Literature Review

Economic Analysis of Climate Change Adaption in B.C. Agriculture

November 2014

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Acknowledgements

Guidance was provided by: Jennifer Pouliotte, adaptation advisor with the B.C. Climate Action Secretariat; Jim Johnston, economist emeritus, Ministry of Forests, Lands and Natural Resource Operations; Dr. David Scoones of the University of Victoria, Department of Economics; Tom Goddard, Alberta Ministry of Agriculture and Rural Development; Selma Low, Ministry of Agriculture; and Stephen Smith and Li Xue of Agriculture and Agri-Food Canada.

Project funding provided by:

This project was funded in part through the internship program of the Pacific Institute for Climate Solutions. This project was also supported by the Ministry of Agriculture through *Growing Forward 2*, a federal-provincial-territorial initiative.

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1. Introduction

Despite agricultural producers' propensity to adapt to changing conditions, the climate change currently underway is anticipated to impact agriculture on a much larger scale than ever before. The 2012 Risk and Opportunity Assessments of B.C. agriculture, by the B.C. Agriculture and Food Climate Action Initiative (CAI), discuss climate change projections for five regions of the province and explore the sector's adaptive capacity. Climate impacts such as increases in the number of hot days, changes to precipitation patterns, and more frequent and intense extreme weather events (e.g. wind-storms, hail and droughts) are anticipated to affect B.C. agriculture. These climate impacts would also be associated with effects such as increases in as flooding, erosion, excess moisture, wild fires and pest outbreaks. Climate change will result in more uncertainty and farm management complexity. These changes will also impact Ministry of Agriculture programs such as Production Insurance and Agricultural Emergency Management.

The B.C. agriculture sector will have to adapt successfully to climate change to maintain growth and profitability. The Ministry of Agriculture, through the *Growing Forward 2* (GF2) initiative, is funding programming to direct and support agriculture sector adaptation at the regional and farm levels. This programming is delivered by the CAI. The CAI has completed four regional adaptation strategies and evaluations of six on-farm management practices. Regional adaptation projects are implemented through joint funding by regional partners and GF2, and farmers can access funds to pilot innovative farm practices through the Farm Adaptation Innovator Fund (see Appendix 1 for more details on the CAI).

Adaptation actions have begun in B.C., yet there have been few attempts to assess the economic costs associated with climate change or the benefits of adaptation in the province. The purpose of this literature review is to identify and assesses methodologies that could be used to estimate the economic benefits of adaptation.

2. Methodology

<u>Section Overview</u>

- This is a broad literature review and jurisdictional scan
- Overview papers from international research institutes guided the search
- The economics literature focused on hedonic (Ricardian) pricing or Integrated Modelling Systems (IMS)
- Analysis of insurance programs may require further research, although some analysis techniques are reviewed
- A draft report by Golder Associates formed the foundation of this literature review

This literature review is a broad scan of the intersection of four topic areas: economic analysis, climate change, adaptation and agriculture. Key word searches focus on these four terms. The state of research in this topic area was assessed through the review of literature in Canada and other jurisdictions with similar climate risks, political, and economic systems (e.g. US and Australia). Government agricultural agencies in Alberta, Ontario and the federal government were also contacted to gauge progress on this topic.

After starting with overview papers[1], the research focused on individual papers and methodologies best suited to answer the research question: What is the economic impact of climate change adaptation in the agriculture sector? While assessing the impact of climate change is more common in the literature, a more limited body of work incorporates adaptation into the analysis.

The economics literature related to climate change focused on hedonic (or Ricardian) pricing through regression analysis of land values or integrated modelling systems (IMS). IMS combine crop simulation models, hydrology models and economic models, both of which were highlighted in the overview papers. Extreme weather events, incentives and insurance could be found in the economics literature;[2] however connections, to the broader questions of climate change and adaptation were limited or non-existent. Some of these analysis techniques are reviewed in this document, but due to the lack of direct overlap, may require further research with a separate central question.

The draft report *Development of Climate Change Adaptation Case Analysis Literature Review* by Golder Associates served as a template for this literature review. It is an excellent overview of current work in the area of economic analysis and climate change (with a focus on the mining sector).

[1] OECD (2008), World Bank (2010), German Society for International Cooperation (GIZ), and Smit (2002)
[2] Kimura (2010). Kimura (2012), Cheng C.S. (2012)

3. Definitions

Section Overview

- Hard and soft adaptation
- Equilibrium
- Autonomous adaptation
- Planned adaptation

a) Hard and Soft Adaptation

A challenge associated with economic analysis of climate change impacts and adaptation (particularly with cost benefit analysis), is the tendency to focus on "hard" adaptation measures as they are relatively easy to quantify.[3] Hard adaptation measures include physical infrastructure, changes to natural capital such as irrigation systems, land terracing and earthen dams. "Soft" adaptation measures include modified institutions, planning processes and incentives which aim to alter the circumstances under which private or autonomous adaptation investments are made. Cost and benefits of soft adaptation such as knowledge, skill development, networks and institutions are comparatively more difficult to quantify[4]. The focus of most studies on the assessment of hard adaptation may lead to the neglect of potentially critical adaptation measures. A historical example of a critical soft adaptation measure is the development in the 1930s of the Prairie Farm Rehabilitation Administration in Saskatchewan and the Special Areas Board in Alberta. These have generally been viewed as successful institutional adaptations to the severe extended drought conditions of the time.[5]

Most of the climate adaptation actions in B.C. have been preliminary soft adaptations, including: researching impacts and solutions, disseminating information, strengthening information networks and encouraging producer collaboration on climate change. Regional agricultural adaptation strategies have been completed for the Cowichan Valley, Delta, Peace and Cariboo regions. These documents include specific adaptation actions and identify the stakeholders and networks that could be leveraged to implement each strategy. The Farm Innovator Fund provides funding for innovative adaptation pilots to enable farmers to take risks and share the knowledge gained with other producers.

b) Equilibrium

In general, equilibrium can be characterized as a state in which various opposing forces or influences are balanced. Equilibrium in an economic context implies that forces of supply and demand are balanced in the absence of external forces. When an external force (or shock) is applied to a "steady-state" equilibrium the system returns to the original equilibrium. Conversely, an "unstable" equilibrium will diverge from the original point of balance or move to a new equilibrium when an external force is applied.

