarios were based on percentage changes in land use, aforestation, tillage practices, and agro ecosystems data from a previous study done in the United States. That study was done on the "Bread Basket" States in the United States. These percentage changes were applied to our case since the data from CEEMA is only available for the year 2001.

Results from Chapter one show that around 28% of the water in the Okanagan watershed is below desirable standards. The provincial results were obtained only for the lower part of BC. They show that the basins along the main rivers of this part of the province, where there is intensive agriculture, contain water that is barely suitable for aquatic life and not suitable for drinking water or aesthetics. In the case of the Okanagan watershed under a $25/tonne carbon equivalent price scenario there is around a 4% decrease in the total pollutant loadings ending up in the water. The biggest decrease is in Nitrogen, around 7%, with TSS being around 6%, and Phosphorous being insignificantly under 1% change. The results show that the water quality ancillary effects of GHG mitigation strategies are substantial.

In Chapter two I model farmer's decision under uncertainty introducing pollution, to compare farmer input mix choices based on his risk attitudes. Although the analysis done in Chapter two is radically different than the one in Chapter one, I use this chapter to try to illustrate the possible changes in input choices that could happen at a farmer's level that could bring about improvements in water quality. Chapter two focuses on applying the state contingent approach to a scenario of a farmer that produces a crop under uncertainty adapting pollution into the analysis. For this I use the beaker diagram of input use transformation from the state contingent approach and adapt it to incorporate pollution transformation. With this adaptation the analysis incorporates the farmer's preferences over returns and the pollution that he produces but does not concern him.

Chapter two then analyzes, using the beaker diagram of pollution transformation, two supposed scenarios that a carbon equivalent price will create, and which aims to reduce pollution which includes runoff and airborne NO_2. The two scenarios include an increase of the price of all the inputs and an increase only in the price of N-based fertilizers. Uncertainty caused by production, climate, and input use is incorporated into the analysis. Chapter two develops a diagrammatic framework to analyze input transformation and the scenarios caused by the presence of a carbon equivalent price aimed at reducing GHG. This type of framework is relatively new in the literature and provides intuition that has not been discussed before while analyzing GHG mitigation.

Chapter I

Ancillary Effects from Greenhouse Gas Mitigation Strategies in Agriculture: The Case of Water Quality in the Okanagan Valley of British Columbia

1.1 Introduction

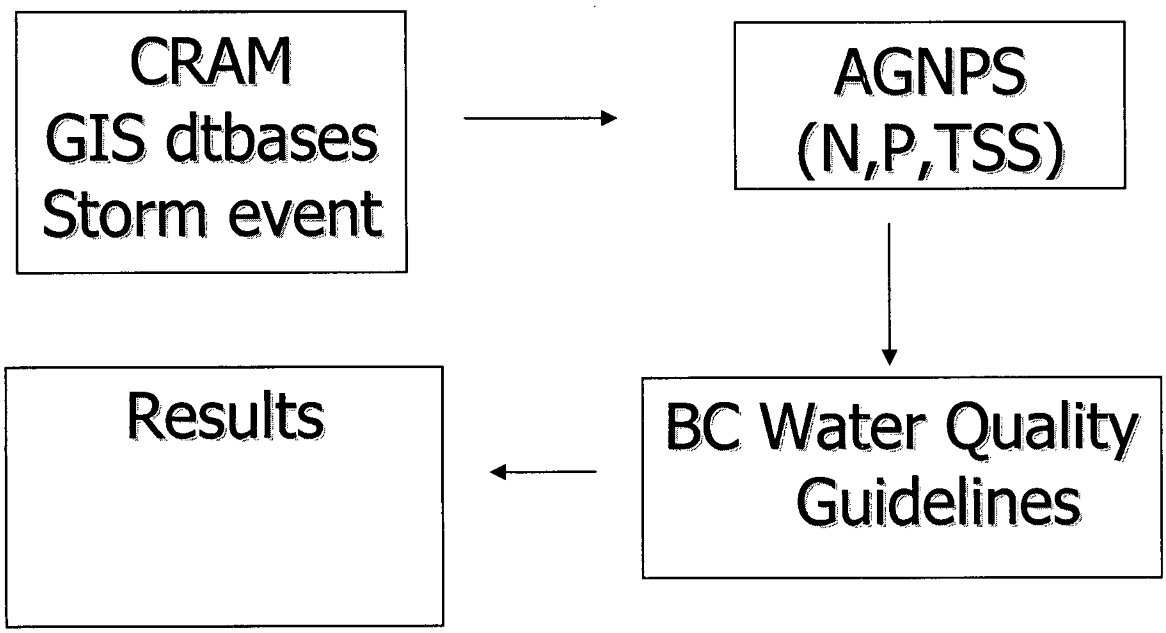
Most studies on Greenhouse Gas (GHG) mitigation focus on the direct benefits and costs of mitigation. However, GHG abatement can also have other indirect effects (or ancillary effects). Ancillary effects from GHG mitigation in agriculture and forestry include: impacts on water quality, soil quality, soil erosion, biodiversity, and acidification. According to a review of studies commissioned by the Intergovernmental Panel on Climate Change (IPCC), ancillary benefits can be anywhere from 30% to over 100% as large as direct GHG abatement benefits (Pearce et al. 1996). To my knowledge, these ancillary effects have mostly been ignored in the literature studying GHG mitigation. Including ancillary effects will allow us to obtain a more accurate assessment of the overall impact of GHG mitigation.

In this Chapter I present a specific ancillary effect of GHG mitigation: the water quality impact of a policy designed to mitigate greenhouse gases. To illustrate this ancillary effect I present a case study of the Okanagan watershed in the Province of British Columbia. I consider a GHG mitigation policy that charges all users a fee for carbon equivalent emissions. In the first scenario, there is no GHG mitigation policy in place. Individuals face a zero price. In the second scenario, individuals face a 25$ per tonne price for carbon equivalent emissions. The aim is to provide an estimate of the reduction in pollutant loadings in water that result from this GHG mitigation policy. The study does not capture the resulting social economic benefits but focuses on the physical co-effects of GHG mitigation strategies on the quality of water.

To estimate the change in water quality I link an agricultural sector model with a water quality model. I then estimate the changes in water quality that occur when there is a price charged for carbon equivalent emissions. I find that moving from a baseline of zero prices, to charging a 25$ per tonne price for carbon equivalent emissions causes a reduction in pollutant loadings in water. When assessed according to the British Columbia Water Quality Guidelines these reductions bring about a significant improvement in water quality.

To estimate changes in agriculture that result from a 25$ carbon equivalent price I use the Canadian Regional Agricultural Sector Model (CRAM). To estimate the water quality changes associated, I use the Agricultural Non-Point Source Pollution Model (AGNPS). This model is developed by the United States Department of Agriculture, National Sedimentation Laboratory. CRAM provides land use, and fertilization parameters. These parameters are used as inputs into the AGNPS. The AGNPS calculates Erosion, Nitrogen, Phosphorus and other Non-Point Source (NPS) pollutant loadings for a given watershed. The model requires other geographical data, agro-ecosystems data like wetlands and forested areas, climate, land use and fertilization data. The geographical and agro-ecosystems data is obtained from publicly available Geographic Information Systems (GIS) databases found at the different Provincial Ministries' websites. The climatic data was obtained from Environment Canada (2001). A general overview of the study is shown on Figure 1.1.

Figure 1.1 General Overview of the Models and Linkages used in the Study



Consider the baseline scenario of zero carbon equivalent prices (the conditions in 2001). Based on the British Columbia provincial water quality guidelines the results gained from the AGNPS imply that the Okanagan Lake/River is not clean enough to be classified as suitable for Aquatic Life. Further, according to the estimates, the watershed as a whole is just below the Recreation and Aesthetics category. I also estimate water quality for other watersheds in southern British Columbia which are inside the following 2001-Agricultural Census Sub-Zones 1, 2, 3, and 4. They are: Vancouver Island/Coast, Mainland/Southwest, Thompson/Okanagan, and Kootenay, respectively. The results indicate that the water along the main rivers of this area is below Recreation and Aesthetics standards.

Now consider the scenario where individuals face a 25$ carbon equivalent price. I find that when a 25$ carbon equivalent price is adopted there is about a 7% decrease in the total loadings of Nitrogen. In the case of Phosphorous, the change is below 1% and in TSS the change is close to 6%. Overall, I find that there is a 4% decrease in pollutant loadings in the Okanagan Watershed from adopting a $25 carbon equivalent price. CRAM data for this scenario is not available. I thus use an extrapolation of the base scenario data based on changes in land use, fertilization, and agroecosystems from a similar study in the US (specifically on the Breadbasket States: Illinois, Ohio, Missouri, and Michigan). I assume that proportional changes in land use, and fertilization would be observed in British Columbia when such carbon equivalent prices are adopted. All parameters other than land use, agroecosystems, and fertilization are assumed to remain constant across the two scenarios.

In Agriculture, many of the practices that have been historically used to improve the quality of the environment overlap with practices that are used for GHG mitigation. Quantifying these ancillary effects can help to better target and assess GHG mitigation policies. In this Chapter I wish to present and specify an ancillary benefit from a GHG mitigation policy using the case of water quality in the Okanagan Valley of British Columbia. I would like to point out that these numbers are not exact estimates. The purpose of this Chapter is only to illustrate that GHG mitigation strategies are likely associated with significant ancillary effects. My purpose is not to quantify these effects exactly.

The plan for the rest of the Chapter is as follows: In Section 1.2 I present the methodology for the study. In Section 1.3 I describe the Okanagan watershed and why it serves as a good candidate for a case study. In Section 1.4 I discuss the data requirements for the study and where the data was obtained. I integrate the methodology and data sections in Section 1.5 where I discuss the interface between the two models. I present results in Section 1.6, and conclude in Section 1.7.

1.2 Description of Methodology

In this section I describe the methodology used to calculate pollutant loadings in British Columbia under two GHG mitigation policy scenarios. I consider a specific GHG mitigation policy that charges all users a fee for carbon equivalent emissions. In the first scenario, there is no GHG mitigation policy in place. Individuals face a zero price. In the second scenario, individuals face a 25$ per tonne price for carbon equivalent emissions. The aim is to provide a first estimate for the reduction in pollutant loadings in water that result from such a GHG mitigation policy. These hypothetical carbon equivalent prices were selected to represent values which are usually evaluated for land-based carbon mitigation (Subhrendu et al. 2002).

Water Quality as an Ancillary Benefit

To a large extent, policies for limiting emissions of greenhouse gases (GHGs) have been analyzed in terms of their costs and benefit in terms of these gases. However, actions to slow atmospheric GHG accumulation are also related to a reduction in conventional environmental pollutants. The effects that result are often referred to as "ancillary" to the benefits and costs of GHG abatement (Dallas Burtraw and Michael Toman, 2000).

I consider the actions utilized to limit GHG's from agriculture. Mitigation of GHG's in agriculture can be done through 1) carbon sequestration, 2) reduction of GHG emissions from management practices, and 3) substitution of renewable biomass based products for materials and processes that generate GHG emissions through fossil fuel combustion (CEEMA documentation, 2002). These mitigation strategies generally overlap with strategies that improve water quality. These include land retirement, afforestation, and low tillage. They generally create better retention of sediments by the land, accumulate pollutants, and decrease the speed of loadings. This facilitates the decaying and reincorporation cycles of the pollutants.

A reduction in water pollutant loadings from agriculture has large potential benefits. In the United States, the most recent *National Water Quality Inventory(2001)* reports that agricultural non-point source (NPS) pollution is the leading source of water quality impacts to surveyed rivers and lakes, the third largest source of impairments to surveyed estuaries, and also a major contributor to ground water contamination and wetlands degradation. Agricultural activities that cause NPS pollution include confined animal facilities, grazing, plowing, pesticide spraying, irrigation, fertilizing, planting, and harvesting. The major agricultural NPS pollutants that result from these activities are sediment, nutrients, pathogens, pesticides, and salts (Mackay, 1995). Of these pollutants, nutrients such as N and P, and sediment such as TSS have the most significant effects in the quality of water (Dickinson and Rudra, 1991). Please see Chapter one's Appendix 1 for a detailed description of the impact of the three pollutants: N, P, and TSS.

Models used to Estimate Changes in Water Quality

To estimate the changes in water quality associated with GHG mitigation I linked two separate models. These were, the Canadian Economic and Emissions Model for Agriculture (CEEMA 2.0) and the Agricultural Non-Point Source Pollution Model (AGNPS). Finally, I used the British Columbia Water Quality Guidelines to assess the results gained from these models.

The Canadian Economic and Emissions Model for Agriculture (CEEMA 2.0)

CEEMA 2.0 is a second generation model. This model encompasses all major forward and backward linkages of agricultural production in Canada. CEEMA consists of two sub-models: (1) An Economic Optimization sub-model, which generates resource allocation levels under a given set of economics and technological conditions; and (2) a Greenhouse Gas Emissions Sub-Model, which estimates the GHG emissions from the output of the first model. The economic optimization model output becomes input into the estimation of GHG emissions. An overview of this model is shown in Figure 1.2.

The economic optimization sub-model used is called the Canadian Regional Agricultural Model (CRAM). The CRAM's output is linked to the Greenhouse Gas

Emission Sub-Model (GHGSM) giving total emissions of GHG from the Agricultural and Agri-food Sector. The results for the GHGSM were not available at the time of this study, thus only results from CRAM and technical documentation from CEEMA was used for the study.

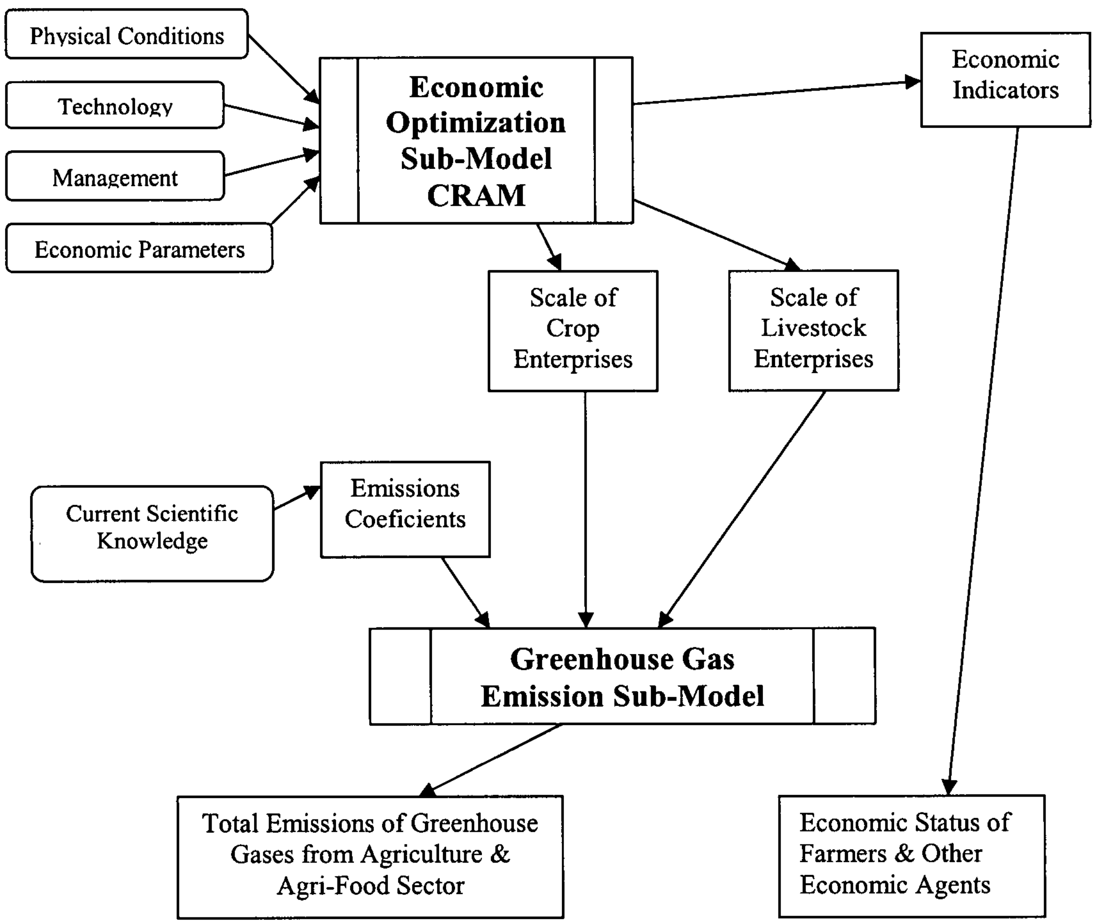


Figure 1.2 Structure of the Canadian Economic and Emissions Model for agriculture Version 2.0.

