DESIGNING AN INTEGRATED APPROACH FOR EVALUATING ADAPTATION OPTIONS TO REDUCE CLIMATE CHANGE VULNERABILITY IN THE GEORGIA BASIN

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Final Report

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Table of Contents

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1. Introduction

This research project is funded by the Climate Change Action Fund and has been coordinated by Adaptation and Impacts Research Group (AIRG)/Environment Canada, and Sustainable Development Research Institute (SDRI), University of British Columbia (UBC). The Principal Investigator (PI) is Dr. Yongyuan Yin. The project seeks to provide a better scientific understanding of the vulnerabilities of human and ecological systems to climate change, and thus provide a sound scientific basis for decision making on climate change adaptation.

One challenging issue in climate change impacts and adaptation options research is to design and apply integrated approaches to estimate likely future economic, social, and other human vulnerabilities to (and impacts of) climate change, and to identify desirable adaptation measures or options which could be used to reduce those vulnerabilities. Given the great uncertainties associated with climate change, it is difficult to be certain which adaptation options are the correct ones to pursue. Research on developing well-designed adaptation strategies will provide the information and understanding necessary for identifying more effective adaptation options and better management plans for ensuring the sustainability of our life-support-system. A concrete approach to compare and evaluate options is important because it will provide policy-makers with insight into the kinds of trade-offs stakeholders are willing to make in efforts to pursue adaptations for reducing climate change vulnerability.

In this respect, the purpose of this study is to design and apply an integrated assessment (IA) approach in the Georgia Basin (GB). The IA approach possesses the following characteristics which are fundamental for regional IA approaches: a) it involves multiple stakeholders, b) it is systematic and holistic, c) it accounts for multiple objectives and sectors, d) it is able to identify trade-offs easily, and e) it serves to link climate change and regional sustainable development. The focus has been to link climate change with coast regional sustainability, and to examine and report on alternative adaptation options for alleviating the adverse consequences of climate change in the region. Many different computer-based methods including simulation modeling, geographical information system (GIS), internet survey, and multi-criteria decision making (MCDM), were used to the formation of the integrated approach.

The project's geographic focus is the Georgia Basin: the Lower Fraser Basin and eastern Vancouver Island in British Columbia. It is the centrepiece of several international case studies in which SDRI has been closely involved to explore the prospects for sustainability in rapidly urbanizing regions. Georgia Basin's climate is an invaluable asset that makes its high quality of life possible. From the world's best ski resort in Whistler to the rich agricultural lands of the Fraser Valley, the Basin's natural and managed ecosystems are highly sensitive to temperature and precipitation. With various ecological systems, urban infrastructure, lower levels of coastal areas, and an energy and natural resources based economy, the region may experience impacts of climate change on food production, fisheries, energy, water resources, and human health. Moreover, the region's adaptive capacity has not been examined systematically. The region is facing substantial challenges including rapidly growing population, increasing demands for food, land, energy and water, and deteriorating fish and forest resources.

Since its starting in July 2000, the research project has been examining the extent to which particular sectors in the Georgia Basin have been vulnerable to climate variations and change, the potential environmental and socio-economic impacts of climate variations and change, and adaptation options desirable to deal with climate vulnerabilities. In particular, the study has accomplished the follows:

- The project has successfully developed an integrated assessment (IA) approach to identify the societal vulnerabilities to climate scenarios. The approach as we have applied it, integrates climate change impact assessment, vulnerability identification, adaptation option evaluation, multi-criteria decision-making, and multi-stakeholder participation.
- The IA has identified various regional vulnerabilities to climate change, key information gaps and research needs to answer questions related to climate change issues.
- The IA approach was applied in the Georgia Basin to evaluate a number of adaptation options that could be undertaken to reduce vulnerabilities associated with climate change in the coastal region and communities of the GB.
- The research effort has included a series of workshops and internet based surveys with participation by a broad range of public and private stakeholders, to identify sustainability indicator priorities, as well as a series of desirable adaptation policies. The IA framework facilitated the participation of regional stakeholders in climate change impact and adaptation option evaluation.
- The study has improved our understanding of the interactions between regional sustainability and climate change impacts.
- The findings of the project have suggested desirable and practical adaptation options and/or plans to effectively handle climate change impacts and to ensure sustainable development.
- When conducting the research, two graduate students and a visiting scientist from China got train to design and apply IA methods in a real world context. and
- The product of the research project is this final report submitted to the CCAF Office. Additional efforts are undergoing to publish peer reviewed journal articles to provide scientific information to other parts of the world.