[3] OECD (2008)
[4] World Bank (2010)
[5] Marchildon (2008)

c) Autonomous adaptations

The agriculture sector is familiar with adaptation in response to external forces such as price volatility, regulatory changes and climate. It is reasonable to assume that producers will respond to incentives and climate pressures to improve their outcomes without any direct government involvement. Autonomous adaptations refer to adjustments private individuals would take in response to climate change in the absence of government intervention. Many autonomous adaptations will take place at the farm level through changes in crop mixes, planting dates and fertilizer use.[6] However, they will be influenced by the economic environment and public policies. Although autonomous adaptations are important, they can be difficult to separate from total adaptation in the sector. Moreover, autonomous adaptations alone may only partly drive the full degree of adaptation required by the sector.

d) Planned adaptations

Hard and soft adaptations both fall under the classification of planned public sector adaptations.[7] These adaptations involve actions by governments to provide public goods or incentives to motivate action by the private sector. Governments may choose to participate in planned adaptation because certain adaptation actions have benefits that cannot be captured by private individuals, resulting in under investment. For example, a farmer may choose not to experiment with a new technology because his success will be copied by others (free rider problem). Development of new irrigation infrastructure, land-use arrangements and property rights, water pricing and training for the private and public sector (capacity building) are some examples of planned adaptations.[8]

[6] OECD (2008)
[7] World Bank (2010)
[8] Rosenzweig and Tubiello (2007)

4. Economic Analysis Techniques: Climate Change Adaptation

Section Overview

- Decomposition of the price of land into various components to assess the economic impact of climate change on agriculture is Ricardian (or hedonic) pricing
- Partial and general equilibrium models are a diverse family of tools and have been used alone or in combination with other models to ascertain the economic impact of climate change
- Integrated Modelling Systems are combinations of models that work together; several examples and potential configurations are discussed
- Adaptation Gap Analysis is a basic tool to determine the cost of adaptation on infrastructure projects

This section discusses specific modelling and estimation approaches that could be used to estimate the economic impact of climate change adaptation in B.C. Each subsection highlights the usefulness of the approach, its drawbacks and data requirements.

a) Ricardian (or Hedonic) Pricing

Ricardian models or hedonic pricing models are used to answer the questions: What is the economic impact of climate change, and in some cases, How is this reduced by adaptation? Hedonic pricing models are used to isolate the price effects of various characteristics, for example, the amount a nearby green space increases the value of a home. For this project, Ricardian analysis would be used to quantify the costs of climate change through lower land values. Farm land values are used to estimate the long-term economic impacts of different climate conditions than those observed in the past.

This technique is derived from the writing of David Ricardo (1817), who stated that "net land value is equal to net productivity".[9] The hedonic pricing technique assumes that land owners will maximize the productivity of their land and the price paid for a piece of land is equal to its productive capacity. The value of land is decomposed into its various components by regressing the price of land on historical climate data, land characteristics and agriculturally significant historical events. For example, the price of land without irrigation may be lower than land with irrigation. The hedonic pricing technique isolates the effect of irrigation on land price, holding all other characteristics fixed. Alternative regression approaches use farmer profits or net revenue in lieu of land values.[10] Land values are then calculated from profits: they are assumed to be equal to the present discounted stream of rental rates. In other words, land values are the discounted sum of future profits from the use of the land.

This technique assumes that farmers are actively adapting to climate change and findings are therefore net of autonomous adaptations. As a result, Ricardian models can be used to assess what would happen in the absence of a government intervention. Adaptations can be difficult to include in these models because they rely on historical information. If there was a major infrastructure project in

[9] Moeller (2010)
[10] Deschenes (2007)

the past, a parameter could be estimated to model the impact of a similar hard adaption in the future. Similarly, if there was a past change in incentives through the introduction of a government program, a soft adaptation could be modelled in the future. In the absence of either of those past events, impacts of future adaptations cannot be estimated.

Time series data can be difficult to compile and require more stringent data analysis techniques. Due to this, most Ricardian models use cross-sectional data (multiple locations). Using climate, water flow, soil and economic variables Kurukulasuriya and Mendelsohn (2008) estimate the impact of climate change in 11 African countries under two different climate scenarios.[11] This analysis does not incorporate adaptation. In order to isolate the effects of past adaptations in a given region of B.C., time series data of land values and regional climate and historical infrastructure projects would be required.

Advanced Ricardian regression techniques have used multinomial probability distributions to determine the probability that an Agro-Ecological Zone (a proxy for productivity developed by the Food and Agriculture Organization) will be present in a given district.[12] Different Agro-Ecological Zones have different net revenues and crop suitability. As these zones shift across the continent due to climate change, net revenue and crop choice will change in a given district. This method allows for one type of adaptation (changing crop mix in response to climate change) but requires advanced econometrics. The results of this study found that there would be fewer high-value Agro-Ecological Zones in Africa, resulting in a negative impact of climate change on the African economy.

b) <u>Partial Equilibirium (PE) and General Equilibrium (GE) Analysis</u>

Many methods for modelling the economic impact of climate change adaptation require modules to link predicted physical and biological changes to the choices of individual economic agents such as farmers and municipalities. Ultimately these predicted changes flow through to the economy through market (and government) mechanisms.

Typically economists posit that economic systems under a given set of inputs, production and consumption conditions will move towards a particular equilibrium and that if the system is changed (shocked) it will move towards a different equilibrium. Economists aim to measure the impact of the system change by measuring the difference in the two predicted equilibriums. Changes or shocks will typically have market (and government) impacts that are largest for the economic systems and factors directly affected. These impacts will diminish in size and speed of effect for those indirectly affected. For example, a flood in the Peace Region would have the largest effect on the businesses and residents in the inundated areas, a somewhat smaller effect on the businesses and communities in the immediate area and even less in other regions of the province.