The Canadian Regional Agricultural Model (CRAM). CRAM is a regional and sub-regional equilibrium model of the Canadian agricultural sector which is disaggregated across both commodities and regional space. It was developed by Webber *et al.* 1986 and Homer *et al.* 1992. Based on a given set of economic and market conditions, CRAM determines the optimal use for agricultural land, as well as the allocation of other resources. The model selects combinations of crop and livestock activities that maximize producer plus consumer surplus less transportation costs.

CRAM provides results in two types of output: (1) Level of economic activities related to crop and livestock production, and (2) Economic indicators reflecting farmer's welfare. The scale of crop production activities are the basis for GHG emissions estimation and will serve as our basis for water quality modelling. I obtained CRAM estimates for the year 2001 for all the Canadian Provinces disaggregated into Agricultural Census Sub-Zones.

Agricultural Non-Point Source (AGNPS) Pollution Model.

The output from CRAM was used as input into AGNPS. Note however that the livestock data provided by CRAM could not be used for our study. AGNPS needed livestock data in much greater dissagregation than that provided by CRAM. As a result we calibrated AGNPS so as to exclude livestock.

The AGNPS is a distributed parameter model developed by the USDA Research Service's scientists and engineers. It predicts soil erosion and nutrient transport/loadings from agricultural watersheds for real or hypothetical climatic events. The model simulates nutrient movement and erosion in a watershed based on agricultural, geographical and climatic data. It subdivides a watershed to be simulated into a grid of square cell areas, or elemental areas, assumed to have uniform physical characteristics, and then it applies three lumped parameter models to each element. These models are, 1) an erosion model based on the Universal Soil Loss Equation (USLE) and applied on a storm basis. 2) A hydrology model based on the Soil Conservation Service Curve Number technique. And 3) an ARS (Agricultural Research Services) developed model named CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems) to predict nutrient/pesticide and soil particle size generation, transport and interaction.

Each AGNPS elemental area (which is typically about 100 m square in the Okanagan Watershed) requires 22 parameters (coefficients) in order to estimate pollutant loadings. These data requirements include description of each element's antecedent conditions (land use), physical characteristics (*e.g.* soil type and slope steepness), management practices, and rainfall. To predict NPS pollution, the three lumped model relationships are computed for each element as a function of time. N, P and erosion loadings are obtained from AGNPS as function of time, for each watershed element (outputs for pollutants are given in pounds per acre per day). The AGNPS integrates these predictions for each element's behavior into a distributed watershed simulation.

For this study's purpose, the AGNPS allows to study a watershed and predict pollutant loadings for an average year under different land use scenarios.

Analyzing the Results

To analyze the results from the AGNPS I use the British Columbia water quality guidelines (2001). These guidelines allow the study to assess the loadings of pollutants in the water system. The Ministry of Environment Land and Parks (now called Ministry of Water, Land and Air Protection) developed the British Columbia Water Quality Guidelines (Criteria) Report — 1998 in order to assess water quality data and to prepare site-specific water quality objectives. The guidelines have been approved by the province and, as noted above, will be used to assess water quality in BC. Approved guidelines are given to protect six major water uses: Drinking Water, Aquatic Life (freshwater and marine), Wildlife, Recreation and Aesthetics, Agriculture (Irrigation and Livestock Watering), and Industrial (e.g., Food Processing Industry).

The pollutant loadings obtained with AGNPS are in pounds per acre per day values. While calculating these loadings AGNPS accounts for pollutant decay and airborne dissipation in the time frame of a year. These loadings also depend on the accumulation of rainfall during an average year for the area studied. The loadings in pounds per acre per day are transformed to concentrations (mg/L) using transformation values obtained from the BC Watershed Guidelines (1996). These values are shown in Table 1.1.

Table 1.1 BC Water Quality Transformation Values

Chemical	Estimated Loadings (kg/d)	Estimated Increases (mg/L)
Total Nitrogen	1.425	0.25
Total Phosphorus	0.123	0.036
Suspended Solids	20.6	4.87

Results from AGNPS are then presented using a water quality classification provided by the British Columbia water quality guidelines (2001). Table 1.2 shows the classification along with the pollutant maximum concentrations for each category of water quality.

We can see that the category of Recreation and Aesthetics has low pollutant concentration requirements, and, in the case of Phosphorous the same as Drinking Water. This is recommended by the guidelines to protect recreational users who may ingest water. In the case of Aquatic Life, this criterion is designed primarily to protect fish habitat and changes in communities of organisms such as invertebrates which are important themselves or which may be important fish-food organisms. The fourth category, Non-desirable, represents water that has high levels of the pollutant concentrations. This type of water can be damaging to human and aquatic life consumption, and could also cause undesirable effects on the ecosystem.

Table 1.2 Water quality levels based on the BC Water Quality Guidelines.

Water Quality	Phosphorous	Nitrogen	TSS
Drinking Water	10 μg/L (max)	10 mg/L (max)	5 mg/L (max)
Recreation and aesthetics	10 μg/L (max)	20 mg/L (max)	15 mg/L (max)
Aquatic Life	15 μg/L (max)	100 mg/L (max)	25 mg/L (max)
Non-desirable	Over 15 μg/L	Over 100 mg/L	Over 25 mg/L

1.3 Area of Study

For the analysis I have focused on the Okanagan watershed in British Columbia. There are 9 major watersheds in the province of British Columbia (Figure 1.3). These major watersheds collect all the water from the province and empty it into large rivers or directly to the ocean. The province can be split into two sections: The west side of the province along the coast which contains smaller watersheds, and the east side of the province which contains 4 watersheds that feed vast rivers. The Okanagan Watershed is part of the Major Columbia Watershed.

Each of these major watersheds is divided into smaller watersheds that feed secondary rivers. There are a total of 247 secondary watersheds in the province of British Columbia (Figure 1.4).

Figure 1.3 Nine major watersheds of British Columbia.

Figure 1.4 Secondary Watershed divisions in British Columbia.

Okanagan Watershed

For the case study we focus on the Okanagan River Watershed. The Okanagan watershed extends north from the Columbia Plateau in Washington State to the height of land separating the drainage basins of the Columbia and Fraser Rivers (Figure 1.5). The majority of the Okanagan River mainstem lies in a valley that is a long north-south trench located in the Interior Plateau of British Columbia. The valley is 18 kilometers wide at the northern end, and only 5 to 10 kilometers wide at the southern end. From a few miles north of Armstrong, BC, the entire valley drains south to the Columbia River. Many of the tributaries to the Okanagan River are small systems that arise in the hills that surround this valley.

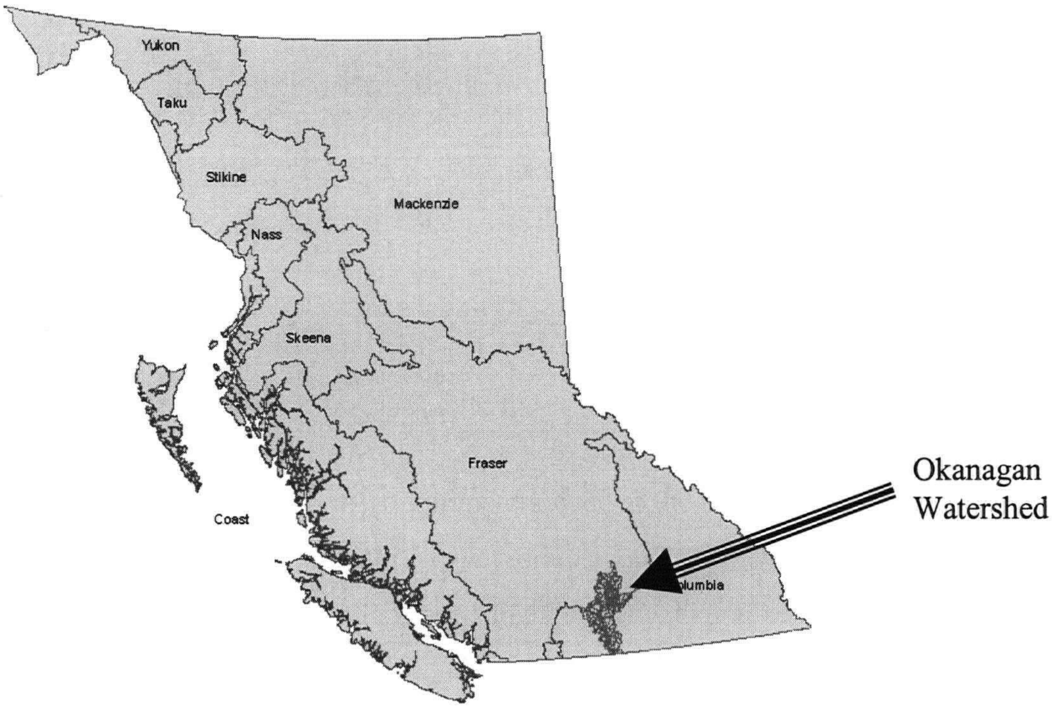


Figure 1.5 Location of the Okanagan Watershed in British Columbia.

Some notable and fish bearing main tributaries to the Okanagan River include the Similkameen River, Mission Creek, Kelowna (Mill) Creek, Vernon Crick, Penticton Creek, Powers Creek, Trepanier Creek, and Peachland Creek. The Okanagan watershed also contains several large lakes. The largest of these is Lake Okanagan, which extends approximately from the City of Vernon in the North to the City of Penticton in the South. Next in size and position downstream is medium sized Skaha Lake, followed by the small sized Vaseux Lake. Osoyoos Lake is a medium sized lake that straddles the Canada-US border. Kalamalka Lake flows into Okanagan Lake via Vernon Creek, and Okanagan Lake empties into Okanagan River at Penticton. Okanagan River flows into Columbia River in the United States.

There are four major types of soil in the Okanagan watershed. Brown soils and Dark Brown in the lower parts, both of which occur in well drained areas. Black soils are in the higher north pars of the watershed, and are associated with grassland vegetation. The intermountain podsol soils that are predominant in the north Okanagan are of little agricultural importance (Ministry of Sustainable Resource Management, 2001). The type of soil is used by AGNPS since it greatly affects the amount of pollutants going into the water system (I discuss the data requirements of the AGNPS in greater detail in the next section).

Concerns about Water Quality in British Columbia, and the Okanagan Watershed

The Okanagan watershed makes a good candidate for the case study. This is for two reasons. Firstly, it is widely believed that non point source pollution and specifically agriculture is an important cause of pollution in the Okanagan basin. Secondly, the government of BC recognizes that effective water protection depends on how well land use is managed. I discuss this in greater detail below.

Efforts to protect British Columbia water quality by regulating point discharges from municipal and industrial sources have generally been successful, and it is widely recognized that the major remaining cause of water pollution in the province is from non-point sources. These sources are largely unregulated and associated with urbanization, agriculture, and other forms of land development (British Columbia Ministry of Environment, Lands and Parks. 1998). More importantly, there are several drinking water sources that have been impacted by, or are exposed to, threats from human-related activities, including agriculture development (British Columbia Ministry of Environment, Lands and Parks. 1998).

Accordingly, the government of BC recognizes that effective water protection hinges on managing the land uses on the surfaces over or through which water flows. Accordingly, one key condition for successful water protection is integrated management of both water and the land uses that affect it (Auditor General BC, 1996). Agriculture plays a very important role on these conditions. In this case, there are some groundwater sources in the Fraser Valley and in other areas of concentrated agricultural activity which are contaminated by nitrates from agricultural wastes.

The Okanagan River at Oliver, B.C., is in the southern central part of the province (Figure 1.5). It drains an area of 7 590 km^2 from Enderby upstream to the United States border. On the Canadian side, the river flows through several lakes from the south end of Okanagan Lake to Osoyoos Lake. The water qualities of the river and these lakes are somewhat interdependent. Earlier studies (Zeman et al., 1982) focused on nitrogen and phosphorus, but their main focus was the impact of nutrients on the ecological nature of lakes in the Okanagan basin with less emphasis on the river.

A recent study of Osoyoos Lake, which is just downstream from the Okanagan River at Oliver, found no significant change in its water quality over the last 20 years (Bryan and Jensen, 1994; Bryan, 1995). The British Columbia Water Quality Status Report (Ministry of Environment, Lands and Parks, 1996) gave Osoyoos Lake a poor rating because the phosphorus objective was never met from 1987 to 1993 (Environment Canada. Ministry of Environment, Lands and Parks Canada, 1996).

1.4 Data

The analysis requires a broad range of data. This includes spatial and topographical data, sediment runoff data, climatic data, and finally land use data, and economic data from CRAM. In this section I describe the different sources used.

AGNPS requires 22 input values (its distributed parameter information) for each cell element. These parameters include data on the flow routing information like cell aspect, how it drains and if there is a defined channel within a cell. Data on the hydrologic characterization of the cell is also necessary, this type of data deals basically with the geographical aspects of the cell like the average land slope, slope shape, length, channel slope and different geographical coefficients of the cell all which are found in the GIS databases found at the different Ministries. Soil erosion coefficients are also necessary to run AGNPS, they are calculated through the GIS interface AGNPS-ARCGIS. The work was made more straightforward by the availability of an interface of AGNPS with the ARCGIS software (GIS interface for AnnAGNPS, 2003). This made the handling of the data and transformations easier than by using only the AGNPS software given that the available data was ready to use on the ARCGIS software. Transformation of data, watershed delimiting and the division of the cells was done using this interface. Once the output data was obtained the ARCGIS data transformation application was used to convert the results into manageable formats (MS EXCEL).

To obtain elevation data, location of streams, watershed boundaries and characteristics, and soils data I used publicly available GIS databases. These were used to assign slope, distance from the nearest water body and soil characteristics (soil type and erodibility properties) to every parcel. The geographical spatial data delimiting the different watersheds for British Columbia was found at the Ministry of Water, Land and Air Protection. This Ministry has now been divided into the Ministry of Water, Land and Air Protection and the Ministry of Sustainable Resource Management, and the database server is located at ftp://ftp.elp.gov.bc.ca/dist/arcwhse/watershed_atlas/. Other geographical data was obtained from the Ministry of Sustainable Resource Management's Land Data BC (http://www.landdata.gov.bc.ca/), Base Mapping and Geomatic Services Branch (http://mascot.gdbc.gov.bc.ca/mascot/), and the Geographic Information Systems Section (http://srmwww.gov.bc.ca/gis/).

Data on agro-ecosystems came from: the Ministry of Water, Land and Air Protection website, which contains data explaining different types of ecosystems present at each small creek watershed inside the Thompson-Okanagan Watersheds, further dividing each sub-watershed into 3 or 4 small creek watersheds. This information is located on a publicly available database server found at ftp://kamftp.env.gov.bc.ca/pub/outgoing/. This database gave information of the acreage of land divided into different agro-ecosystems and crop land found on each creek watershed belonging to a sub-watershed. Agro-ecosystem distributions are also found on the CEEMA 2.0 documentation. The agro-ecosystems included: Agricultural land, forested land, wetlands, dry land, grasslands, and shrub lands.