Major findings of the project are summarized as follows:

In Georgia Basin, the limited energy and natural resources have to provide a number of competing users with a range of different and often conflicting functions to meet their demands. While the demands for energy and natural resources increase dramatically as population and economic grow, the availability and the inherent functions of energy and natural resources are being reduced by climate variation and change, environmental pollution, salinization, rapid urban expansion, and ecological degradation. Unsustainable resource uses have created a sharp decline in natural resource availability and increase in energy and resource use conflicts.

Under climate change conditions, extreme whether events are likely to become more frequent and severe. Sea level rise (SLR) and associated storm surges can have a number of negative impacts on coastal ecosystems, commerce, industry and transportation infrastructure, human settlements, tourism, and cultural systems. Climate change may cause negative impacts on human health. Air pollution in the Georgia Basin is expected to increase due to climate change, which may cause health effect and increase hospitalizations or mortality rates. Heat stress will also affect human comfort levels and health.

The impacts of climate change on fish species and the fishing industry in the Georgia Basin are confounded by natural variations in ocean temperatures, large-scale atmospheric circulation, food availability, as well as the effects of fishing and fisheries management. Most forested ecosystems including those in coastal British Columbia will tend to shift northward and upward. Trees and forest ecosystems may face an increased risk of disturbance under climate scenarios. These include trees being broken or uprooted by extreme storm events, forest damage by increasing the occurrence of debris avalanches, pests outbreaks, and forest fires. Moreover, increased winter precipitation with a warmer temperature will fall mostly as rain rather than snow. Thus, less snow accumulation in ski resorts will affect winter sport activities.

In response to potential impacts of climate change, scientists in Canada have begun identifying, assessing, and in some cases evaluating measures to adapt to climate change. Western Canada is not all well adapted to climate and there is abundant evidence in terms of the crop and livestock losses from climate variations and extreme weather events. Many areas of the region are experiencing energy price increases and economic losses associated with weather related natural hazards.

We need the development and application of integrated assessment methods to deal with issues related to climate change vulnerabilities, adaptation, and sustainable development. However, lack of knowledge in the region may become barriers to conducting integrated studies. The CCAF funded project enabled the region improving science capacity and assessment tools and information aimed at the most vulnerable sectors. The study focused assessment of climate change impacts on a range of economic sectors and ecological systems sensitive to climate. These include agriculture, coastal zones, fisheries, forests, water resources, energy, and human health.

The focus of the research activities has been to examine and report upon alternative adaptation options for alleviating the adverse consequences of climate change in Georgia Basin. The adaptation option evaluation is linked to regional sustainability indicators. Different computer-based methods were adopted to form the integrated approach. These include environmental simulation modeling, geographical information system (GIS), multi-stakeholder consultation, internet survey, and multi-criteria decision making (MCDM). Alternative adaptation options to deal with various vulnerabilities were evaluated against sustainability indicators. The study results provide a prioritized ranking indicating the overall preference for each of the adaptation options in several key economic sectors of the study region.

2. Developing the Integrated Approach – Methodology

The IA approach is built on many years of research experience of the PI in integrated climate change impact and adaptation studies in the Mackenzie River Basin, and Great Lakes Basin in Canada, and the Yangtze Delta in China (Yin and Cohen, 1994; Yin et al., 1999a; Yin et al., 1999b; Yin et al., 2000). Figure 1 describes the main components of the research approach.