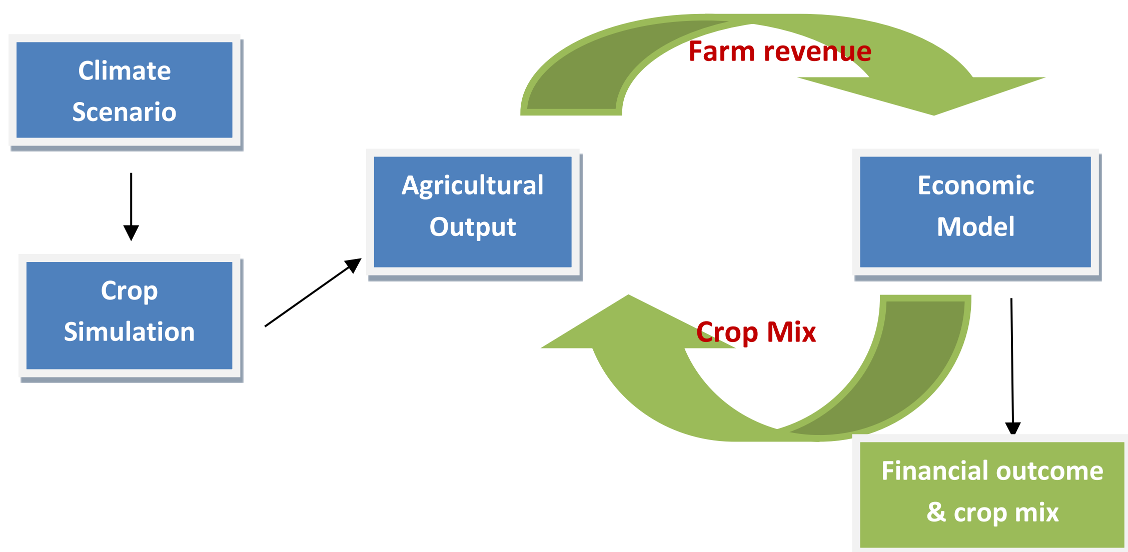
The terms “partial equilibrium” and “general equilibrium” refer to a more limited or extensive analysis of these ripple effects through the economy. In PE analysis, the effect of a change or shock is considered in one sector of the economy, while in GE analysis the model incorporates the effects on all

[11] Kurukulasuriya and Mendelsohn (2008)
[12] Kurukulasuriya and Mendelsohn (2008)

interrelated sectors of the economy. The Agri-Environmental Policy Analysis group at Agriculture and Agri-Food Canada (AAFC) uses a PE model of the Canadian agriculture sector to evaluate policy.[13] In relation to climate change, both PE and GE models provide a framework that allows a user to look at potential interactions between climate change impacts, adaptation options and the economic system. This is achieved by forecasting future market changes based on driving forces observed in the past and assumptions of market mechanisms[14]. These PE and GE models are often incorporated within an integrated modelling system (see Figure 1). Furthermore, PE and GE models rely heavily on historical estimates of market behaviour, which adds considerable uncertainty to models in which adaptation efforts induce behavioural changes over time. [15] In other words, the PE and GE models reflect the historical structure of the economy and may not reflect the structure of the economy in the future.

PE and GE models are very diverse, and are created to answer a range of different economic questions. Within these broad categories there are also static models, which stay the same over time, and dynamic models which allow changes over time. They can focus on a range of geographic areas, from regional or national to international trade and can focus on different combinations of commodities. Each economic model is based on a series of assumptions to answer a specific question. One good example is the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model, developed by the International Food Policy Research Institute., This is a GE model that determines global food supply, demand and agricultural food prices at the country or sub-regional level, then aggregates these values to the global scale. The model has been combined with a water simulation model in an integrated modelling system to incorporate water availability concerns. However, weather variability due to climate change has not been included in the analysis and is not reflected in the results.[16]

c) Integrated Modelling Systems (IMS)



[13] Canadian Regional Agricultural Model (CRAM)
[14] Noleppa, (2013)
[15] Noleppa, (2013)
[16] Rosengrant (2008)

Figure 1. Integrated modelling system (adapted from the World Bank 2010)

Integrated modelling systems in which several models work together to generate economic impacts of climate change on agriculture are the new standard in this area of analysis. The IMS approach is common at the global scale[17], and has also been used in region specific climate adaptation studies.[18] Climate scenarios, crop simulations, and representative agent (economic) models are common components of IMS used to measure impacts of climate change adaptation (Figure 1). In the figure above, the baseline scenario would model the outcome of climate change on the agriculture sector without adaptation. A representative farmer economic model would show which adaptations would be selected by allowing farmers to choose different crop types or management techniques (such as higher efficiency irrigation). A PE economic model would demonstrate the aggregate impact on the agriculture sector; however the adaptations chosen by producers would need to be assumed in the alternate scenario. The IMS can be tailored to suit the research question through the choice of economic model.

The system is created by linking several distinct models together by matching outputs of one model to inputs of another. Climate change scenarios produce future projections of daily, monthly or annual temperature and precipitation. This information is an input into hydrology models and crop simulations, which produce estimates of water availability and crop growth respectively. Based on projected crop yields and water availability, economic outcomes are estimated with farm level decision making or sector level PE models. In Figure 1, each blue box represents an individual model, arrows represent outputs from one model and inputs into the next, and the final outcome is in the green box. Along with Ricardian analysis, the IMS technique is at the forefront of economic research on the topic of climate change, adaptation and agriculture.

IMS are flexible tools tailored by the modeller to fit the specific climate change projections and adaptation options of interest. For regional analysis, downscaled climate change scenarios are required. Crop simulation can be done with physical models or econometric estimates (see below). Adaptation options must be incorporated into the crop simulation or economic model components. Developing the expertise to work with models from several different disciplines and finding or creating linkages between these models is the most difficult aspect of the analysis.

The Agri-Environmental Policy Analysis group at AAFC is currently developing an IMS (see Figure 2) using downscaled regional climate scenarios, the DSSAT crop simulation model (see below), and their in-house PE model, the Canadian Regional Agricultural Model (CRAM).

[17] Tan 2003, Rosegrant (2008)
[18] World Bank (2008), Rosegrant (2012)