Output from CRAM for the year 2001 was obtained through Professor Suren Kulshreshtha from the University of Saskatchewan. The data is divided into 8 census sub-regions of the Province of BC. I distributed the data among the sub-watersheds inside the Okanagan Watershed by following the subdivisions of the Agricultural Census of Canada (2001). In these sub-divisions the Okanagan region is divided into 3 zones and then into smaller zones which are close to the regions delimited by the sub-watersheds.

The data from CRAM was used to obtain the Cropping factor for USLE, Practice factor for USLE, Surface condition constant (factor based on land use) and the chemistry data which included the Fertilization level, Incorporation factor (% fertilizer left in top 1 cm of soil), and the Point source indicator (indicates existence of a point source input within cell). The ARCGIS-AGNPS interface provided the tools to automatically calculate these data.

The module from CRAM involving Crop Data was used for our study. Please see Chapter one's Appendix 2 for a detailed description of the CRAM crop module and how the data was used in AGNPS. From the *crop module,* the data on land use, crop areas, and crop yields was used. Also, data related to fertilizers (N-P-K), tillage systems, area and production by economic indicators, crop areas and production by region.

Information on each parcel's slope and aspect relative to the stream or river were then used by AGNPS to create flow paths or channels that directed the flow of runoff from upslope areas in the watershed to the nearest water body. Flow channel length varied considerably.

Sediment run-off data for the land-use patterns described above were also generated by using Agricultural Non-Point Source Pollution (AGNPS). The model was parameterized to reflect the hydrological conditions in the watershed with the available data. Many of the AGNPS parameters such as curve number, Manning's coefficient, surface condition coefficient, conservation factor, and chemical oxygen demand were obtained from the Ministry of Sustainable Resource Management (2000) embedded with the geographical data.

Climatic data for southern BC were made available by Environment Canada via Oregon State University's Spatial Analysis Climate Service (http://www.ocs.orst.edu/prism/). The basin receives approximately $431 \times 10^6 m^3$ of precipitation annually (Environment Canada, 2000). Summers tend to be warm and dry with brief showers or thunderstorms. The southern part of the Okanagan Valley around Osoyoos and Summerland is much dryer with more extreme temperature fluctuations compared to the northern part. Osoyoos and Summerland receive between 310 to 330 mm of precipitation annually (Environment Canada, 2000). These data were used as a one-year storm event for the Okanagan. AGNPS was then used to obtain estimates of the channel deposition ration coefficients for every land management plan in each flow path.

Land parcels differ considerably in their slopes and on-site erosion. Slopes range between 0.5% and 15% with 39% of eligible parcels having a slope of 2% or less and 29% of the parcels having a slope of 10% or more. While some parcels have very erodible soil based on the geographical data and according to AGNPS they generate about 0.5 tons of on-site erosion per acre. The amount of sediment from inland areas in the watershed that reaches the parcels in the buffer zone also varies across the flow paths, this flow can be described by the better water quality found on the upper parts of the watershed.

1.5 Model Processes

In this section I bring together the description of the methodology and data to describe the method used to estimate the improvement in water quality from a specific policy for GHG mitigation. Recall that I have considered two GHG mitigation policy scenarios. In the first scenario, there is no GHG mitigation policy in place. Individuals face a zero prices. In the second scenario, individuals face a 25$ per tonne price for carbon equivalent emissions. These hypothetical carbon equivalent prices were selected to represent values which are usually evaluated for land-based carbon mitigation (Subhrendu *et al.* 2002).

The geographical and climatic data remain the same for the two scenarios. Changes occur in the agricultural and agro-ecosystems data. I simulate these changes using data from CRAM and a similar study performed in the United States by Subhrendu K *et al.* in 2002. Such a simulation was done as CRAM data was available only for the year 2001. This data was used as conditions for the world with no carbon equivalent prices or the "baseline conditions". Data from CRAM included crop mix, tillage practices, fertilizer use, and land allocation between crops, and data on different agro-ecosystems (agricultural land, dry land, forested land, wetlands, grasslands, and shrub-lands). This data was changed to reflect conditions of a 25$/Tonne carbon equivalent scenario from previous work done in the USA (Subhrendu *et al*, 2002). The changes in data in their study were available at a national, regional and Breadbasket state level of aggregation. The only local analysis presented was for the Breadbasket States. For that reason, I chose the changes that occurred in the breadbasket states as the approximate changes that would occur in the Okanagan. Please note that I do not wish to make any claims for the accuracy of these changes. The purpose for this study is just to illustrate the possible changes in water quality that occur from a GHG mitigation policy. In other words, the same percentage changes that occurred in the breadbasket states was applied to the Okanagan Watershed data. The changes that were applied to our study are described in Table 1.3. The work done by Subhrendu et. al is described in section 1.6.

Variable	$25 Percentage Change
Dry land	-0.0126
Grass land	+0.539
Afforestation	+4.804
Irrigated land	-6.151
Crop production index	-1.847
Crop land	-8.333
Wetlands	+1.563
Shrub	+1.784
Conventional tillage	-4
No-tillage	+3
Mulch	+1
Fertilization N	-3.77
Fertilization P	-0.89
Wheat, feed grains, hay	-1.225
Silage	-0.925
Corn	-6.725
Forages	1.721
Summer fallow	3.88
Other Crops summerfallow	1.247
Other Crops SB	-0.08

Table 1.3 Changes applied to CRAM and Agro-ecosystems data due to a 25$ Carbon Equivalent price

This changed data was inputted into the AGNPS. The AGNPS then calculated new pollutant loadings. Once again as the output was obtained in total loadings it was transformed into pollutant concentrations following the transformation increases in the BC Water Quality Guidelines (described earlier).

1.6 Overview of Study Done in the United States

In order to obtain the simulative changes which occur when there is a carbon equivalent price scenario in place we have used changes obtained in a study performed by Subhrendu et al (2002). In this section an overview of this study is presented. This study links a US national level water quality model to a national level agricultural and forest sector model to jointly analyze both the GHG reduction and water quality implications of GHG mitigation strategies in US agriculture. The model used to simulate mitigation policies in the agriculture and forestry sector is the Agricultural Sector Model-Greenhouse Gases (ASMGHG, Schneider and McCarl, 2002). This model has linkages between the sectors through land markets. The results generated by ASMGHG are then used as an input to the National Water Pollution Control Assessment Model (NWPCAM) developed by the Research Triangle Institute. NWPCAM is designed to simulate water quality.

In this study, they investigate the sensitivity of land markets to agricultural and forestry mitigation efforts simulated by the introduction of a market price for GHG reduction, expressed as $ per tonne of carbon equivalent (CE). They investigate agricultural crop mix and land use sensitivity to the introduction of a market price for GHG reduction in ASMGHG. Using the results form ASMGHG as inputs, NWPCAM simulates national impacts on water quality of terrestrial GHG mitigation activities. The output from NWPCAM is a water quality index (WQI) on a 1 to 100 scale, representing the relative impact and abundance of six pollutants in the modeled waters.

ASMGHG simulates the market and trade equilibrium in agricultural markets of the US and major foreign trading partners. The market equilibrium reveals commodity and factor prices, levels of domestic production, exports and import quantities, GHG emissions management strategy adoption, resource usage, and environmental impact indicators. ASMGHG considers: Changes in tillage intensity, conversion of arable land to grass land and from tree planting, biofuel production, manure management changes, fertilizer usage and livestock manure, fossil fuel use, fertilizer manufacturing, and changes in biomass power plants.

NWPCAM combines spatial data with data on pollutant loadings to model transport, fate, and decay processes within the nation's waters. It uses the US Geological Survey conterminous United States Land Cover Characteristics Data Set. It defines 26 land use classifications that are defined at a square kilometer cell grid level. Each land use cell is assigned to the nearest routed reach for subsequent drainage area, stream discharge, and hydrologic routing purposes. Loadings are then routed through the national network via water quality modeling techniques.

To ling GHG mitigation actions in agriculture and forestry to changes in water quality, they integrated changes in the ASMGHG environmental accounts under alternative GHG prices into the input used by NWPCAM. In turn, NWPCAM was used to estimate changes in the incidence of N, P and TSS in the nation's waters along with estimates of changes in water quality. They compared "baseline" conditions with two scenarios, which reflect agricultural and forestry reactions to two different prices for GHG ($25 and $50 per tonne of C equivalent), as reflected in ASMGHG outputs. They say that these hypothetical carbon prices were selected to represent values in the mid-range of prices typically evaluated for land-based carbon mitigation and not to find the optimal carbon price to reach a desired level of water quality improvement.

ASMGHG chooses regional crop mix, tillage practices, fertilizer use and land allocation between crop, grazing and forest uses based on relative economic returns, inclusive of returns to GHG fluxes. Thus, it provides GHG scenario level data on changes in land-use, crop acreage and livestock holdings for the 63 regions in the model. The allocation was then done at the county level in a fashion most consistent with the USDA's Natural Resource Inventory (NRI) and Agricultural Census observations on observed county level cropping patterns. This allows the loadings calculated to be mapped by county code to the 1km^2 grid cells in NWPCAM.

The results that they obtain indicate that the water quality co-benefits are highest in the Breadbasket and in the Gulf States. In many of these states, the agricultural sector has a large economic and environmental presence. Water quality improves in every aggregate region in the country, although the level of improvements varies under the pricing scenarios. These differences in improvements are the result of economic forces re-allocating the more intensive production practices in response to inter-regional comparative advantages in crop production and GHG mitigation.

The study obtains the following results:

- Nationwide water quality increased 1.38 water quality index points under both GHG pricing scenarios.

- Five regions, all roughly East of the 100^{th} meridian experienced the largest water quality improvements ranging form about 3 to 8 percent.
- Breadbasket states experienced the largest change in water quality nearly a 4 point improvement.
- Gulf States have the highest co-benefit elasticity, revealing the largest improvement in water quality proportional to the amount of GHG mitigation.
- Nitrogen loadings in the Gulf decrease by about 9 percent, whereas phosphorous loadings decrease by about 2%.

1.7 Results

I present the results at two levels: the individual Okanagan watershed and province wide results. The results from the Okanagan Watershed help to identify the spots where there are the greatest effects on water quality. The provincial results help us to see a broad representation of the potential impacts that the GHG pricing alternatives will have on the overall quality of water.

Results from the Okanagan Watershed

Using AGNPS I divided the Okanagan watershed into 52 smaller sub-watersheds. These sub-watersheds feed the creeks which make up the main tributaries of the Okanagan River/Laker. Dividing the Okanagan Watershed helped me to obtain local readings of pollutant loadings going into the smaller watersheds. The results obtained for Nitrogen, Phosphorous, and TSS were classified following the BC Approved Water Quality Guidelines (mentioned earlier). Four levels of water quality were constructed following the contents of N, P and TSS generated by AGNPS for a 1 year storm event as shown by Table 1.2.

Baseline Scenario: 0$ Per Tonne of Carbon Equivalent.

The results for the baseline scenario are shown in a map in Figure 1.6. Please see Table 1.5 in Chapter one's Appendix 3 for the data that constitutes the map. This Figure displays the classification of the different watersheds according to the level of pollutant loadings obtained with AGNPS. The conditions presented here are for a scenario with no carbon equivalent prices. In this Figure, the worst quality of water is located at the lower zones of the valley where the highest concentration of agricultural and populated land is found. The central zone of the Okanagan Watershed has the highest problems with pollutant loadings. In this zone the Peachland, Penticton, Trout, Lower Mission, Trepanier, Finlay and the Shingle Creeks are located. These Creeks are located near cities and several dams, dykes, canalization and redistribution canals have been built to provide the residential districts with water, flood control, irrigation, etc. These Creeks are also under heavy pressure from agricultural development. This is probably the reason why the results show higher non-point source pollution in these areas.

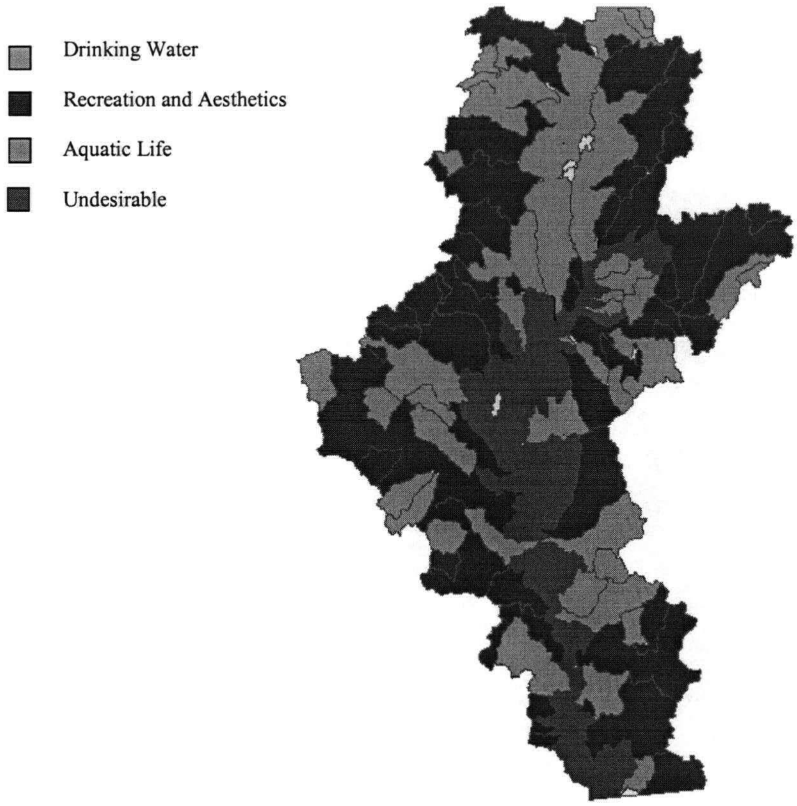


Figure 1.6 Baseline Water Quality Conditions for the Okanagan Watershed.

The results show that the lowest quality of water is found along the Okanagan Lake/River. This could be because the river is the mainstem of the watershed. Even though several processes, like decay and gasification, will lower the amount of pollutants arriving at the Okanagan River, all of its tributaries will carry the pollutants from higher elevations and deposit them into the river. These processes are taken into account by AGNPS and it seems that they do not diminish substantially the amount of pollutants from reaching the river. Another cause for these results could be that agricultural and rangeland activities occur throughout the watershed and its tributaries.

There is a great deal of agricultural activity along the valley's bottom basin, and even on many of the lower slopes above the valley's bottom. This along with the results obtained from the crop section of the CRAM were useful in assessing the results of the AGNPS.

Table 1.4 Okanagan Watershed pollutant concentration results.

Watershed	Total Nitrogen (mg/L)	Total Phosphorous (μg/L)	Suspended Solids (mg/L)
Okanagan	**21**	**8**	**14**

The main results for the baseline scenario indicate that the lowest water quality is found in the central and southern part of the watershed. This is an area of highly agricultural and urban activity. The highest concentration of pollutants is found along the mainstem of the watershed. The Peachland, Penticton, Trout, Lower Mission, Trepanier, Finlay, and the Shingle Creek sub-watershed were found to contain the worst water. They fell on the lower water quality classifications. It is important to note that, when analyzed as a whole, the results for the Okanagan Watersehd lie in the third classification or just apt for aquatic life but below Drinking Water and Recreation Quality. The results for the Okanagan Watershed as a whole are shown in Table 1.4. To obtain the Main watershed's loadings, AGNPS was model to obtain loadings for the entire watershed at a higher reach level. The reach level had to be changed in order to aggregate the data for the watershed. Each cell was recalculated and calibrated using ARC-GIS to a higher reach level basically incorporating the Okanagan watershed into three regions: North, South and Central Okanagan. When comparing these results to previous studies done in the watershed, they seem to be consistent with previous findings of where the major problems in the watershed lay[1].

Results under the 25$/Tonne Carbon Equivalent Price Scenario

When the changes in land use, fertilization and agroecosystems brought by the imposition of a $25/tonne carbon equivalent are fed into AGNPS, the model calculates new amounts

[1] Okanagan Water Quality Society, Okanagan Water Project, Ministry of Water, Land, and Air Protection.

of pollutant loadings in the water system. Major changes under this scenario occur in the northern part of the watershed.