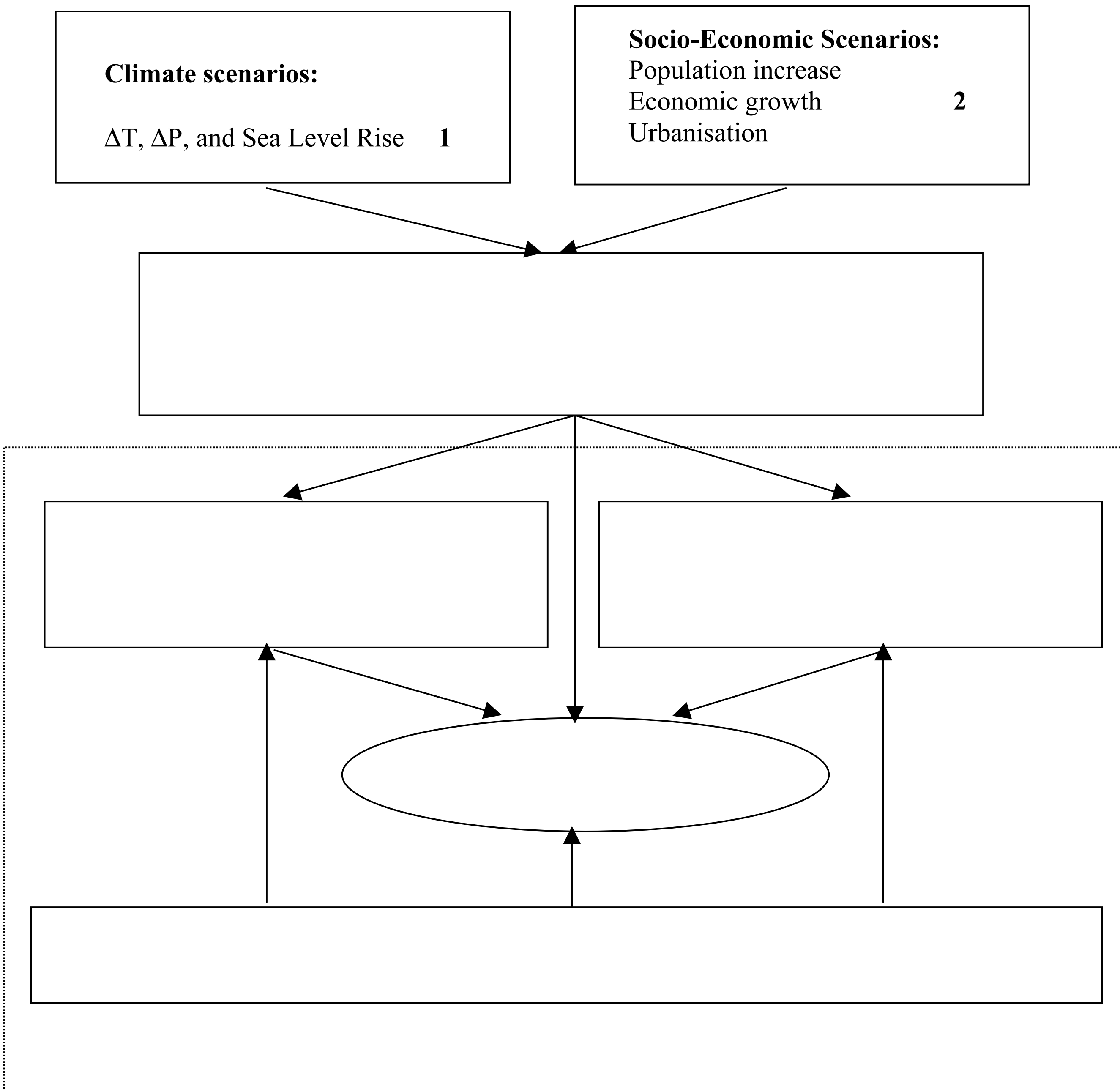


Figure 1. The research framework

2.1 Specifying Climate Change and Socio-economic Scenarios (Steps 1&2)

In conducting a climate change impact assessment and adaptation option evaluation study, climate scenarios need to be specified to examine their economic, social, and environmental impacts. General circulation model (GCM) outputs and historical information can be used to design scenarios representing different climate change conditions. Sea level rise scenarios can also be specified. The climate scenarios applied in this study were selected in a manner that is consistent with the national sets of scenarios that are being produced by the Canadian Climate Impacts Scenarios facility (Barrow, 2000). Socio-economic scenarios used for this study have been developed by the Georgia Basin Future Project (GBFP) undertaken by the SDRI/UBC.

2.2 Identifying Vulnerabilities to Climate Change (Step 3)

Data required for the identification of vulnerabilities to the climate scenarios were derived from several different sources including the following: existing data from previous studies on climate change impacts, government documents, consultant reports, and scientific literature. In areas where the social, economic, and environmental impacts are not well known, additional expert consultation and computer modelling efforts were employed to fill some of the data gaps for those key sectors that are sensitive to climate change. Computer techniques such as simulation models and geographical information system (GIS) were used to provide additional information on the first and higher order impacts (both positive and negative) of climate change. For example, the low-lying areas of the GB are susceptible to accelerated sea level rise (SLR) resulting from climate change, and GIS was used to identify ecosystems, coastal infrastructure, and regional communities that were vulnerable to climate change impacts from SLR.

2.3 Applying a Multi-criteria Adaptation Measures Evaluation System (Step 4)

This part of the project involves the development of a methodology for multi-criteria adaptation option evaluation coupled with multi-stakeholder consultation in the Georgia Basin. It consists of the following:

Identification and Initial Screening of Potential Adaptation Options

Numerous potential adaptation options have been available for dealing with vulnerabilities to climate change. Using sources including existing literature and expert consultation, a set of possible options can be identified for each sector. To facilitate evaluation of the options in later steps of the study, it is desirable to have between 6 and 10 options in each sector. If required, an initial screening process should be performed to narrow down the list of potential options. Preferred adaptation options considered in this study were general, policy-based options that could be implemented by government policy-makers in efforts to minimize climate change impacts and reduce vulnerability of the key sectors in the region.