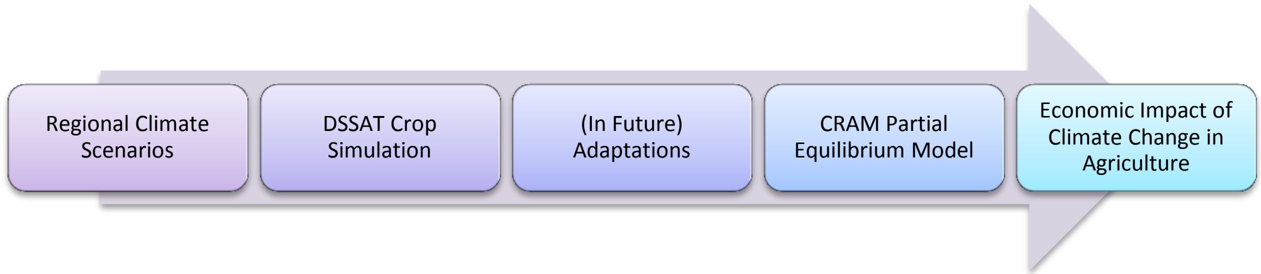


Figure 2. Integrated Modelling System (AAFC)

i) <u>Physical Models</u>

Physical models use plant science or commonly known relationships between soil type, climate, hydrology, and crop type to determine total production. These models use climate scenarios to predict future agricultural production. The climate scenarios are those developed by international climate models, most often the Intergovernmental Panel on Climate Change (IPCC). These global climate models (GCM) are built based on physical science as well as socioeconomic factors that influence global emissions of greenhouse gases. GCMs can be downscaled to represent climate projections for smaller regions. There have been many advances in downscaling techniques and the most recent iteration of climate scenarios for B.C. provided by the Pacific Climate Impacts Consortium (PCIC)[19] provide daily temperature and precipitation levels for 1951-2100 at a 10 km spatial resolution.[20] This data is crucial for modelling hydrology and plant growth, key components of IMS.

(1) Decision Support System for Agrotechnology Transfer (DSSAT)

Developed by several universities and research institutes, the Decision Support System for Agrotechnology Transfer (DSSAT) is software that, for over 28 crops, simulates growth, development and yield as a function of the soil-plant-atmosphere dynamics. [21] This model was used at the global scale to model the effects of climate change on food production[22], but can be used for on-farm precision management and regional assessments of climate change adaptation.[23] The yield output under various climate change scenarios could be used as part of an integrated model to determine the economic impact on agriculture. The latest work-in-progress version of this model has been acquired from DSSAT for use on this project.

(2) Environmental Policy Integrated Climate (EPIC) Model

EPIC is a cropping systems model developed to estimate soil productivity and erosion. It was created as part of the analysis for the 1980 *Soil and Water Resources Act* in the US and is housed at the

[19] PCIC is a regional climate technical service centre at the University of Victoria that provides information on the physical impacts of climate variability and change, including support for long-term planning with climate projections for regions of B.C. based on downscaled global climate change models. www.pacificclimate.org
[20] PCIC poster #GC43C-1069 (2013)
[21] University of Florida, the University of Georgia, University of Guelph, University of Hawaii, the International Center for Soil Fertility and Agricultural Development, USDA-Agricultural Research Service, Universidad Politecnica de Madrid, Washington State University, and other scientists associated with ICASA
[22] Rosegrant (2012)
[23] http://dssat.net/about

Texas A&M University. It has been used to examine climate change and drought impacts on crop yields and soil erosion[24]. Although both DSSAT and EPIC model crop yields, EPIC is better at modelling erosion and other environmental impacts[25]. The EPIC model can be extended to evaluate agricultural policy by incorporating Agricultural Policy/ Environmental eXtender Model (APEX) to consider the impact of management practices on a variety of agricultural and environmental indicators.

(3) Agriculture Water Demand Model (AWD)

The Agriculture Water Demand (AWD) model was developed by the B.C. Ministry of Agriculture to support planning to address water shortages across the province. Water demand models have been created for 10 watersheds across B.C., mostly in the south of the province. The models use a cadastre provided by regional districts to inform detailed land use surveys to determine which crops are being grown and if there is irrigation present on a given piece of land. [26] This information is combined with soil and historical climate data to determine water demand at various levels of regional aggregation. The AWD uses climate projections provided by PCIC to model future water demand.

The AWD model developers have run several scenarios similar to climate change adaptation by altering the number of irrigated farms and the type of irrigation or increasing the number of active farms. The model can generate an intermediate output of the number of irrigated acres of a given crop in the watershed, which can be used to determine the share of irrigated farms. These two numbers can be combined with a measure of the average value of a particular crop in that particular region to estimate the total value of production. This approach is especially useful for running scenarios based on water use and crop mix adaptations and already incorporates the climate scenarios developed by PCIC. It may also be possible to use AWD models with estimates of the increased value from irrigation to measure the economic impact of increased irrigation or water storage for irrigation as adaptations to climate change. [27]

AWD models have not been completed for all regions of B.C., so the analysis would be restricted to specific regions, some of which are smaller than the regions for which the CAI has completed climate change risk and opportunity assessments. The AWD model requires intensive surveying of agricultural land use, which is the major delay in completing all regions of B.C. and also results in data that is somewhat dated for regions completed earlier (e.g. the Okanagan). This model is useful for running scenarios in which adaptations are (or are not) implemented; however climate stressor scenarios such as droughts or increased precipitation would require new climate projections to be developed by PCIC. The feasibility of developing these climate stressor scenarios has not yet been explored. Finally, although this approach generates dollar figures for the cost of climate change and the benefits of adaptation, it neglects the economic incentives by excluding an economic model. It is an integrated model (see Figure 3), but it does not model producer profitability and the forces that might induce an

[24] http://epicapex.tamu.edu/epic/
[25] Discussion with Tom Goddard at Alberta Agriculture and Rural Development
[26] A cadastre includes details of ownership, tenure, location, dimensions (and area), crop cultivations, and the value of individual parcels of land.
[27] Samarawickrema (2008), Faux (1999)

investment in adaptation; nor does it model how water availability would affect the structure of the agricultural sector.

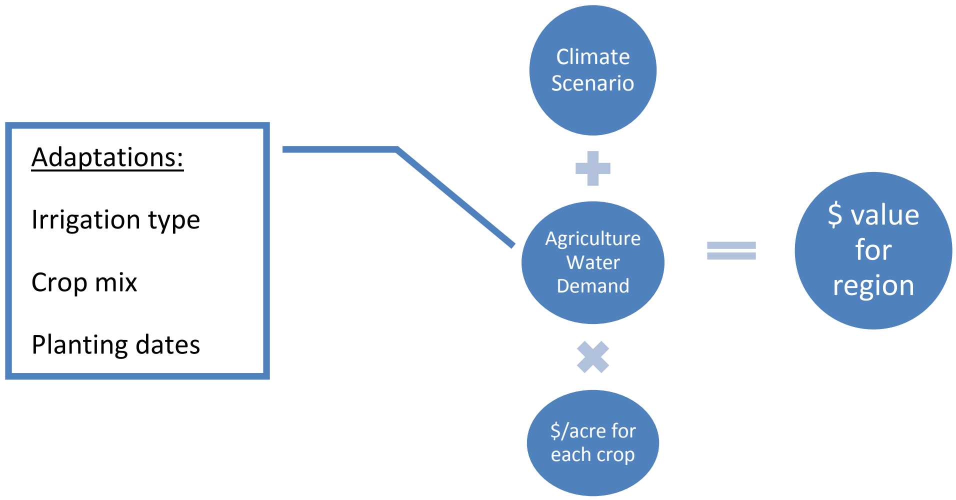


Figure 3. Integrated Modelling System (AWD and B.C. production insurance data)