Figure 1.7 shows the results for the changes brought by a $25/tonne carbon equivalent scenario. Comparing this graph with Figure 1.6, we can see that the changes occur in places where the agricultural sector has a large economic and environmental presence. This map format makes it clear to see where the changes occur and compare them with the previous scenario.

It is important to note that the watershed as a whole changes its water quality level to the second level: Recreation and Aesthetics. This change is caused by the close to 7% change in Nitrogen loadings compared to the baseline scenario. The changes on Phosphorous loadings are under 1% which means that they are not affected by this price scenario.

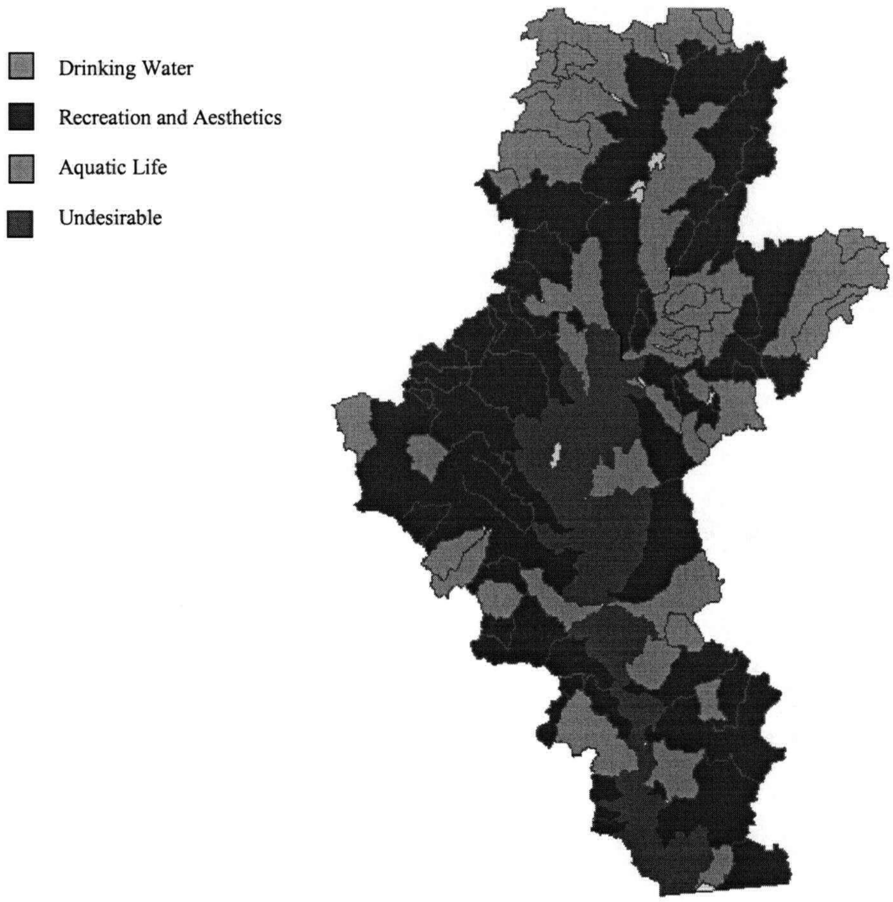


Figure 1.7 Water quality under $25/Tonne Carbon Equivalent scenario

Under a $25/tonne price scenario there is an average of 4% decrease of pollutant loadings in the region. This figure is obtained by calculating an average of the changes that occur in all pollutant loadings between scenarios. Following the same calculations we can see that the higher changes occur in Nitrogen with a decrease in loadings of about 7%. Total Suspended Solids also has an important decrease of about 6%. The change in P is insignificant with changes being less than 1% compared to baseline conditions. The major changes occur in nitrogen which is the most important pollutant produced by agricultural practices.

It is important to note that in the case of the Okanagan, there is a huge amount of urban development throughout the basin. I do not account for urbanization in our current study, but urbanization can have serious potential impacts to water quality. Most potentially developable land in the basin has now been developed. This includes land that was covered by wetlands before and only 9% of the natural grasslands that are native to this valley remain due to the construction of orchards, roads and urban development. It is anticipated that urban development will continue to expand at a great rate in the Okanagan basin, and to continue to be a major stress on aquatic, terrestrial, and wetland ecosystems. This has lowered the amount of beneficial agroecosystems that usually act as filters of the water. The changes of land use toward agricultural and urban use causes even higher water pollutant loadings that should be accounted for in future studies.

Provincial Results: Baseline Scenario Only

In order to obtain results for the entire province an analysis like the one done on the entire Okanagan Watershed has to be done to the rest of watersheds in the province. This analysis requires extensive data transformation and management. Each sub-watershed, the size of the Okanagan Watershed was divided into 1-3 subzones which were consistent with the Agricultural Census sub-zones (2001).

Provincial data is not publicly available; therefore I ran AGNPS for Southern BC where data availability was not an issue. The results for southern BC are given for the census sectors 1-4 for the province of BC: Vancouver Island/Coast, Mainland/Southwest, Thompson/Okanagan, and Kootenay. This area consists of about ~62 million Acres. AGNPS was calibrated for a reach level incorporating a total of 60 small watersheds.

These small watersheds were then aggregated into 32 watesheds each about the size of the Okanagan Watershed. The Data for each watershed was aggregated in a higher reach level in order to be able to run AGNPS. In order to do the analysis only big and important tributaries were taken into account based on data from the Ministry of Sustainable Development.

The results, shown in Figure 1.8, indicate that the worse water in this region of the province is found along the main tributaries. The main tributaries are The Fraser, Okanagan, and Columbia rivers. These are areas where there is high agricultural activity especially along the valleys that surround the mentioned rivers. These results are not done for the different policy scenario since the management, transformation and handling of the data is very intensive.

Figure 1.8 shows that most of the water along the southern part of the province belongs to the second and third classification of water quality. It is classified in the Recreation and Aesthetics, and Aquatic Life Categories. Figure 1.8 might provide an indication where the government should focus on obtaining water quality improvements.

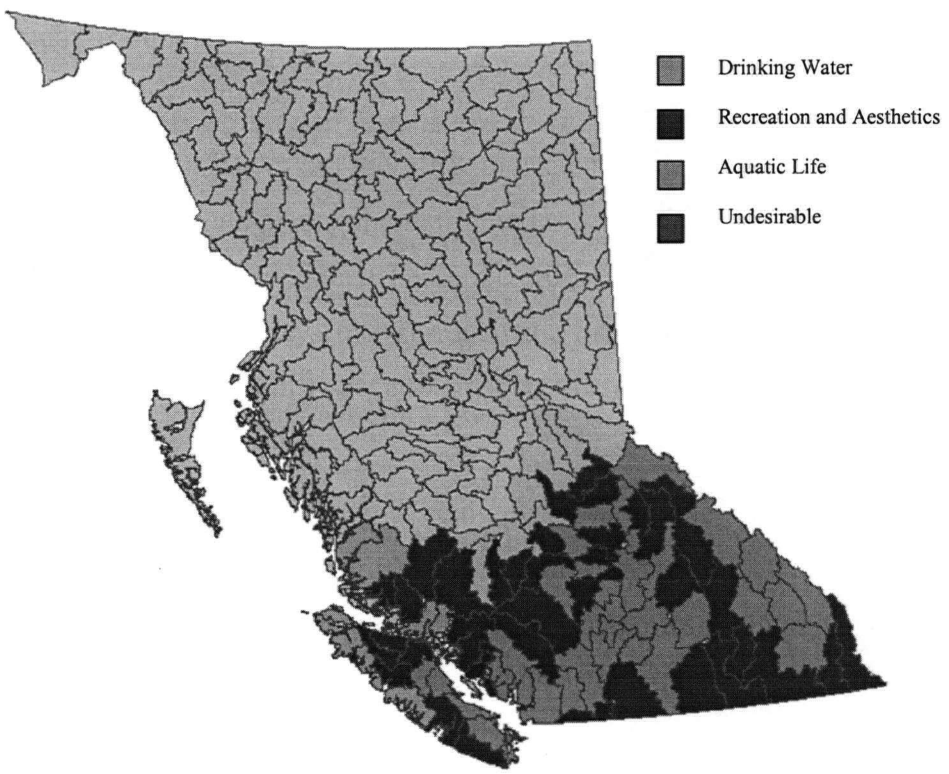


Figure 1.8 Present Water Quality Conditions for BC's regions 1-4.

1.8 Conclusions

Through this Chapter I present an example of the ancillary effects from GHG mitigation strategies. I have focused specifically on the effects on the quality of water which could serve in future extensions to calculate social economic benefits. The objective is to illustrate that water quality co-effects are present and that they can be measured according to preset guidelines. I wish to point out the presence of these water quality changes so that they can be incorporated while designing policy specifically in future extensions dealing with social economic benefits.

It is important to remember that the results presented in this report only cover certain land use activities related to agriculture (livestock activities are ignored). However, even without accounting for livestock operations our results show that water quality effects are present and should be taken into account when evaluating mitigation policies.

I find that generally water quality effects are higher along the mainstems of the watershed. The results also show that under the $25 carbon equivalent price scenario there are decreases in N, P, and TSS which create changes in the Okanagan watershed. The total watershed moves up one level from Aquatic life to Recreation and Aesthetics. This occurs since the presence of a $25/tonne price results in an average of 4% decrease of pollutant loadings in this region. The higher changes occur in Nitrogen and TSS, which have an approximate of 7% and 6% decrease respectively. The change in P is insignificant being less than 1%. It is important to note that these results are based on an average by census zone, and watershed. Specific reaches and rivers may not have the same changes in water quality.

Chapter I – Appendix

Appendix 1. **The Effect of N, P, and TSS on Water Quality.**

Nitrogen. Nitrogen compounds are a necessary and integral part of the aquatic ecosystem since they serve as essential nutrients for photosynthetic and bacterial production. However, as with many other necessary chemical compounds, they can be harmful to man, other animals, or aquatic biota if present in sufficiently high concentrations (Dickinson and Rudra, 1991). Nitrogen can be discharged into the water system in any of three particular nitrogen compounds. The three major forms of Nitrogen are nitrates, nitrites and ammonia (M. Goss *et al.* 1991). Nitrogen can, under some circumstances, stimulate excessive algal growth in streams and lakes, causing environmental degradation and damaging beneficial uses of water. Nitrogen compounds can affect aquatic organisms not only through their direct toxicity, but by reduction of dissolved oxygen concentrations caused by the nitrification process. Similarly, supersaturation of nitrogen gas (N_2) in water can cause gas bubble disease in aquatic organisms (M. Goss *et al.* 1991).

Phosphorous. Eutrophication is the process by which lakes and streams become biologically more productive due to increased supply of nutrients (P and/or N). If sufficiently large amounts of nutrients enter lakes and streams, man's use of waters can be impaired by the algal biomass present (Dickinson and Rudra, 1991). A number of negative consequences may result from the presence of excessive amounts of algae. Algae in drinking water can impart unpleasant tastes and odors and cause additional costs for water utilities, which must have increasingly expensive treatment to remove algal particles. There have been many reports of persons exhibiting allergic reactions to ingestion of water containing algae or to having algae in contact with skin when swimming (M. Goss *et al.* 1991).

Total Suspended Solids. Although many concerns have been raised in recent years regarding the impacts of toxic chemicals released into the aquatic systems, the mobilization of fine inorganic particles and their subsequent deposition in sensitive habitats constitute an important problem facing aquatic environmental managers. Some activities such as forest management, agricultural management, road building, construction, dredging, and gravel pit operations can cause marked changes in the physical, chemical, and biological characteristics of the watercourses located nearby and those located downstream. The type and concentration of suspended matter controls the turbidity and transparency of the water. Agricultural drainage increases both sediment load (TSS) and stream conductivity of these sediments (Lovejoy et al. 1985).

Suspended sediments in water supplies can cause both health and aesthetic effects. Excessive suspended sediment may be visible and, therefore, aesthetically objectionable. High levels of suspended sediments can also shield pathogens from the effects of disinfection. Organic suspended matter can act as a source of nourishment thereby promoting the growth of micro-organisms (Singleton, 1985). The deposition of fine sediment in stream ecosystems is also detrimental to aquatic organisms, because of reductions in streambed substrate composition and permeability (Young et al. 1991).

Appendix 2. **A More Detailed Description of CRAM data and how it is used in AGNPS**

The module from CRAM involving Crop Data was used for the study. This module included data on crop type, pastures, soil preparation, area, fertilization, and land use. The data was distributed following the total agricultural land per sub-watershed. That is, the data from CRAM was first divided equally following total agricultural land from the Census divisions in each sub-watershed. Then following studies done by Natural Resources Canada (1998), Okanagan Watershed Monitoring Committee (2002), and the Ministry of Environment, Lands and Parks (1999) on agricultural, animal and forest presence, each watershed was assigned an amount of agricultural, pastures, dry land, forest and different agro-ecosystem land. In all cases, the sub-watersheds were further divided into 3-4 smaller creek watersheds in order to allocate the data. This information was then used to introduce the agricultural data in each cell following data on agricultural, and agro-ecosystems presence and impact data found on the Ministry of Water, Land and Air protection's server ftp://kamftp.env.gov.bc.ca/pub/outgoing/. The data was further divided into each sub-watershed's creek areas following the agricultural presence and impact data mentioned before.

For the Southern Provincial Results data pertaining to the Census Sub-zones 1, 2, 3 and four, described in Figure 1.9, was used from CRAM, this data was further divided into the main watersheds following the Agricultural Census (2001) subdivisions. The CRAM's data on these regions was distributed along the sub-zones according to the total amount of crop land in each region.

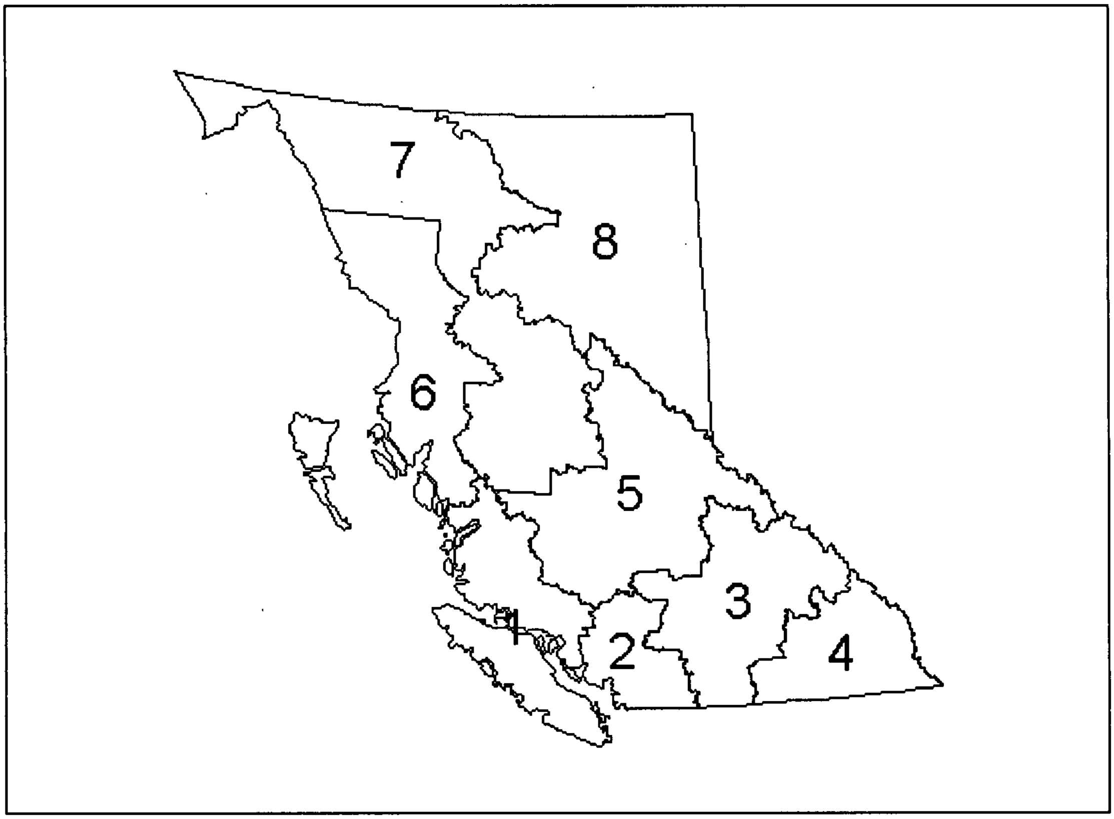


Figure 1.9 British Columbia Census Subdivisions 2001.