Sustainability Goals or Criteria Setting

The research procedure continues with an identification of sustainability goals. In this approach, the goals are evaluation criteria or standards by which effects of climate change or/and the effectiveness of alternative adaptation options can be measured. Given limited time for this research, only three broad goals (of the environmental, economic, and social dimensions of regional sustainable development) were identified as evaluation criteria.

Multi-Stakeholder Consultation and Multi-Criteria Evaluation of Adaptation Options

Multi-criteria options evaluation (MCOE) of adaptation measures is a major component of the study. It is used to identify desirable adaptation options that decision makers can use to alleviate the negative consequences and to take advantage of positive impacts associated with climate change in the Basin.

To select desirable measures among alternatives, multi-stakeholder consultation (MSC) and MCOE can be employed to relate impact information to decision-making requiring subjective judgment and interpretation. In this study, alternative options were evaluated by relating their various impacts to the three broad sustainability goals. These goals were used as multi-criteria by which the strengths and weaknesses of the various adaptation options could be evaluated. The analytic hierarchy process (AHP) is a multi-criteria decision making (MCDM) technique that can be adopted as an adaptation evaluation tool to identify the priorities of sustainability goals/indicators (Yin and Cohen, 1994), and to rank the desirability of options.

AHP was developed by Saaty (1980), and can be used to compare and evaluate options in an orderly and systematic manner. It is useful when the problem can be broken down into hierarchical levels. The process involves asking stakeholders to compare alternatives on each level in a pair-wise manner (two at a time) to determine their relative preference or relative importance of each alternative. In this study, a stakeholder could therefore specify the relative importance of the three broad sustainability goals with respect to their individual importance in reducing climate change vulnerability in the GB, and could then compare specific adaptation options according to their relative effectiveness at achieving each goal.