d) Econometric Crop Simulation

Econometric crop simulation models are calibrated using historical data on climate, soil profile, management practices and other explanatory variables to estimate the relationships between these independent variables and production output. In practice, crop yields are regressed as a function of historical climate, soil profile, economic and region specific variables to determine parameter values. These parameters are used to estimate future crop yields using climate projections. As with the Ricardian technique, similar hard adaptations must have occurred in the past in order to estimate their impacts in the future. Soft adaptations, cannot be incorporated because they are specifically designed to alter the relationships (change parameters) between inputs and outputs, which must remain fixed in the simulation. It is also common to estimate the rate of technology or adaptation adoption by farmers, which must be based on survey results.[28]

Econometric analysis of crop yields has so far only been used to look at past relationships between yield and climate variables; however, Sun (2013) suggests that it could be used for climate change modelling. This technique inherently overstates longer-term potential impacts of adaptation projects because costs or damages in the case "without adaptation project" are overestimated due to the exclusion of autonomous adaptations. The econometric regression can incorporate spatial climate data; however, the scale of the climate scenario has a significant impact on the economic impacts measured. Smaller scale climate data consistently results in less favourable economic implications for agriculture, in that the parameter values for unfavourable weather have larger impacts on production.[29] In other words, when the climate projections are focused on a smaller region, more hot days or different precipitation patterns have a larger negative effect on agricultural production.

[28] World Bank (2010)
[29] Adams (2003)

e) Adaptation Gap Analysis: Cost of Adaptation

Adaptation gap analysis calculates the increase in costs for an existing project if it were redesigned to consider climate change adaptations.[30] The adaptation gap is the additional amount that an existing project would cost in order to be upgraded to include climate adaptation measures. This method is used for existing capital projects being evaluated for their climate change suitability. It is useful to derive a cost of adaptation but gives no insight into the benefits of adaptation or the costs of climate change.

[30] World Bank (2010)

5. Climate Stressor Scenarios

<u>Section Overview</u>

- As part of an integrated and forward looking analysis, scenario development can help determine the impacts of climate change through a series of “what if” stories
- Three examples of scenarios are given to show how these can be useful for climate change adaptation as both qualitative and quantitative exercises

In contrast to climate change scenarios with and without adaptation, which quantify the costs of climate change and isolate the impact of adaptation on the agriculture economy of the future, climate stressor scenarios model a specific impact of climate change. Climate stressors such as sea level rise, more frequent floods, and droughts are often cited as consequences of climate change. However a great deal of uncertainty surrounds the extent, timing, and location of these climate stressors. In order to plan for these hazards without exact data on frequency or magnitude, climate stressor scenarios are built using reasonable assumptions.

a) <u>Coastal Flooding in Australia</u>

The CSIRO estimated the impacts of coastal flooding in Australia using current dollars and assumptions about future population and number of buildings at risk. [31] Three scenarios are defined based on changes to planning and building regulations and the defence of existing homes and buildings. The first scenario holds regulations fixed so that the *proportion* of people and buildings at risk is the same but applied to a larger population, while the second scenario allows for no further risky developments. The third scenario holds the *number* of people and buildings at risk fixed (a smaller proportion of the future population).[32] This type of approximation may be useful for very rough estimates of the impact of climate change in agriculture: estimates of the proportion of producers at risk from climate change in a given region could be used along with an assumption of how this proportion would change with various adaptation measures.

b) <u>Flooding in the Fraser Valley, B.C.</u>

A similar analysis has been applied to flooding scenarios in the Fraser Delta region of British Columbia. [33] Sea-level rise due to climate change exacerbates the flooding risks faced by this major agricultural production region. The report quantifies the economic costs of a major flooding event in Delta, Surrey and Richmond, B.C. The authors defined the perimeters and weather events that would cause major flooding in the region using “vulnerable areas” identified from previous flooding studies and municipal plans and the corresponding types of floods (dike breach, seepage, freshet melt) that would inundate these areas. Ministry of Agriculture land use inventories informed the type of agricultural activity and the proportion of total provincial production that occupy each vulnerable area.

[31] Wang (2010)
[32] Wang (2010)
[33] Robbins, M and Tatebe, K (2014)

The purpose of this assessment is to highlight the general economic risk of failing to adapt to climate change because all of the vulnerable areas could not be flooded with a single flooding event.

Case studies based on past flooding events were the primary evaluation technique to determine the economics losses associated with major flooding induced by climate change. Farm-gate receipts are pro-rated to the vulnerable areas to estimate lost revenues. Agricultural impacts depended on: the amount of agricultural activity in the vulnerable area, the timing of the flooding event, the salinity of the flood waters and the rate at which it could be removed from the land. Economic costs associated with each scenario are calculated based on total economic impact, additional farmer costs and total farmer costs. The total economic impact is lost farm gate receipts plus secondary impacts (estimated as exactly the amount of lost farm receipts) which makes total economic loss two times the lost farm gate receipts. Additional farmer costs, which seeks to quantify lost capital investments, is equal to damage to buildings and equipment plus lost livestock feed and replanting costs. Total farmer costs are additional farmer costs plus lost farm gate receipts.