From the Crop Production Activities Module we have used data on 63 crop production activities taking the year 2001 as baseline conditions. The 63 crop production activities include division into major crops and crop activities which are described below:

63 crop production Activities:

-Major Crops: barley (feed and malting)

Canola

Corn (grain and silage)

Field peas

Flax

Lentils

Oats

Potatoes
Soybeans
Wheat (spring and durum)

-Crop Activities also included:

Summerfallow
Forage (hay)
Improved pasture
Unimproved pasture

As mentioned before, information from Agriculture Canada, different Ministries and private firm data was used in order to allocate crop and agro-ecosystem land for each elemental AGNPS grid cell. The agricultural census zone pertaining to the Okanagan Watershed is classified in CRAM in the BC3 region. Results from CRAM for British Columbia are divided into eight development regions or zones. The subdivisions, displayed in Figure 9, overlap with the main watersheds in the province. The subdivision that we used is Subdivision 3: Thompson/Okanagan which contains the Okanagan Watershed. This watershed is further divided into three zones: Upper, Middle and Lower Okanagan in the Agricultural Census. Basically, the data for each subregion was obtained from CRAM, and was allocated to each sub-watershed following agricultural and agroecosystems data found in the Agricultural Census (2001) and in the Ministry of Water, Land and Air Protection.

The geographical databases were then used to complement the AGNPS requirements. AGNPS was first calibrated delimiting the Okanagan Watershed and its sub-watersheds. This step involved introducing the geographical data which includes the stream and land system in the watershed. After this, the simulation period data was introduced which included the climatic data and the time frame. The next step involved the creation, profile, and division of the cells. The field, reach and reference data was then selected and introduced into the model. Once all the data requirements were fulfilled, two scenarios were run using AGNPS. For the two scenarios, the geographical and climatic data remained the same. The changes for the two scenarios occurred in data obtained from CRAM and the agroecosystems.

Appendix 3. **Data for Okanagan Watershed Subdivisions**

Table 5 Okanagan Sub-watershed Pollutant Results.

Sub-watershed	Drainage Area (acres)	Total Nitrogen (mg/L)	Total Phosphorous (um/L)	Suspended Solids (mg/L)
Allison Creek	139274	12.225	27.6	12.4
Ashnola/Snowy Mtn	294493	12.363	7.6	8.9
Bellevue Ck	22969	7.258	5.9	6.8
Brandt's Creek	6250	6.269	14.3	18.1
BX Ck	32286	7.369	29.4	7.8
Coldstream Ck	45309	13.562	23.6	26.8
Copper Creek	41259	2.314	1.4	2.6

Deep Creek	75614	0.283	58	3.6
Deer Ck CWS	5105	7.894	11.2	4.7
Dillard Creek CWS	9525	3.478	3.6	5.2
Ellis Ck	38869	2.967	10.9	17.8
Equesis Creek	49174	1.8	34.6	32.1
Faulkner Creek	2850	2.891	14.4	12.3
Hayes Creek	194442	6.554	17.8	7.8
Hedley/McNulty Creek	97169	0.084	22.3	17.9
Hydraulic Creek	36325	0.039	1.5	9.2
Irish Ck	8186	3.138	7.8	7.68
Kelowna Creek	54363	2.236	11.3	28.4
Keremeos Creek	61776	0.417	8.9	10.8
Lambley Creek	67213	1.853	11.1	9.8
Lower Vernon Creek	44232	8.365	31.5	19.2
McDougal Ck	13026	0.965	1.2	8.5
Mission Creek	200155	1.618	9.8	17.5
Naramata Creek	19407	7.028	3.6	13.6
Nashwhito Ck	21812	8.142	18.3	11.7
NW Tulameen River	193706	4.859	3.6	2.4
Okanagan Lk	351164	29.145	36.9	17.8
Okanagan R	229496	25.358	37.1	19.6
Oyama Ck	10900	11.789	5.2	7.6
Pasayten River	46416	3.298	3.8	3.5
Paul Creek (Merritt)	27045	2.429	1.9	5.2
Peachland Creek	37066	1.025	1.9	4.8
Pennask	22480	7.288	15.7	9.1
Penticton Ck	45545	1.255	5.8	6.5
Powers	35804	16.843	13.2	12.8
Shingle Ck	70148	11.257	15.8	17.9
Shorts Ck	45773	12.256	16.2	8.9
Shuttleworth Ck	24698	19.288	21.5	19.3
Smith Creek	30777	17.221	17.8	11.5
SW Tulameen River	193747	0.7583	1.8	8.9
Trepanier Cr.	63444	0.992	7.8	5.8
Trout/Eneas Ck	209721	8.756	9.4	12.6
Upper Vernon Ck	31594	9.829	9.8	9.5
Vaseaux Ck	73481	15.685	26.7	28.8
Westbank Creek	58352	15.037	12.4	26.5
Whipsaw Creek	45632	0.388	1.8	19.8

Whistle Creek	26802	5.684	2.9	7.7
Whiteman Ck	52393	4.367	8.6	11.5
Wolfe Creek	58317	1.251	2.5	9.8

Table 1.5 shows the results obtained from AGNPS for the 52 sub-watersheds in the Okanagan watershed. This table shows pollutant loadings into the water-system of the sub-watersheds for a typical year in the Okanagan region.

Chapter II

Application of the State Contingent Approach to Analyze the Effects of Carbon Equivalent prices

2.1 Introduction

Carbon equivalent prices induce changes in cropping, management (e.g., conventional to no-till agriculture) and land use (afforestation). The associated changes in agricultural pollutant loadings of nitrogen, phosphorus, and eroded soil have allowed us in chapter one to predict water quality changes. In this chapter I introduce the State Contingent Approach (Chamber and Quiggin, 2000) to analyze the effects that a carbon equivalent price will have on the management practices made by the farmer, specifically regarding input choices.

Even though this Chapter introduces an analysis which radically differs from the analysis in Chapter one, the analyzed input choice changes provide an example of the possible micro-foundations for the effects quantified in the previous Chapter. For Chapter two, I analyze the farmer choices depending on his risk attitudes. I assume that the presence of a carbon equivalent price will have one of two effects: An increment on the price of nitrogen based fertilizers or an overall increment on the prices of all the inputs. I then introduce non point source pollution into the model and analyze the effects that the new input choices, caused by the effects of a carbon equivalent price, will have on pollutant loadings.

Empirical evidence has recently emerged to support the ability to reduce non point-source pollution by targeting agricultural production practices, like by the use of a carbon equivalent price (Bontems and Thomas, 2000). However, not many studies compare the relative efficacy of different policy schemes to decrease pollution under uncertainty caused by the weather, input use and production. This is why the aim of the Chapters two is to develop an innovative diagrammatic framework to analyze input use under two carbon equivalent price effect scenarios and the respective pollution production.

Chapter two introduces the state contingent approach and models the choices of a farmer that produces a certain crop under uncertainty and is faced by two carbon equivalent price effect scenarios. Then, I expand the beaker diagram of input transformation presented by Chambers and Quiggin (2000). I adapt the beaker diagram that maps input transformation of returns into a diagram that maps input transformation of pollution.

Nitrogen (N) based fertilizers react to different states of the environment. Under the right climatic conditions, Nitrogen containing fertilizers are responsible for producing higher yields. The opposite occurs when these climatic conditions are not optimal; in this case, fertilizer can substantially lower crop yields. Furthermore, according to Houghton et al. (1997), a significant amount of nitrogen contained in the fertilizers is lost from agricultural soils through leaching, runoff, and trough nitrous oxide emissions. This loss is incremented when bad weather conditions are predominant. Under these conditions fertilizer can also cause toxicity for the plants.

It is also important to note how a plant responds to N-Fertilization. Generally, a plant will absorb nitrogen increasingly up to the point when it no longer needs N at the same rate. From this point on, the excess nitrogen that is fertilized is not of much use to the plant. This type of absorption causes a slow steady increase of pollution up to the point when the plant does not need any more Nitrogen; from there pollution increases more rapidly since the excess N is not being absorbed by the plant. This means that the resulting pollution will increase more rapidly than before. The uncertainty brought by the use of fertilizer, given these conditions, has caused the farmer to treat fertilizers as a risk complement input (Chambers and Quiggin, 2000).

In the case of N-fertilizers, they are an essential input in maintaining high crop productivity, but there are some problems associated with their use. Nitrogen based fertilizer use in agriculture causes environmental degradation and green house gas emissions. Amongst the most important environmental impacts of N-fertilizer use are the high levels of nitrates found in fresh water systems, explained in Chapter one, and nitrous oxide going into the atmosphere. Given the wide use of nitrogen based fertilizers, governments have tried to reduce their usage by implementing policies aimed at their reduction.

When analyzing the effects of the policies the state contingent approach proves to be useful since the basic principle of the state contingent approach is that it reduces the choice under uncertainty to a conventional choice problem by altering the commodity structure appropriately. I chose the state-preference approach since it is distinct from the conventional "microeconomic" treatment of choice under uncertainty, such as that of von Neumann and Morgenstern (1944), in that preferences are not formed over "lotteries" directly but, instead, preferences are formed over *state-contingent* commodity bundles. State contingency depends on states and choices of actions which are effectively functions from states to outcomes. The basic proposition of the state-preference approach to uncertainty is that commodities can be differentiated not only by their physical properties and location in space and time but also by their location in "state". By this I mean that "ice cream when it is raining" is a *different* commodity than "ice cream when it is sunny" and thus are treated differently by agents and can command different prices. State allocations serve as an excellent way of analyzing farmer reactions to carbon equivalent price effects facing different climatic conditions. This is certain since farmers react differently if their subjective probabilities and preferences make them lean toward a certain state outcome.

To analyze the effect of a carbon equivalent price on input use we use the Beaker diagram of input transformation developed by Chambers, 1997. This diagram helps to incorporate the way in which the different inputs are used and transformed, given the two states, into an efficient frontier of total production of returns and pollution. Non-point source pollution is affected by the state of the environment that is realized after fertilization has been done. When bad weather conditions prevail, pollution has a tendency to increase. In such a case, fertilizer runoff is greater and returns are lower. In this case we use the Beaker diagram to map input transformation into returns and a mirror image depicting input transformation into pollution. This gives us a pollution production frontier and a returns transformation frontier for both states. This type of approach helps us to change the output and pollution frontiers when facing the two carbon equivalent price effect scenarios by responding to changes in the use of the different inputs in the presence of uncertainty. This model differs from the standard approach that links fertilizer use directly with pollution, and simply converts a decrease or increase of fertilizer use into a decrease or increase of pollution respectively.

The farmer's attitudes toward risk have shown to cause distortions from optimal levels of polluting inputs (Babcock, 1998). Under uncertainty, Leathers and Quiggin (1991) demonstrated that a nitrogen tax, for instance, could lead to modifications in fertilizer use that are opposite to policy goals in terms of environment conservation. It has also been extensively documented that the actions of farmers change in the presence of insurance and when facing climatic uncertainty. Given these conditions, the state contingent approach proves to be innovative and very intuitive when analyzing pollution mitigation policies.

2.2 Adaptation of the State Contingent Model

The current framework considers the decision making of a farmer who produces a single crop using two inputs. The choice of inputs is modeled through a beaker diagram which has been previously used by Chambers and Quiggin (2000). The farmer's decisions are affected by the presence of two carbon equivalent price effect scenarios reflected by changes of the input prices. The framework focuses on society's preferences to reduce pollution produced by one or both of the inputs chosen by the farmers. I also try to explain trough a diagrammatic framework the choices of a farmer given insurance availability modeled by different risk attitudes and how they affect pollution.

In the framework the following assumptions are set. Firstly, output and input prices are non stochastic, and farmers take these prices as given. Secondly, the farmer is risk averse and when fully insured he behaves as a risk neutral individual. Finally, the farmer chooses inputs and outputs jointly in a preference maximizing fashion. For state contingency, there are two states of the environment based on weather conditions affecting the way in which pollution is produced. A good state represented by "G" and a bad state by "B", both states belong to the set of states of nature. $\{G, B\} = S \in \Omega$.

The farmer has a vector **z** of outputs $\in \Re^2_+$ which include the crop "q" and pollution "n". The vector of inputs $\mathbf{x} \in \Re^2_+$ includes nitrogenous fertilizers "x_F" and other inputs "x_O". The state contingent approach, that I follow, is modeled by the input correspondence described below.

Input correspondence

State-contingent Production technology (Chambers and Quiggin) is modeled by a continuous input correspondence. In our case it maps: $X:\Re_{+}^{2x2} \rightarrow \Re_{+}^{2}$, meaning that it maps vectors of state-contingent outputs, z, into inputs capable of producing them:

$X(\mathbf{z})=\{x \in \Re_{+}^{2} : x \textit{ can produce } z\}$

The vector of inputs includes x_F (fertilizer) and x_O (other inputs). Any x chosen will produce a state contingent vector of outputs. This vector of inputs is committed prior to the resolution of uncertainty. So if state s ϵ Ω is realized (picked by nature) and the producer has chosen the ex ante input-output combination (x, z), then the realized or ex post output vector is z^s. The farmer also produces pollution (n^s) which constitutes a burden to society and is given by the input correspondence: $X(\mathbf{n})=\{x \in \Re_{+}^{2} : x \textit{ can produce } n\}$.

To better understand how this framework works I am going to take into account two pollution scenarios. Since pollution is a function of fertilizer use and other inputs, it can be represented by the formula $n^S=n^F(x_F)+n^O(x_O)$. In the scenario where both inputs cause pollution we have that if $\bar{x} = x_F = x_O$, then $n^F(\bar{x})>n^O(\bar{x})$ which indicates that the fertilizer input produces more pollution compared to the other inputs. For the scenario where only the fertilizer input causes pollution, in the case that $\bar{x} = x_F = x_O$ we have that $n^F(\bar{x})>0$, $n^O(\bar{x})=0$.

Risk neutrality and risk averse production equilibria

<u>Risk neutral Farmer</u>

For the risk neutral farmer we have the following problem. He solves: $\max_r\left\{\sum_{s\in\Omega}\pi_s\sum_{m=1}^{M}p_{ms}z_{ms} - c(w,\mathbf{z})\right\}$ which can be reduced to the S-dimensional problem: $\max_r\left\{\sum_{s\in\Omega}\pi_s r_s - C(w,\mathbf{r},p)\right\}$ giving the following problems for both states:

$$\max_r\{\pi_G r_G - C(w,\mathbf{r},p), \pi_B r_B - C(w,\mathbf{r},p)\}$$

FOC:

$$\pi_s - C_s(w,r,p) \le 0,\ r_s \ge 0,\ s \in \Omega \tag{1}$$

We can see in equation (1) that the marginal cost of increasing revenue in any state is at least equal to the subjective probability of that state. This means that the producer equilibrium for a risk neutral farmer is represented by a hyperplane being tangent to her isocost curve. The slope of this hyperplane is determined by the ratio of the producer's subjective probabilities (the fair odds line). The isocost curve is determined by the equilibrium level of revenue-cost. Instead of determining an optimal mix of outputs as in the non-stochastic, multi-product case, the producer equilibrium determines the optimal mix of state contingent revenues. This helps us to interpret the producer's subjective probabilities as the producer's subjective prices of the state-contingent revenues.

Figure 2.1 represents the risk neutral production equilibrium. As demonstrated by Chambers and Quiggin, the risk neutral farmer will produce at the optimal state contingent revenue mix.