The end result of the AHP is a prioritized ranking indicating the overall preference for each of the adaptation options. This technique was chosen because it could offer a multi-criteria evaluation system that was systematic and holistic, involved multiple stakeholders, and was easily able to identify trade-offs. In addition, it allows comparison based on both qualitative and quantitative information (many climate change impacts/vulnerabilities can only be described qualitatively at this point). Overall, the AHP method provides an effective means for synthetic evaluation of the general performance levels of alternative adaptation options based on a multitude of evaluation criteria (goals).

3. Applying the Integrated Approach in the Georgia Basin

Conceptual details of the integrated assessment approach were presented in the section above. The entire approach as described has not yet been applied in a climate change and coast regional sustainability context, and this study uses the Georgia Basin as a case study to apply the approach in a real world scenario. As mentioned previously, the focus of the study has been two-fold: to identify the implications of climate change for coast regional sustainability, and to examine and report on alternative adaptation options for reducing climate change vulnerability in the region.

3.1 The Georgia Basin Study Area

The project's geographic focus is the Canadian portion of the Georgia Basin, which encompasses the Lower Fraser Basin and southeastern Vancouver Island in British Columbia (see Figure 2). The basin includes the major cities of Vancouver and Victoria, and the region is rich in natural and human resources thus making it an attractive location for sustainability research. It is the centerpiece of several international case studies in which SDRI is closely involved to explore the prospects for sustainability in rapidly urbanizing regions.