This approach can estimate the costs of climate change on agriculture, but the inclusion of adaptation is somewhat limited. Some adaptation measures are assumed, such as raising the dikes above the current height standard of 3.56 metres. Other adaptations, such as on farm drainage, are discussed as ways to mitigate agricultural losses without quantifying the impact this would have on economic losses. Other drawbacks include the fact that the study does not specify a time frame, other than the length of the flooding events, and uses fixed dollar assumptions of building and replanting costs. As a result, the study illustrates the costs of flooding due to climate change at some unspecified point in the near future.

c) <u>Climate Change in Alberta</u>

The consulting group Scenarios to Strategy used a seven step planning process to build planning scenarios for natural disasters in Alberta:[34]

1) Clarifying the focus of the scenarios (choosing the focal question)
2) Examining past changes to identify ongoing trends and forces
3) Identifying future changes and underlying forces
4) Identifying the key uncertainties which could lead to distinctly different futures
5) Creating a logical framework based on the uncertainties
6) Fleshing out the major characteristics and developing coherent stories for each scenario
7) Identifying implications for the organization from the scenarios

This framework was used in a workshop setting to develop a scenario related to climate change and to identify priority actions that could have prevented the adverse outcomes illustrated. The activity was qualitative in nature, and used to spark collaborative discussion. However, the scenario planning process and resulting products draw upon past experiences and present conditions. This allows for the development of more quantitative scenarios where data exists.

[34] Brummell and MacGillivray (2007)

6. Insurance Analysis

Section Overview

- Several forces influence the impact of climate change on agriculture insurance programs
- Critical threshold analysis is a means to determine the future cost of insurance programs in light of climate change
- Probabilistic methods can help measure how risks for agriculture will change due to climate change and help programs adapt to new climate change risks
- More detailed research should be pursued in this topic area

Crop insurance, or production insurance, is both an adaptation and a program at risk under climate change.[35] The availability and type of crop insurance can have significant impacts on land use allocations by agricultural producers, which could both support adapting to new crops or incentivize producers to grow crops that are no longer viable by shielding producers from climate change impacts.[36] In other words, easy access to insurance can make agriculture more vulnerable to climate change by reducing the incentives for adaptation. Agriculture income stabilization programs could undermine climate change adaptation[37] by reducing the incentives to diversify crop types or locations through program disqualification. On the other hand, access to insurance can allow farmers to quickly adapt to new climate realities by providing liquidity.

The production risks of new and potentially better adapted crops will need to be evaluated and incorporated into the existing insurance programs. Several studies have examined the impact of different insurance schemes on producer crop choices. [38] Although insurance may decrease climate change vulnerability by increasing a producer's ability to adapt, it may inadvertently create a moral hazard whereby the producer increases his or her exposure to physical hazards[39]. The substitution between self-insurance (adaptation) and buying insurance could also reduce the base for loss sharing and increase actuarial risk through adverse selection: producers who are better able to take adaptive actions might disproportionately opt out of buying insurance.[40]

The increased prevalence of extreme weather events, such as drought and floods, anticipated under climate change projections, places new pressure on the provincial Production Insurance and AgriStability programs. This section explores methods best suited to analyze the effects of crop insurance on agricultural adaptation and the effects of extreme weather on agricultural insurance programs.

[35] Adaptive Design and Assessment Policy Tool (ADAPTool): Government of British Columbia Agriculture
[36] Adaptive Design and Assessment Policy Tool (ADAPTool): Government of British Columbia Agriculture
[37] Bourque et al (2007)
[38] Boere & Van Kooten (2014 in Print), Turvey (2012)
[39] Mcleman &Smit (2006)
[40] Adaptive Design and Assessment Policy Tool (ADAPTool): Government of British Columbia Agriculture

a) Critical Threshold Analysis

In order to determine if there will be a greater number of insurance claims in the future, this method seeks to determine what critical weather event thresholds have previously triggered large numbers of insurance claims.[41] The relationship between weather (measured by indexes or monthly totals) and insurance claims is used to determine when weather thresholds trigger high average numbers of insurance claims. This information is then combined with regional climate scenarios to determine how much more often weather will surpass these thresholds. The frequency of increased claims is then combined with the associated payouts to determine the higher cost to the insurer under the climate scenario. This method is still subject to the uncertainties associated with downscaled climate data and requires data on monthly insurance payouts by region.

b) Probabilistic Methods and Extreme Weather Events

Most climate change models predict not only changes in the means of climate variables but also that the frequency of extreme weather events will increase. Coupled with this, we know that uncertainties surrounding possible events are a key determinant of people's behaviour. We should therefore expect that climate change uncertainties will also be a key determinant of their adaptation behaviour.

Choosing the key weather hazards of concern and then modelling the future probability of these hazards is a difficult process. In probabilistic models, the relationship between the defined hazard (i.e. intensity or rainfall, river height, number of floods exceeding a certain height) and the probability of a hazard occurring are captured in a probability density function (pdf) with the hazard intensity measured on the x axis and the probability of occurrence measured on the y axis.

In the science of modelling natural catastrophe probabilities the relationship between probability of a hazard and the intensity are measured with an *exceedance curve*.[42] The estimation of the exceedance curve allows for the probabilistic estimation of monetary loses due to natural disasters. Sometimes these curves are presented with frequency on the vertical axis and intensity on the horizontal axis (see Figure 4).[43] To determine the exeedence curve, a researcher requires information about the frequency, the intensity and the resulting economic impacts of extreme weather events. Estimating probability distributions can be difficult for high-intensity, low frequency events. Although it is very difficult to determine how exactly future climate scenario will alter the distribution, appropriate assumptions can be made.

[41] Cheng C.S. (2012)
[42] World Bank (2010)
[43] http://understandinguncertainty.org/node/622

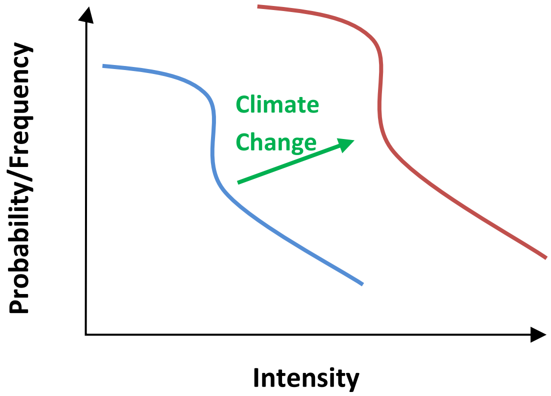


Figure 4. Effect of climate change on the intensity-probability function (Adapted from World Bank 2010)

Previous applications of probabilistic methods have been in weather simulators which use Monte-Carlo simulations to generate daily weather variables.[44] Downscaled climate models now include daily temperature and precipitation data which could allow for new applications of probability distribution. Although it has yet to be attempted, an econometric crop simulation which uses distributions of daily temperatures could be used to estimate production outcomes for a representative farmer. This could be useful for insurance analysis because it would allow different coverage options to be tested against these simulated outcomes to determine expected insurance liabilities under climate change.