Summing over the first order conditions in (1) we get:

$$\sum_{s\in\Omega} C_s(w,\mathbf{r},p) \geq \sum_{s\in\Omega} \pi_s = 1 \qquad (2)$$

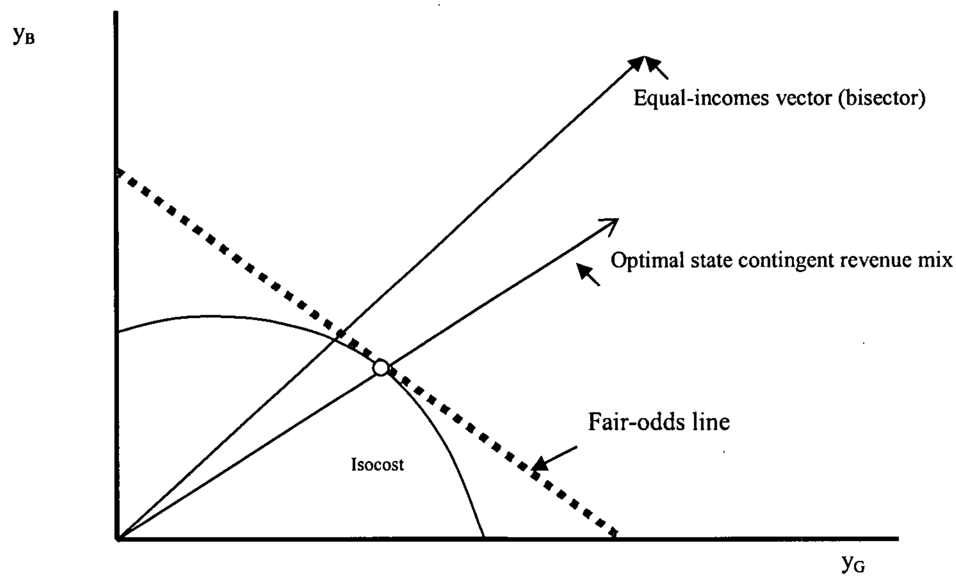


Figure 2.1 Risk-neutral equilibrium

Looking at Figure 2.1 and equation (2) we can see that the left hand side of the expression represents the derivative of the cost function in the direction of the equal-revenue ray (bisector). So $\sum_{s\in\Omega} C_s(w,\mathbf{r},p)$ is the marginal cost of increasing all state contingent revenues by the same small amount. Equation (2) also requires that this marginal cost be at least as large as the uniform increase in returns given by the inclusion of revenue in the revenue cost function. If it were not, the decision maker could increase profit with certainty by increasing each state-contingent revenue not worrying about the cost. In order to obtain an interior solution equation (2) must hold as an equality (Chambers and Quiggin, 2000).

Risk averse farmer

For the risk averse farmer, he chooses state-contingent revenues to maximize:

$W(\mathbf{y}) = W(\mathbf{r} - C(w,\mathbf{r},p)1_s)$ where 1_s is a vector of ones.

$$\max_{r} W\{r_G - C(w,\mathbf{r},p), r_B - C(w,\mathbf{r},p)\}$$

From the first order conditions, assuming $\mathbf{r} > 0$, we get:

$$\frac{W_G}{(W_G + W_B)} = C_G$$

$$\frac{W_B}{(W_G + W_B)} = C_B$$

Summing over the first order conditions we get:

$\sum_{s\in\Omega} C_s(w,\mathbf{r},p) \geq 1$ and $r_s \geq 0$ with complementary slackness.

From this, we can see that the risk averse farmer chooses a revenue vector that is in the efficient set. The efficient set is the set of revenue vectors **r** satisfying equation (2) for a given **w** and **p**.

Comparing Risk neutral and risk averse production equilibria

Now it is good to distinguish between the risk neutral and averse farmer equilibria for our case. A risk neutral for an interior solution chooses his state-contingent revenue so that:

$$\frac{C_G(w,\mathbf{r},p)}{\pi_G} = \frac{C_B(w,\mathbf{r},p)}{\pi_B}$$

Also, summing the risk neutral FOC's and by complementary slackness we have that:

$$\sum_{s\in\Omega} \pi_S r_S - \sum_{s\in\Omega} C_S(w,\mathrm{r},p) r_S = O$$

We can see with this equation that for a risk neutral farmer the marginal profitability of increasing the optimal state contingent revenue vector is zero.

Graphically Figure 2.2, which graphs the returns frontier for the Good and Bad states, we can see that depending on how risk averse the farmer is, he will produce along the efficiency set shown by the concave to the origin curve in Figure 2.2. He will choose to produce between point A, where the completely risk averse farmer with max-min preference produces, and point B which is the risk neutral equilibrium.

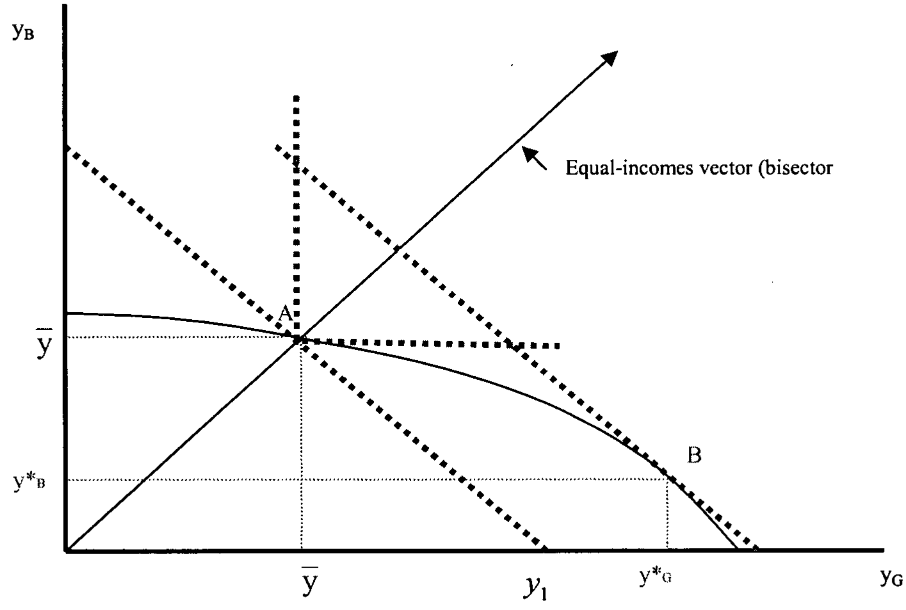


Figure 2.2 Risk-neutral and risk averse production equilibria

Since the indifference curves of a risk averse have to be tangent to the fair-odds line along the bisector (risk averse farmer always prefers certainty) this increases the subjective probability of a state leading to a rotation of all the decision maker's indifference curves along the bisector.

The introduction of the state contingent approach has laid the framework that will be used to introduce pollution into the model. Further explanations of the approach can be found in Chambers and Quiggin (2000) book. Although this approach is relatively new compared to the regular choice under uncertainty approach, it proves to be more intuitive and useful when analyzing farmer's choices. It also adds the extra dimension of different states of nature into the analysis, which is very important when analyzing farmer's choices.

2.3 Adaptation of Beaker diagram to model pollution transformation

After describing the state contingent approach and using it to model farmer's choices I turn to focus on input use and the resulting pollution. Specifically, I look at how pollution is transformed according to different input choices resulting from the farmer's response to the presence of a carbon equivalent price. It is important to note how pollution is modeled in this Chapter to respond according to the state of the environment in which it is realized and the way in which it is absorbed by the plant. The Beaker diagram of input transformation is used to model both of these situations.

Since I assume that output and input prices are the same for all states, comparing input demands by risk neutral and risk averse farmers is done by simply comparing the same input demand function evaluated at two different optimal state-contingent revenue vectors. Generally speaking, comparing different input demands arising from the same technology requires the ability to compare different state contingent revenue vectors.

The use of inputs by the farmer is best modeled by a beaker diagram in the state contingent approach. The beaker diagram displayed in Figure 2.3 pictures the case of two inputs. The horizontal axis represents the amount of resources available for acquiring inputs or the revenue cost function, going from left to right indicates fertilizer usage, $x_F = \frac{c}{w_F}$, and from right to left the amount of other inputs, $x_O = \frac{c}{w_O}$. The two different curves represent the returns transformation functions for the two inputs given the chosen input mix. The higher curve, going from left to right, represents the transformation of fertilizers use into returns in the good state. This curve shows how returns are affected when more fertilizer is used, increasing or decreasing total output which in turn affects returns.

The lower curve shows the transformation of the other inputs and the returns in the bad state. The left vertical axis represents returns in the bad state and the one in the right represents returns in the good state. If a certain amount of fertilizer is chosen the rest of the resources will be spent on the other inputs. In the case that the good state is realized the returns will be given by drawing a line from the amount of fertilizer chosen to the good state returns transformation curve and then joining this point with the respective point in the good state axis. In the case that a bad state occurs, we simply see where the line coming out from the input choice selection meets the bad state returns transformation curve and see where it is in the bad state axis. This point gives us the return in the bad state.

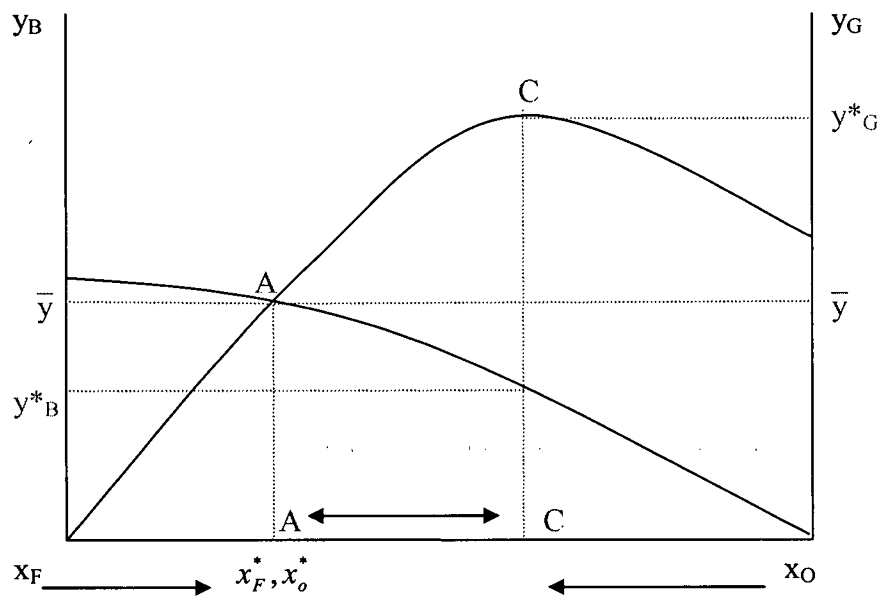


Figure 2.3 Beaker diagram showing input use for risk averse and risk neutral farmers.

In Figure 2.3 we can see the input selections by both a risk averse farmer, point A, and by a risk neutral farmer, point C. For our case, depending on how risk averse the farmer is he will choose the input mix between points A and C on the bottom input use line.

The beaker's diagram points transfer into the state contingent graph, by mapping the returns in each case into an n-state graph shown in Figure 2.4. It might be thought of as a state-contingent product-transformation curve. Its negative slope, which can be thought of as a state-contingent marginal rate of transformation, and its shape (concave to the origin) reflect the presumption that increasing one state contingent output can only be achieved at increasing cost in terms of the other state-contingent output. In our case it contains two states. Figure 2.4 shows how the production efficient frontier maps from a beaker diagram into the state contingent 2-dimensional graph. Point A and point B from the beaker diagram in Figure 2.3 are mapped into Figure 2.4. This figure also maps our case where a good state produces more revenue than a bad state.

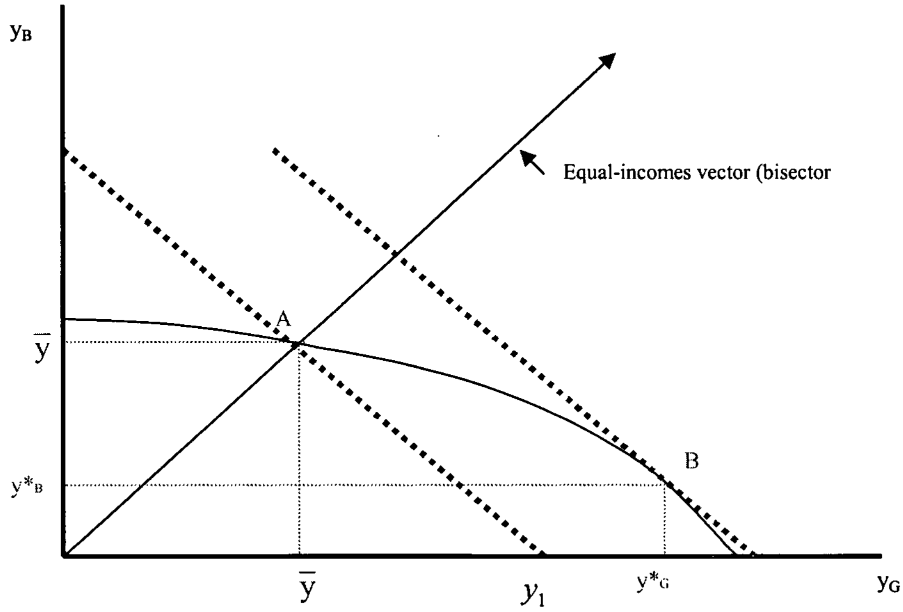


Figure 2.4 The two state returns frontier given by the beaker diagram (Figure 2.3)

In the presence of actuarially fair insurance Chambers and Quiggins demonstrate that farmers will produce at the same equilibrium as a risk neutral farmer would. That is, the farmer will choose to produce at the optimal state contingent revenue mix array. So to analyze the effects of the different carbon equivalent price effects in the presence of insurance we will have to see what happens to the risk neutral equilibrium and how its input choices are affected.

Since input and output prices are the same for all states, comparing input demands by risk neutral and risk averse farmers is done by simply comparing the same input demand function evaluated at the two different optimal state-contingent revenue vectors. For the study, because there are two states and only one output, the stochastic production-function technology illustrates z and X(z) by: $X(z)=\{x:z_G=f(x,G),z_B=f(x,B)\}$ in the Beaker diagram. The assumption that the technology displays an state contingent product-transformation curve (isocost) curve with skewness towards the good state's return like in the case of returns of a given crop subject to bad or good climate conditions is seen on Figure 2.4.

2.4 POLLUTION

The beaker diagram can also be used to show the amount of pollution caused by the different inputs. This can be done by creating a mirror image of the returns transformation beaker diagram which maps the transformation of pollution cause by the choice of inputs. This is shown in Figure 2.5. In here, the top represents returns transformation and the bottom represents pollution transformation. Differing from before, the amount of pollution does not necessarily have a steady increase with an increase of fertilizer use, as seen on the bottom part of Figure 2.5. Fertilizer uptake by the plant can reach a steady level from which it can deviate if more fertilizer is applied. This pollution is also state contingent. This steady level where pollution does not sharply increase even if you increase fertilization occurs when most of the fertilizer is taken up by the plant efficiently given weather conditions and other factors. But if you keep increasing the amounts of fertilizer, runoff will again begin to cause problems and pollution will discharge again.