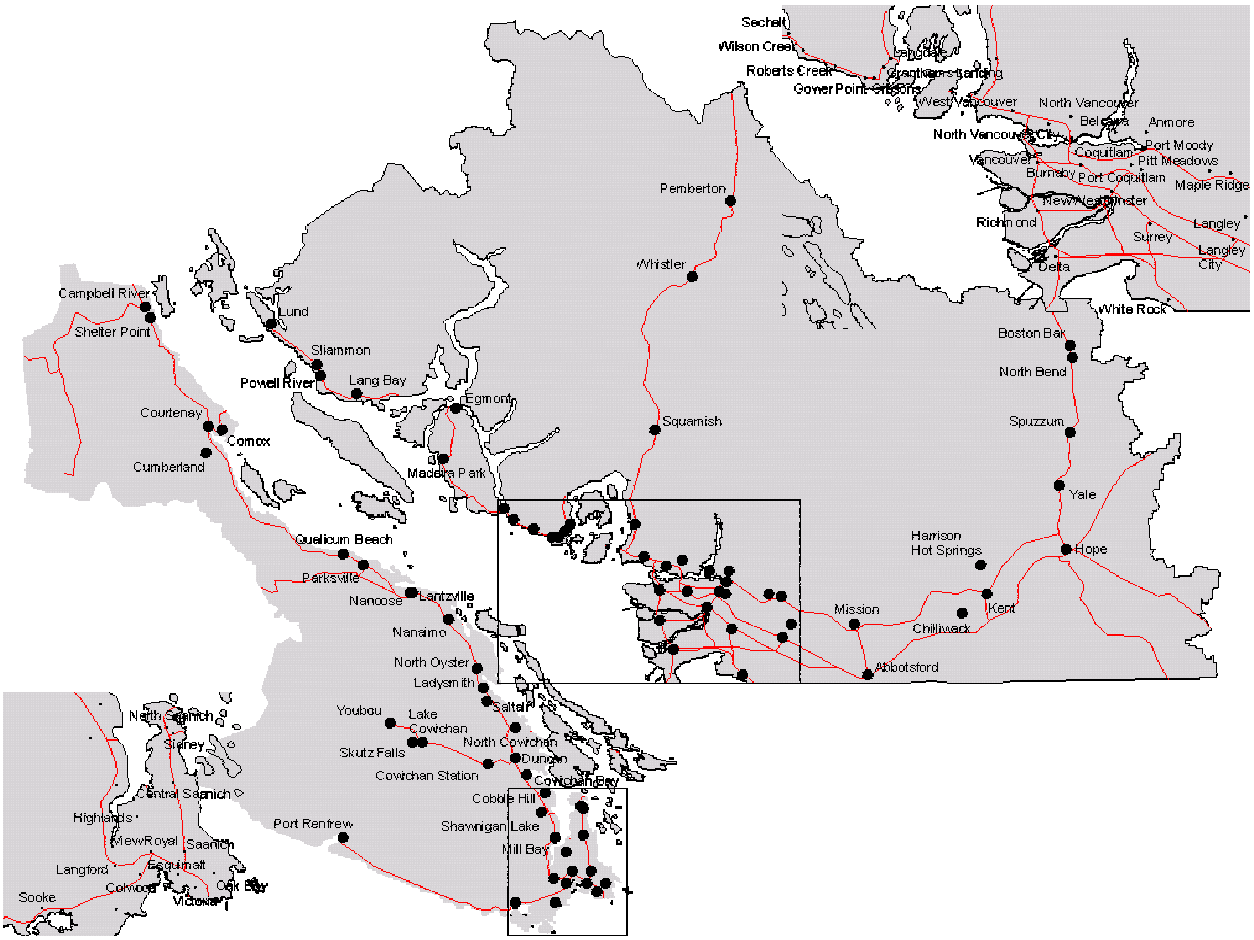


Figure 2. Map of the Georgia Basin

3.2 Specifying Climate scenarios

To facilitate coordination with other research activities involving the Georgia Basin at SDRI, a 40-year timeline was chosen for evaluation. The climate scenarios created by Canadian Climate Impacts Scenarios Project for this region over the 40-year timeline include warmer temperatures year-round, with wetter winters and drier summers (Barrow, 2000). The magnitude of the temperature increase was assumed to be between 1 and 5 degrees Celsius. Winter precipitation should be approximately 10% greater, and summer precipitation about 9% less than current averages.

3.3 Identifying Vulnerabilities to Climate Change and Potential Adaptation Options

Seven different sectors in the GB region were chosen for detailed examination in this study. They represent some of the key economic activities in the region, and are especially vulnerable to climate change impacts. These sectors include: Agriculture, Coastal Regions, Energy, Health, Fisheries, Forestry, and Water.

In most sectors, impact and vulnerability information was obtained using existing data from previous studies on climate change impacts. There were many cases, however, where data were not available for GB region specifically, and some key vulnerabilities were determined after consultation with experts knowledgeable about issues relevant to the GB. Some computer modelling and GIS technique were applied to calculate impacts in the Coastal Regions and Health sectors (see below for details).

The next section of this report is broken down into the seven sectors, and describes in detail the climate change impacts and vulnerabilities in each. As well, the final list of adaptation options is also presented for six of the seven sectors. Each list is the product of an initial screening process conducted with the help of other sustainability researchers at UBC, to reduce the number of options for further detailed evaluation. The group arrived at a collective recommendation of 7-9 adaptation options (in each sector) that were suitable for multi-stakeholder consultation and multi-criteria evaluation.

4. Agriculture

Agriculture is an important industry in the Georgia Basin, and in the Fraser Valley in particular. The flat and fertile lands of the Fraser Valley region (from Hope to Vancouver) are some of Canada's best agricultural soils, and this is the most concentrated farming region in the province (MAFF, 1998a). Relatively wet and mild climatic conditions in the region allow for the production of a wide variety of crops. Much of the land (over 60%) has been devoted to animal production and associated forage crops, although substantial areas are used to grow various types of small fruits (berries) and field vegetables. The selection of commodities produced in the Georgia Basin ranges from dairy products, poultry, eggs, and hogs, to berries, vegetables, floriculture, and nursery products (Zebarth et. al., 1997; MAFF, 1998b).