The insurance choices of three representative farmer types in Saskatchewan were modelled by Kimura et al (2012). The authors simulated future yields using four climate change and adaptation scenarios as well as the farmer's endogenous choice among four risk reduction strategies (individual yield insurance, area yield insurance, weather indexed insurance and ex-post government payments). High risk farmer's increased their purchases of weather indexed insurance but yield area insurance had the largest increase in demand with marginal climate change. Area yield insurance also enhanced diversification strategies. The paper goes on to quantify the budgetary costs of the various insurance options and the uncertainty surrounding future climate scenarios and farmer's adaptation choices. The paper uses advanced modelling techniques and regional yield data from Saskatchewan from 2003-2008 for wheat, barley and canola[45]. Some results are difficult to interpret for the purpose being investigated here. For example, welfare gains are measured in dollars per acre and are not aggregate to show total gains for various policies. Although very thorough and precise, the paper requires lots of data and modelling expertise and does not report the results of interest to this project.

[44] World Bank (2008)
[45] Kimura et al (2012)

7. Traditional Project Evaluation Techniques

Section Overview

- This section summarizes well known and commonly used economic analysis techniques: Cost Benefit Analysis, Cost Effectiveness Analysis, Multi-Criteria Analysis, and Multiple Accounts Analysis
- The usefulness of each technique and its drawbacks for this particular research question are highlighted

c) Cost Benefit Analysis (CBA)

CBA is best suited to hard adaptation projects where investment amounts and resulting benefit streams are easily monetized. Investment amounts are measured and discounted according to when the cost is incurred. Similarly, income or benefit flows are estimated and discounted. This method requires a tangible investment in climate adaptation, such as a dike or a seawall, and is best suited for specific infrastructure projects. In the case of soft adaptations, such as access to information or research into new crop varieties, a CBA would require assumptions to be made about the timing of these adaptations.

The nine steps for a CBA are: [46]

1. **Define the relevant group**: for example: region, commodity, representative farmer or aggregate farm revenue
2. **Select the portfolio of project options and define project timelines (implementation dates, time horizon)**; for example, adaptation measures such as
    a. Water management (regional or on farm)
    b. Crop insurance or weather derivatives
    c. Adopting/developing new crop varieties
3. **Catalogue potential impacts and select management indicators**:
    a. Increased water availability on crop yields
    b. Effect of insurance on total farm income
    c. Effect of new varieties on crop yields
4. **Predict quantitative impacts over project life**: economic model of relationship between impacts and indicators, based on historical relationship and reasonable assumptions
5. **Monetize all impacts**: convert crop yields into revenue, aggregate farm income to regional or provincial level
6. **Calculate Net Present Value, Internal Rate of Return, Payout Time, Benefit Cost Ratio**: choose a social discount rate that is appropriate for climate change and adaptation analysis
7. **Indentify distribution of costs and benefits**: Who bears adaptation costs? Who receives benefits? Are there externalities?

[46] Adapted from Peter Kennedy's (University of Victoria) Cost Benefit Analysis course notes

8. **Perform sensitivity analysis**: make changes to reasonable assumptions to determine how sensitive the results are to small changes. This is particularly important for all parameters whose future values are uncertain.
9. **Make a recommendation**

d) Cost Effectiveness Analysis (CEA)

A CEA determines how an objective can be achieved in the most cost-efficient way.[47] It is often used when it is difficult (or impossible) to assign monetary value to benefits (for example: the value of human life).[48]Benefits are still quantified although not as monetary values. The output of a CEA is the ratio of discounted costs to benefits (Cost-Benefit Ratio, or CBR). The lowest CBR indicates the lowest cost per unit of benefit. If there are multiple types of benefits from an adaptation project, a CEA requires that all benefits must be measured in the same units.[47]

e) Multi-Criteria Analysis (MCA)

Unlike a strictly economic CBA, MCA includes an economic analysis component but also evaluates projects based on qualitative assessment of cost-effectiveness, co-benefits, required resources and ease of implementation. This allows projects to be ranked and prioritized based on a broader set of factors. MCAs are most commonly used when benefits cannot be measured quantitatively or when multiple benefits cannot be aggregated.[49]

MCA has been used by CAI to assess the climate adaptation potential of several on-farm practices.[50] Instead of ranking the various practices, the MCA is used to improve understanding of how each practice relates to climate change adaptation. Selected based on producer surveys, the evaluation criteria are: effectiveness, economic efficiency, flexibility, adaptability and institutional compatibility.

f) Multiple Accounts Analysis (MAA)

MAA is a system to document the important implications of a project or program. In complex situations, it is not possible to “add everything up to one number”. As an alternative, implications of different options or scenarios are organized in specified “accounts” such as financial performance, environmental implications, and economic development impacts. The process involves three main steps: 1) identification of evaluation accounts, 2) documentation and assessment of implications in each account, and 3) presentation and documentation of results.[51]

[47] Noleppa (2013), UNFCCC (2011)
[48] Golder Associates (2014)
[49] Golder Associates (2014)
[50] CAI B.C. Farm Practices and Climate Change Adaptation Series (2013)
[51] Craig et al (1993)

Clear guidelines have been developed for the use of MAA in Socio-Economic and Environmental Assessments (SEEA) done for the Government of B.C. Economic development goals are quantified through input/output models or other techniques which show direct, indirect and induced impacts on employment and GDP but are limited by time specific economic multipliers. Net economic value is measured with a CBA to derive the change in economic activity net of project externalities. Fiscal impacts are also quantified through changes in government revenue and expenditures, and assessments of social implications, aboriginal implications and environmental impacts are blended with these economic dimensions to generate a comprehensive MAA.[52] The MAA presents the various implications for decision makers, who apply their own weighting to the importance of the different accounts.

g) Existing Resources for Project Analysis

The German Society for International Co-operation (GIZ) developed a CBA Template which is an Excel document designed to sum and discount streams of costs and benefits for three separate adaptation projects. This may be useful if combined with an integrated modelling system using baseline (without adaptation) economic outcomes as costs and with adaptation scenarios as associated benefits. Initially designed for adaptation projects with explicit costs and measurable benefits overtime, it may be challenging to apply the template to soft adaptations.