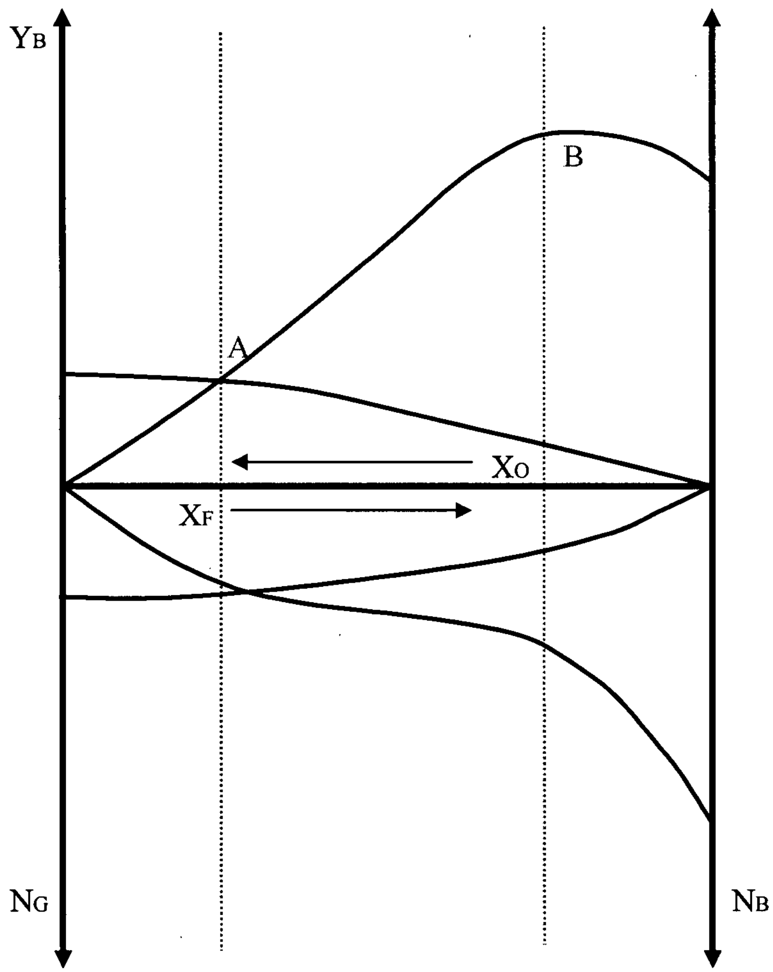


Figure 2.5 Transformation of input use into returns (top) and pollution (bottom).

Figure 2.6 shows the Beaker diagram picturing the two inputs, fertilizer and other inputs, and the pollution transformation functions that each creates given their use. Figure 2.6 shows the case when both inputs produce pollution. As the graph shows, the increase of pollution caused by the increment in fertilizer use depends on the rate of absorption that the plant possesses. This rate reaches a steady level, after which it shoots up again.

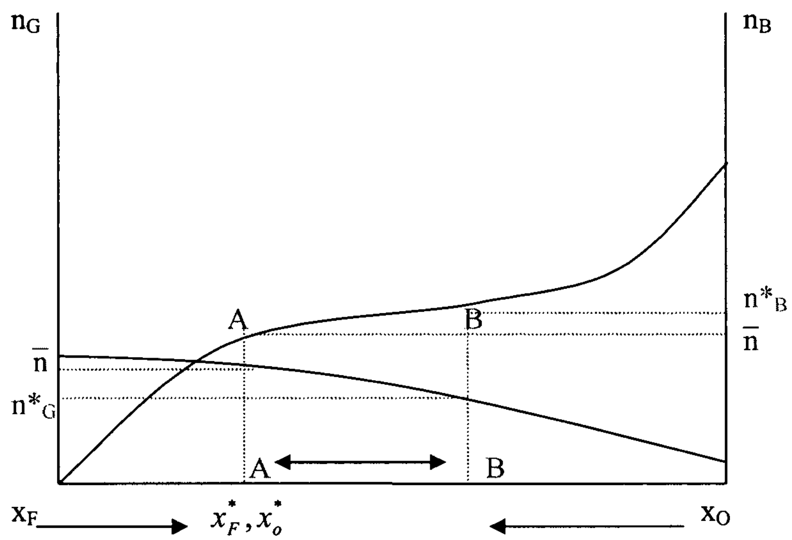


Figure 2.6 Beaker diagram showing input pollution transformation when both inputs pollute.

Figure 2.7 shows the beaker diagram depicting the case when only fertilizer causes pollution. The other inputs do not produce any pollution. As before, the two vertical axes show the pollution in the good and bad state. The production choices of both the risk neutral and averse farmers, the amount of pollution caused by them will be given by different points between A and B in Figures 3.4 and 3.5.

By transposing Figures 3.4 and 3.5 into the 2-state dimension graph, represented in Figure 2.8, we can see two types of pollution frontiers. Frontier A, concave to the origin, represents the case when both inputs produce pollution. We can see that in this frontier there is a skeweness toward the bad state. This is caused by the higher pollution that is caused by N-fertilizer if a bad state of nature is realized. This differs from the returns production frontier which is skewed towards the good state. Frontier B represents the case when only fertilizers cause pollution. In this case we can see that the pollution frontier has a skeweness toward the bad state, but this frontier does not form a closed structure. This is caused by the fact that if a farmer does not use fertilizers and uses all his resources in the other inputs, if any state is realized, no pollution will be produced.

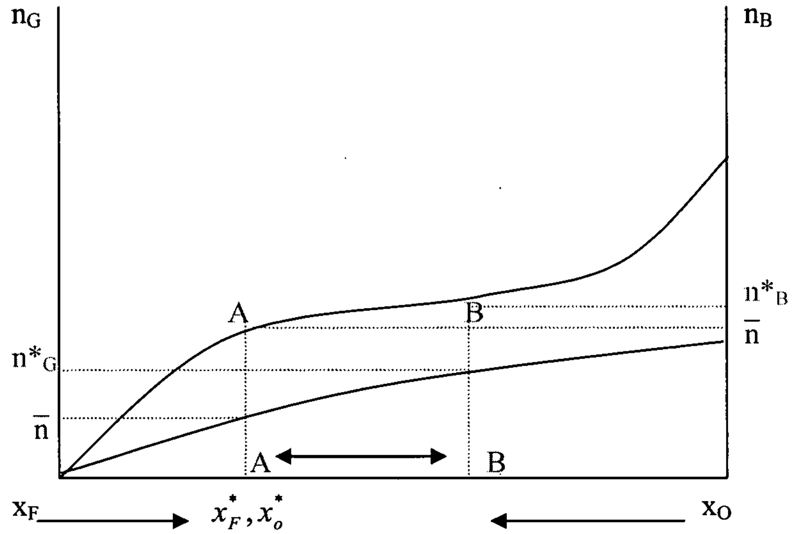


Figure 2.7 Beaker diagram showing input pollution transformation when only fertilizer causes pollution.

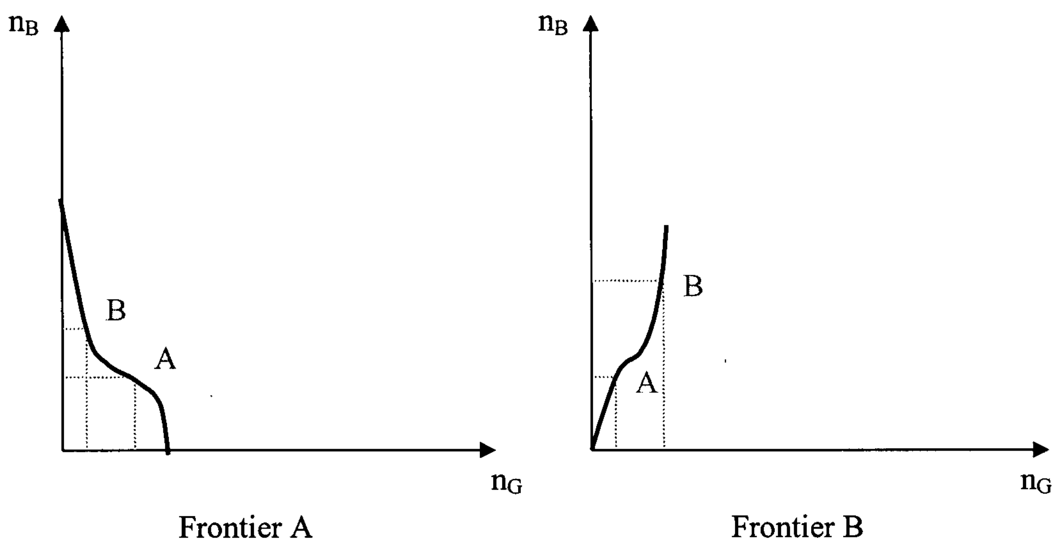


Figure 2.8 Pollution transformation frontiers produced by the production (Frontier A) or not (Frontier B) of pollution by the other inputs.

In Figure 2.8 we can see how pollution is modeled with respects to the choices of both the completely risk averse and the risk neutral farmers, point A and B respectively. Higher amounts of pollution will occur in the bad state and lower pollution in the good state. In the case of risk neutral farmers, they will produce using the maximum amount of fertilizer possible to obtain the most returns. In terms of pollution, this choice means that they will produce pollution at the end of the pollution "steady" increments given by the saddle point in the beaker diagram. As mentioned before, this is caused by the absorption of nitrogen up to a point where it won't use any more nitrogen. After this, with the application of excess nitrogen, it will all be lost to a form of pollution. This is the point where pollution starts to climb again after having a slow increase in the graph.

2.5 APPLICATIONS AND RESULTS

<u>Scenario 1: Increment in all of the input's prices</u>

When faced by a carbon equivalent price, I assume that the farmer faces an increment on all of the input prices that act like a tax on his returns. Taking this into account, the farmer will solve the following problem:

$$\max_{r}\{(1-t)z_G - C(\bullet), (1-t)z_B - C(\bullet)\}$$

$$C_G = \frac{W_G(1-t)}{W_G + W_B} \qquad C_B = \frac{W_B(1-t)}{W_G + W_B}$$

First order conditions, from which we get:

$$C_G + C_B < 1$$

As intuition would suggest, we can see that the farmer will produce a lower quantity than the efficient frontier that was characterized by $C_G+C_B=1$. Graphically we have that the efficient frontier in the 2-state dimensional graph has decreased compared to the optimal efficient frontier (Figure 2.9). The decrease in returns is the same for all states, that is, the increment of input prices will be the same in either state. Since the return's decrease is proportional, the risk neutral farmer will stay in his optimal revenue mix input choice. This occurs since he still faces the same subjective probabilities, and since the change in the isocost curve is proportional, the shift of the fair odds line, given these probabilities, will also be proportional. The less returns caused by this type of carbon equivalent price effect will, assuming a direct income effect, transcribe into less resources available for the acquisition of inputs. Also assuming that both inputs are not complete substitutes, we can see in Figure 2.10 that there will be a proportional shift inwards on both sides of the bottom axis that represents amounts of inputs available to use. This shift also creates a proportional decrease of the returns transformation functions in the Beaker Diagram of Figure 2.10.

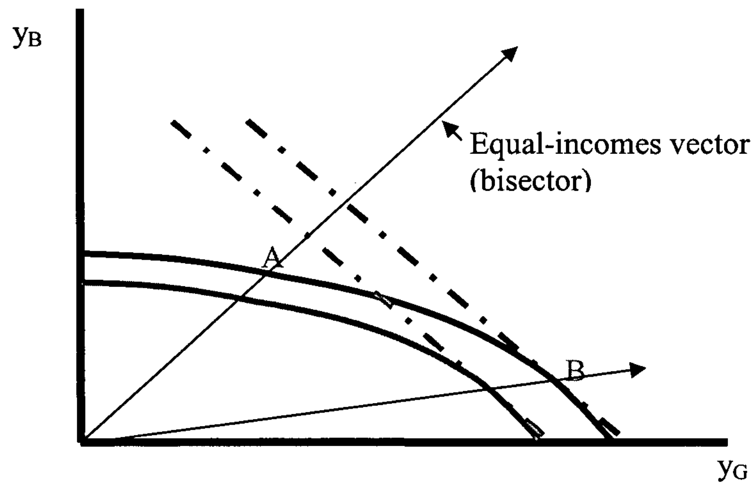


Figure 2.9 Overall input price increments and the change on the efficient set

These changes suggests that the effects of insurance (risk neutral equilibrium) won't be affected since the risk neutral farmer will produce using the same input proportions that he was using before. The difference lies in the proportional decrease of the returns frontier. This decrease changes the amplitude of production choices available for the farmer, given by the returns frontier between A and B. This means that the distance between the totally risk averse farmer equilibrium and the risk neutral equilibrium will be shortened.

Taking a look at how this transposes into the Beaker diagram (Figure 2.10), we can see that the product transformation curves that transfer into returns of each input will be lowered in equal proportional amounts. At the end this overall input price increment will bring a lower return for the use of each input, decreasing the amount used of each in a relatively proportional amount.

For the case of pollution and what happens when there is an increment in the prices of all the inputs, I found that in the case when both fertilizers pollute, total pollution in both states will fall since the lower returns will mean that the farmers will use less of both outputs. Since by the assumption of the direct income effect given on resources available for input use, and by the non complete substitution effect which causes farmers to stay in the same proportion of quantities of input, the decrease in pollution is also proportional. This causes the amplitude of pollution possibilities to be in the same range as before, but in a lower pollution frontier.

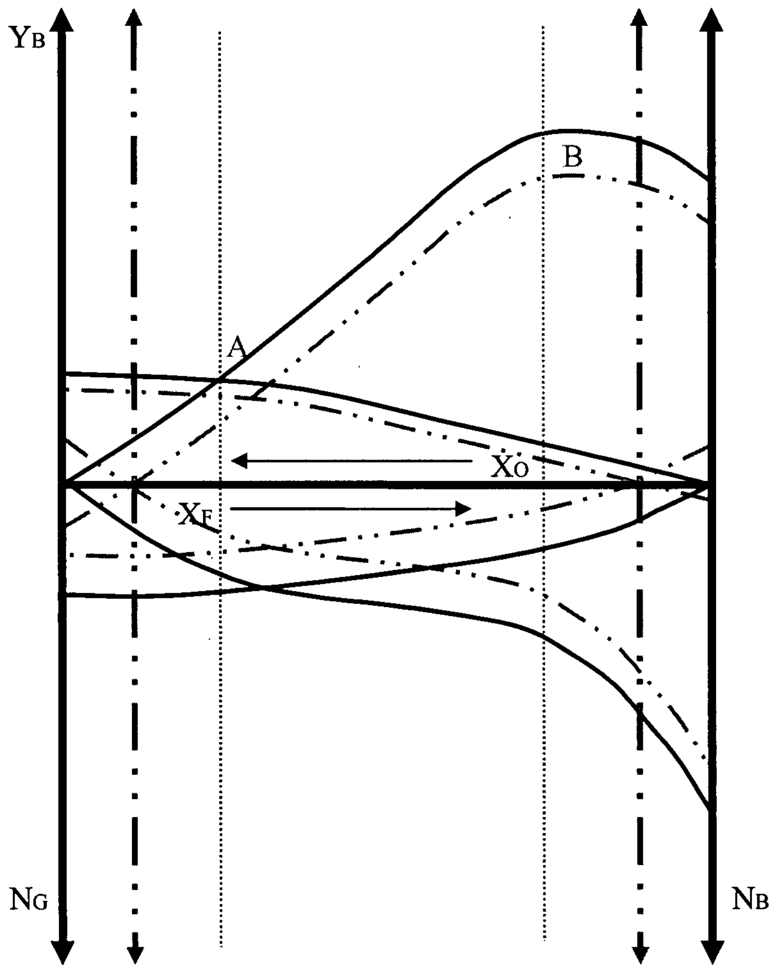


Figure 2.10 Input price increments, input use, and the effects on pollution

In the case when only fertilizers cause pollution, the change happens only in the upper part of the pollution frontier. As it is presented in Figure 2.11 Frontier B, this change could cause the same results as in the former case. These two cases are pictured in Figure 2.11, in which Frontier A and B represent the changes in the cases when the other inputs cause and do not cause pollution. In the case of the risk neutral farmer he, still, will be producing at the optimal revenue mix point. At this point, fertilizer use will be at the maximum absorption point, given the new conditions. This means that pollution will continue to be at the maximum point right after the steady level as explained in the beaker diagram of pollution transformation.