4.1 Potential Impacts and Vulnerabilities

The impacts of climate change on agriculture are not well studied in the Georgia Basin. For forage crops and horticultural production in the region, the overall trend of the climate scenario may prove to be largely beneficial.

Field Crops:

Increasing concentrations of CO_2 can be expected as the climate changes. Many individuals have studied the effects of increasing CO_2 concentrations in the lab and have found that CO_2 has a generally beneficial effect on the growth and productivity of C3 plants (which include most crops grown in the Fraser Valley). In addition, the gas has been shown to increase water use efficiency (Zebarth et. al., 1997; Shriner et al., 1998). The predicted temperature increase should also lead to a longer growing season, making warm season crops more suitable, and increasing the potential for double cropping where a market exists. In one experiment conducted by undergraduate students at the University of BC, the CEREZ-MAIZE model was used to estimate an overall increase in corn yield in the Fraser Valley (Ageson et. al., 1999). In addition, less frequent and severe winter outflow winds reduce the risk of injury to perennial crops, and drier summer conditions may be generally less favourable for fungal diseases (Zebarth et. al., 1997).

Despite these potentially positive impacts of the climate scenarios on crops, however, the agriculture sector remains vulnerable in certain areas. The key vulnerabilities are water-related, and arise from changes in the precipitation regime (drier summers and wetter winters). In general, warmer temperatures and drier conditions will lead to increased moisture deficits on non-irrigated land through the summer, and the ability to irrigate will depend on water supply. In low-lying areas of the Fraser River floodplain, there may be problems of flooding, soil compaction, soil drainage, salinization, and enhanced leaching of pesticides and nutrients. If the spring months are wetter, field access may be a significant limitation in areas where regional water management is not sufficient (Menes, 2001 personal communication; Kowalenko, 2001 personal communication). Another potentially negative impact arises from warmer winters that may be generally more favourable for pests (Zebarth et. al., 1997).

The agriculture sector is a fairly adaptable industry, and according to some researchers, small changes in average conditions are essentially irrelevant for agricultural producers because they are accustomed to dealing with much larger variations on a regular basis (Smit et. al., 2000). Conditions of concern to farmers are the extremes, and if the proposed climate scenario results in a change in the frequency and magnitude of extreme events, it may have substantial impacts on the agriculture sector. Floods, severe droughts, and heat waves increase the risk of reduced crop quality, and in severe cases, crop failure. This leads to income loss for farmers, volatility in the markets, an increased reliance on imports, and an increased reliance on government subsidy and relief programs.

Greenhouse Crops:

Greenhouse producers will be largely unaffected by climate change concerns because of their ability to manage for pests and artificially control climatic factors (temperature and the hydrological cycle). It is likely that these producers will experience decreased heating costs in the winter and increased cooling costs in the summer, perhaps leaving them somewhat vulnerable to energy prices and availability.

Livestock:

Livestock producers in the Georgia Basin will also be largely unaffected by the proposed climate scenarios. Animals will be subject to the direct effects of changing weather conditions, however, the temperature and precipitation changes should not be substantial enough to adversely affect the animal's health. If anything, the warmer temperatures will increase the length of the grazing season, allowing the possibility for more feed to be grown locally.

Overall, it is likely that this sector will be able to adapt to proposed small changes in average conditions. If anything, the much of the Georgia Basin region should experience higher yields and more diverse crops, and adverse effects in other areas of Canada and the world may actually increase the demand for agricultural products from the south coastal region of British Columbia.

4.2 Adaptation Options

The following list of adaptation options was developed to reduce the key climate change impacts and vulnerabilities listed above. These potential options were evaluated and compared by experts and stakeholders in the basin.