[52] SEEA Guidelines (2007)

8. Conclusions and Recommendations

The analysis techniques presented in this document are evaluated in Table 1 (below). Modelling techniques that have not been previously published or attempted (such as an insurance analysis using an econometric crop simulation) have been excluded from this evaluation when they could not be discussed in adequate detail. The project proponents are seeking to quantify the economic impact of climate change adaptation, so all models presented below are quantitative. Economic decision making components, such as PE or GE models, allow individuals or markets to respond to incentives and can allow for autonomous adaptation responses. The literature is quite new on how to quantify the impacts of adaptation, so not all economic analysis techniques can easily incorporate this addition. Hydrology was chosen as an evaluation criterion because water stress was identified as a concern in all of the CAI regional risk and opportunity assessments. If a modelling technique uses downscaled climate data as a direct input, it is easier to quantify the uncertainty because the climate scenarios include measures of uncertainty, and it provides better estimates of the impacts of climate change. Finally, although agricultural insurance program analysis is intended to be included in this project, this was not a common research question in the literature and most techniques have not attempted to incorporate this addition. However, it is possible to incorporate insurance impacts in the very flexible IMS analysis technique.

Table 1. Summary of Methodological Characteristics

	Characteristics						
Methodology	**Quantitative**	**Economic Decision-Making**	**Climate Change Impacts**	**Adaptation Impacts**	**Hydrology**	**Climate Models**	**Insurance Payouts**
Ricardian Analysis	yes	yes	yes	difficult	possible	yes	no
Econometric Crop simulation	yes	no	yes	difficult	possible	yes	possible
IMS: physical crop simulation & economic model	yes	yes	yes	yes	possible	yes	possible
Climate Stressor Scenario	yes	no	yes	possible	no	no	possible
Critical Threshold Analysis	yes	no	yes	no	possible	yes	yes

Ricardian or hedonic price analysis captures autonomous adaptations. It does not provide a good framework to evaluate planned adaptation or the impact of knowledge generating programs designed to encourage autonomous adaptation. Further research could be done by developing the necessary data which pairs detailed land use with land values. Preliminary attempts have been made using B.C. assessment data and Land Use Inventories compiled by the Ministry of Agriculture. Several issues emerge when combining these complex data sets, so a focused research project would be necessary.

Econometric crop simulation requires detailed yield data for regions in which historical and projected climate data can be paired. This technique cannot be applied in the current project because annual yield data for sub-regions of the province has not been found.

An integrated modelling system in which climate, water, agricultural and economic models are linked allows for the greatest amount of flexibility and specificity in modelling climate change adaptation economics. Most major modelling exercises using downscaled climate data use the integrated modelling approach. However, these models have only just begun to incorporate adaptation in the analysis[53].

Scenario analysis is the easiest to implement and has other benefits when undertaken as a group exercise. The integrated and forward looking nature of scenario analysis opens up discussions about key assumptions and uncertainties and allows decision-makers to consider the impacts of several different visions of the future. Given the time and capacity constraints during the delivery of this project, scenario analysis with a workshop of agricultural, climate and adaptation experts has been chosen to illustrate the impacts of climate change on the B.C. agriculture economy.

The insurance programs are more sensitive to extreme weather events, and as such cannot be modelled with basic mean and variance forecasts. A probabilistic approach may better illustrate the financial impacts of weather variability on producer choices and government programs. The critical threshold analysis uses available downscaled climate data and historical regional averages. However, a long enough time series of total claims and values for specific regions of B.C. is not available from the agricultural insurance programs to match with monthly climate data. Data on the month in which a claim was activated would also improve the feasibility of this technique.

Finally, many of the adaptation projects currently supported by the B.C. Ministry of Agriculture, through GF2 and the CAI, strengthen the productive capacity of farmers through innovation and stronger communication networks. These productivity improvements have benefits beyond their impacts in promoting climate change adaptation. Productivity growth increases long run economic growth and standards of living. The causalities between information, networks and productivity growth are complex and have their own separate literature. The benefits of these types of adaptation projects may be better demonstrated through a qualitative discussion of the research surrounding productivity and innovation as key drivers of long run growth in B.C.

[53] Gordon et al (2014) , and work underway at AAFC Agri-Environmental Policy Research

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Appendix 1: B.C. Agriculture and Food Climate Action Initiative

In 2008, the B.C. Agriculture Council and the Investment Agriculture Foundation set up the B.C. Agriculture and Food Climate Action Initiative. The Initiative has been led by an advisory committee of agricultural producers, food processors and representatives from various government agencies. The Initiative assists the agriculture sector with addressing the challenges, and acting on the opportunities associated with climate change.

In the spring of 2012, the Initiative completed a climate change risk and opportunity assessment series for the B.C. agriculture sector (*Adaptation Risk & Opportunity Assessment* report series). Based on the findings of the assessments, the Initiative developed regional agricultural adaptation strategies with local partners in the Peace, the Cowichan Valley, Delta and Cariboo. The Initiative also completed a series of reports on six farm-level adaptation practices.

Approximately $5.7 million in adaptation programming funded through Growing Forward 2 from 2014 to 2018 is planned to be delivered by CAI, B.C. Agriculture Council and the Investment Agriculture Foundation. Three more regional adaptation strategies will be developed and implemented, and farm-level adaptation will be advanced through pilot and demonstration projects.

Home: http://www.bcagclimateaction.ca

Risk and Opportunity Assessments (2012)
The assessments gathered perspectives from agricultural producers about their ability to adapt to current and projected challenges and opportunities, and to identify approaches, tools and resources required to better support adaptation.
http://www.bcagclimateaction.ca/regional/overview/risks-opportunities

Regional Adaptation Strategies (2013)
The risk and opportunity assessments made clear that the ability of agricultural producers to adapt to changes in climate is linked to physical resources and decision-making processes that are beyond the individual farm (e.g. water management, emergency planning, land use practices, economic development, and regional infrastructure). The regional adaptation strategies identify actions and projects that will help to strengthen the agriculture sector’s capacity to adapt and integrate agriculture’s climate change issues into local processes, planning and decisions.
http://www.bcagclimateaction.ca/regional/overview/adaptation-strategies

Farm Adaptation Practices (2013)
This project involved research and engagement with producers across the province about current and innovative farm practices with the intent of evaluating how these practices may support adaptation for climate change. A multi-criteria analysis was used to evaluate the farm practices, to help identify factors involved in farm management decision-making. Reports were done for on water storage, drainage, shelterbelts, nutrient management, management intensive grazing, and conservation tillage.
http://www.bcagclimateaction.ca/farm-level/farm-practices