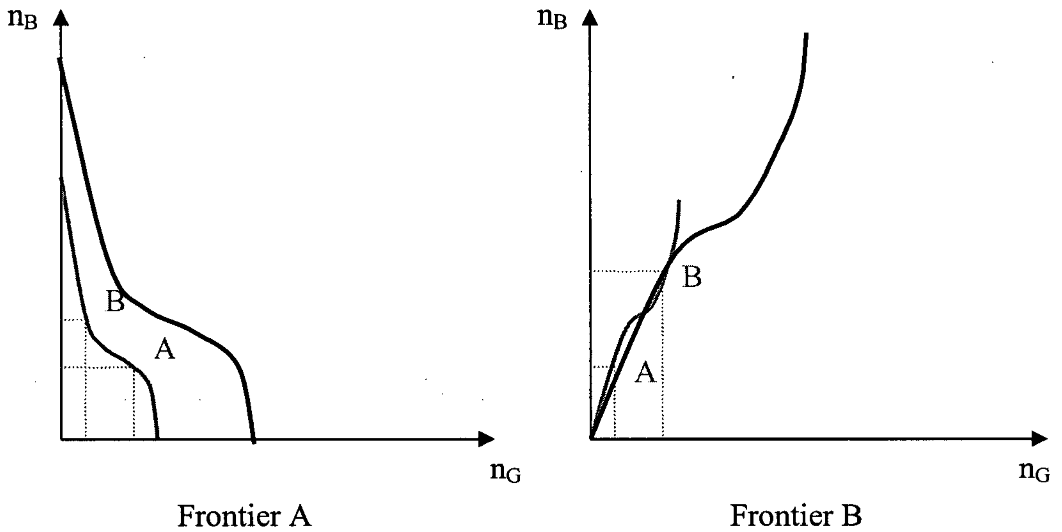


Figure 2.11 Pollution frontiers affected by an increment on the price of all the inputs

Increment on the price of the N-fertilizer input

The effects of an increment on the price of nitrogen based fertilizer caused by the presence of a carbon equivalent price will act as a tax directly on fertilizer. This increment will also lower the efficient returns frontier set, but not in the same manner as the overall input price increment studied previously. Since the farmer could spend all his money in the other inputs, he will still face the efficient set of that input. In the case of fertilizer the efficient set will decrease given that the price increment will lower the returns of this input. Again, this is assuming no complete substitution between both inputs. In Figure 2.12, the Beaker diagram shows the effect on the returns transformation curves of both inputs if there is an increment only in the price of fertilizer.

As Figure 2.12 shows, the left axis will shift inwards representing the lower returns frontier capabilities of the fertilizer input. This can be explained by the way in which farmers maximize preferences. The farmers maximizes inputs and outputs (returns) in a preferences maximizing manner, the effect of using more fertilizer will be subject to a higher price which will lower the returns of this input. This means that the farmer will have to change his previous input proportion choices and not just the quantity. The right axis will not change, since the amount and the transformation curve of the other input will not be affected by a higher price of fertilizers. This translates into the 2-state dimension graph by shifting down the good state returns skew. This happens since the fertilizer is responsible for the incremented returns in the good state.

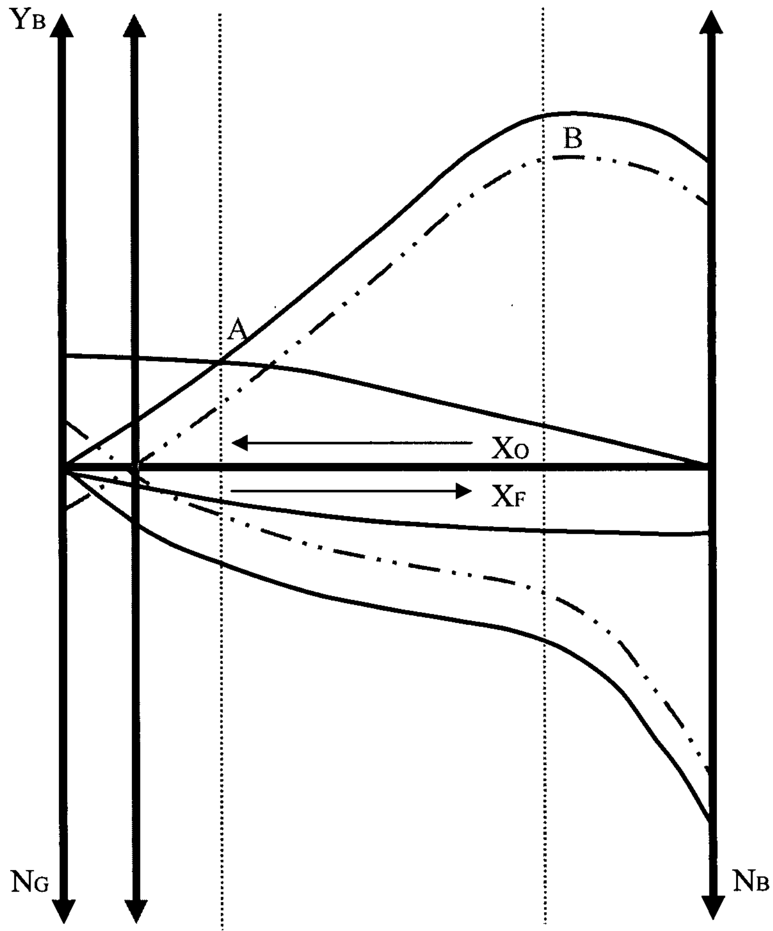


Figure 2.12 Beaker Diagram showing input use with an increment on the price of fertilizer and the effects on pollution

In Figure 2.13, we can see that a higher price of fertilizer will cause the efficient frontier to shift inwards, but only in the good state side. Even if there was a small substitution effect in the use of inputs, this change will be more accentuated in the good state because of the way in which fertilizers affect mostly the good state returns. This change will make the optimal state contingent revenue mix, maximized by the risk neutral farmer, to also shift inward more toward the risk averse equilibrium. Given these new conditions, the risk neutral farmer will choose a different state contingent revenue mix than before when he equates his subjective probabilities to the optimal state contingent revenue mix. He will lower the amount of fertilizer and he will have a new input proportion choice. Under these conditions the effects of insurance will be minimized: The new equilibrium of the risk neutral farmer will be moved towards the risk averse part of the efficient frontier.

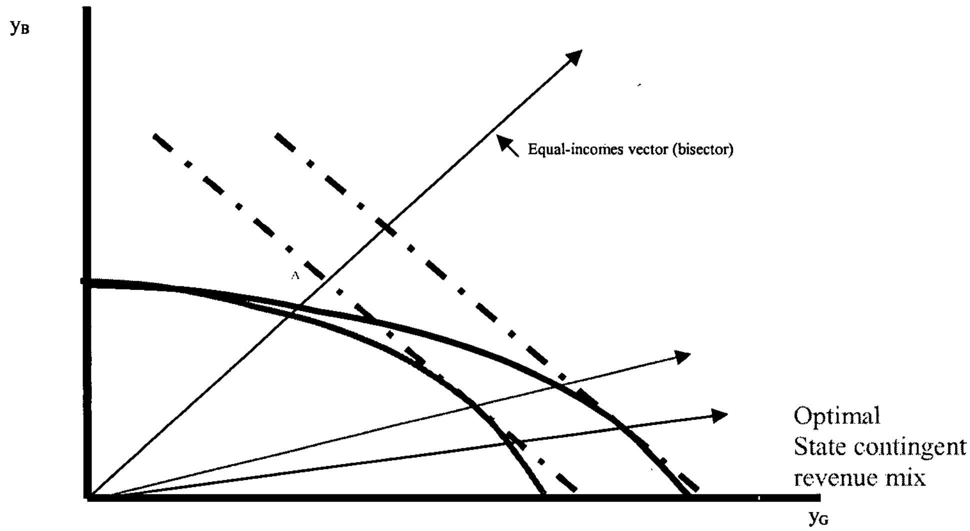


Figure 2.13 Higher fertilizer's prices and the efficient frontier

Looking at Figure 2.14, we can see the different changes in pollution that an increment on the price of fertilizers will have with respects to an increment of the prices of all the inputs. As before, frontier A on the graph represents the case when both inputs cause pollution and frontier B the case when only fertilizers cause pollution. Frontier A shows that there is a shift inward of the pollution frontier, and this shift is more pronounced in the bad state part of the frontier. Since the farmer is going to be producing at a different input choice mix, the total pollution change could be at a similar point of the pollution frontier than before the price change scenario was implemented. His new input choice mix could be as damaging as before causing same amounts of runoff and pollution. In pollution frontier B on the graph the shift moves in a different way than before, since only the effects of fertilizer are changed with respects to the other inputs. I find that the changes in pollution in the risk neutral case (point A) will tend toward the risk averter side given the changes in input use which affect pollution once the bad state is realized.

In the risk averse case the changes in pollution will not be significant since the shift of the curve will be towards the risk neutral part of the frontier. The pollution caused by the risk neutral will shift toward the side of the frontier where there is less change in pollution which is the side of the risk averter.

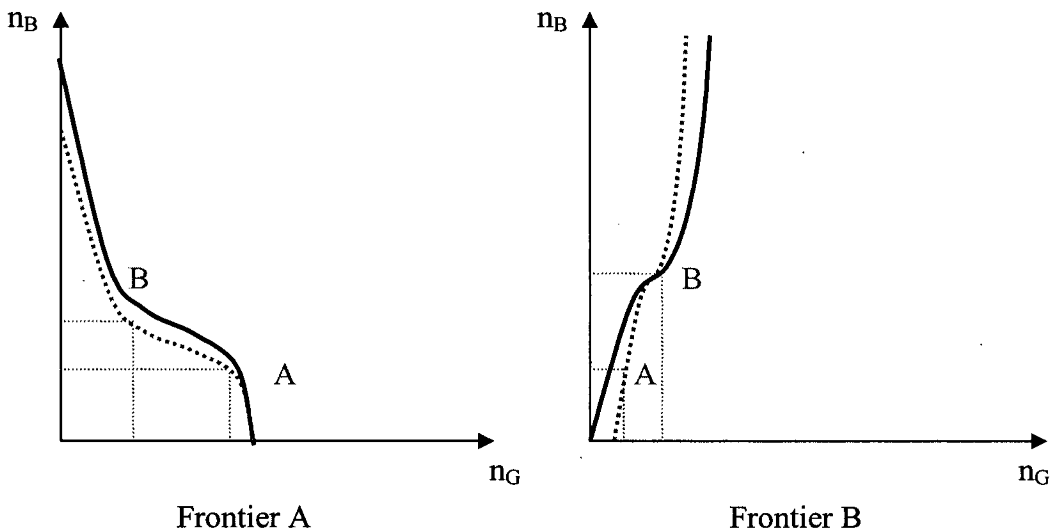


Figure 2.14 Pollution and Production affected by a higher fertilizer price

2.6 CONCLUSIONS

Applying the Beaker diagram to obtain a pollution transformation frontier provides the current analysis with a very intuitive way of describing input choices and their effects on pollution providing an example of the possible micro-foundations for the water quality effects in Chapter one. This approach allows the incorporation of input choices under uncertainty with preferences being only over returns and not over the amount of pollution. The state contingency also helps to analyze the behavior of the inputs under different climatic conditions. I use this expansion of the beaker diagram from the state contingent approach to analyze two input price scenarios that could result from the presence of a carbon equivalent price.

Comparing the two input price scenarios, I find that both scenarios will lower the boundary of the efficiency set or returns frontier. The difference between them is given by the way in which the efficient set is lowered. In the case of the overall input price increment, the efficient set decreases both in the good and bad state causing a decrease on the returns of both inputs. Since fertilizer is assumed to be the only input responsible for the high output and returns in the good state, the decrease of the efficient set due to a higher fertilizer price only occurs in the good state. The farmer's option to completely forgo the use of fertilizer also causes the shift inward, only from the good state, of the efficient set.

In the two carbon equivalent price effect scenarios the use of both fertilizer and other inputs will go down, but the decrease will be close to proportional causing an inward shift both in the good and bad states. With the proportional decrease of fertilizer use, Nitrogen pollution will also decrease proportionally. Given that pollution will decrease proportionally, both the amount of pollution produced by the risk neutral and risk averse farmer will decrease.

The two carbon equivalent price effect scenarios will dampen the risky outcomes on both states. This occurs since the available production choices for the farmers will decreases. This is shown by the reduction of the segment of the efficient set between the completely risk averse and the risk neutral equilibria in both cases.

A higher fertilizer price will cause a decrease on the returns of the good state. This type of price increment will shift the efficient set inward, but this shift will only be in the good state. The risk neutral farmers will change their optimal state contingent revenue mix causing the effects of insurance to be affected by this increment. The risk neutral farmer will move inwards in the efficient returns set and produce more as a risk averse farmer or in the portion of the efficient frontier that is selected by risk averse farmers. The input selection proportions will change. For this analysis I have not taken into account any effects that the substitution of one of the inputs will cause in the performance of the other. If there was a substitution effect between both inputs there could more runoff produced if other than the optimal input choice mix was selected. If we take into account a substitution effect on the interaction of fertilizer with other inputs, it is very important to assess the changes that applying different input mixes on the crop will have on total runoff. Runoff depends on the type of irrigation, soil tillage and other practices which for our study are included in other inputs but are not considered as causing a substitution effect. As mentioned before, a higher fertilizer price could also make the farmer change certain practices that prevent the field from loosing fertilizer by runoff, trying to improve the conditions for the plant to absorb as much as possible. Resources needed for analyzing the different practices necessary to obtain a new optimal mix have also to be analyzed before implementing a carbon equivalent price scheme.

This framework permits giving interesting and intuitive results analyzing both carbon equivalent price effect scenarios and the effects on pollution. In this manner, I find that higher prices of all inputs will keep the farmer using close to the optimal input mix. This will be beneficial if the different input proportions choices produced by the higher fertilizer price cause more environmental damage than by the optimal input mix. This new level of pollution could be best measured with the pollution frontier of both inputs, which is what the current analysis tries to present. Before installing a carbon equivalent price policy, the social planner has to take into account that the farmer produces at the efficient frontier of the other inputs only if the fertilizer input does not affect the productivity of them.

CONCLUSIONS

In this thesis I introduce two different approaches to analyze the co-effects of non-point source pollution mitigation in agriculture. I estimate the indirect effects that the presence of a carbon equivalent price has on the quality of water and one example of the possible micro-foundations that trigger them. This is of great importance since the analysis of policies aimed to reduce GHG emissions must include both the direct and indirect effects caused by their adoption. An inclusion of these indirect effects will help us predict with greater accuracy the costs and benefits reducing GHG emissions and improving the environment.

This thesis addresses the indirect effects of a carbon equivalent price in two different analyzes. In Chapter one, I use two computer models used to assess water quality effects of GHG mitigation. This Chapter shows that a $25 carbon equivalent price changes input choice and land use in agriculture. These changes create associated changes in the quality of water. My analysis is an illustration of the existence of ancillary effects and an illustration of a technique to estimate these effects. With more precise data and further depth of the analysis we could get real estimates and measures of water quality changes caused by mitigation strategies. These estimates could then be used for future extensions calculating economic social benefits resulting from the changes that occur in the quality of water.

Chapter two illustrates the mechanism for ancillary effects to occur. The outline of the second Chapter explains the state contingent approach and how it is adapted to this thesis comparing two carbon equivalent price effect scenarios. This comparison relies basically on the changes of input mix choices that the farmer will make when facing the two scenarios. This analysis shows that even thought the changes that the farmer will make may be beneficial, they could also pose threats to the environment producing higher pollution.

Results show that Agricultural policy to reduce GHG has to take into account all of the different linkages that it affects and that it is affected by. Measures of direct and indirect effects have to be studied before implementing policy decisions. These linkages should be assessed using different methods that incorporate and measure the farmer's decisions and the environment in which these decisions are taken. Results also suggest that incentive policies should primarily target areas closer to the main rivers and tributaries. These areas are generally where agriculture is more intensive and the changes in these areas will differ greatly from areas where there is no agriculture.

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