1. **Farm-Level Adjustments** - encourage farmers to exercise flexibility in their practices to spread risk and reduce negative impacts (e.g. installation of irrigation systems, diversifying and/or changing crop and variety choice, and adopting flexible crop rotation and planting schedules).
2. **Organic Methods** - encourage use of organic farming methods (to increase soil moisture retention and reduce the need for irrigation).
3. **Intensive Modern Methods** - encourage increased use of synthetic inputs such as chemical fertilizers and pesticides to enhance growth and combat pests.
4. **Efficient Irrigation Technologies** - invest in and develop more efficient irrigation technologies.
5. **Water Management Techniques** - invest in regional water management techniques/infrastructure (dikes, drainage and pumping systems) to minimize/remove excess water.
6. **Government Relief Programs** - enhance government relief programs (e.g. disaster assistance, subsidized crop insurance programs, etc.) to reflect the increased probability of extreme events.
7. **Research and Education** - encourage research initiatives related to the development of robust cultivars and practices; implement educational programs such as rural education programs to encourage sustainable land use practices.
8. **Greenhouse Agriculture** - encourage conversion from field to greenhouse agriculture to insulate from climate variability. (Note: farmers become vulnerable to energy availability and cost).
9. **Land Conversion** - allow development of vulnerable land for other purposes.

5. Coastal Regions

5.1 Coastal Region Vulnerability

In general, coastal regions tend to be densely populated, economically productive, and environmentally sensitive. This leaves them especially vulnerable to direct climate change impacts, as well as secondary impacts from both the upland and the marine side. The following discussion concentrates on the impacts of climate scenarios from the marine side, particularly sea level rise (SLR). It is important, however, to keep in mind that changes in weather patterns and upstream activities and development have direct effects on river flows and thus have impacts on the coastal zone.

The impacts of climate change on coastal regions have been broken down into shoreline effects and ecological effects (Beckmann et. al., 1997). Shoreline effects include inundation of low-lying areas, erosion and/or accretion on sedimentary coasts and beaches, and disturbance (including submergence and erosion) in deltas, estuaries, and estuarine wetlands. One concern with saltwater intrusion is related to impacts on overlying lands and wells as well as water extraction from coastal rivers and streams where extraction points will become at or beyond the saltwater front. There is also concern that pumping efforts to prevent saltwater intrusion will need to be increased or could fail. Ecological effects include impacts on human activities and developments, and changes in species biodiversity (with specific effects on wetland and intertidal plant and animal species/communities and sea and shore bird populations).

Shoreline effects depend on the vulnerability of the coast to sea level rise (SLR) and storm events. This vulnerability or sensitivity has been described as a function of numerous factors including relief, rock type, coastal landform, sea level tendency, shoreline displacement rate, mean tidal range, and mean annual maximum significant wave height (Shaw et. al. 1998a). The Geological Survey of Canada has produced a map of the sensitivity of the coastlines of Canada to an accelerated rise in sea level due to global warming which shows that most of the BC coastline has a low sensitivity (because of its mostly high, rocky, fjord and skerry coasts), with moderate sensitivity along parts of the Nanaimo lowland, and pockets of high sensitivity in the Fraser River delta area.

SLR can have a number of negative impacts on coastal ecosystems, commerce, industry and transportation infrastructure, human settlements, the property insurance industry, tourism, and cultural systems and values. Much of the Fraser River delta lies below 4 meters in elevation, and parts of it currently have elevations between 0.5 and 1.5 m below sea level (Clague et. al., 1991; Shaw et. al., 1998b). Extensive dyke systems are already in place to protect much of these lowlands from flooding, and the urban infrastructure and industrial activities of this area are already vulnerable during extreme events. They will almost certainly become even more so if the frequency of these events increases. The SLR analysis described below helps summarize some of the most highly vulnerable areas.

5.2 Sea Level Rise Impacts: A GIS Analysis

To further examine the effects of sea level rise in the Georgia Basin, and to quantify the impacts of sea level rise in the highly sensitive delta area, a simple GIS operation was performed. Sea level rise is a combination of eustatic, steric, isostatic readjustment, tectonic, and wind/current effects. The IPCC has predicted a global rise in sea level (due to eustatic and steric effects only) of 10.0 to 53.5 cm by the year 2040 (Carter and Hulme, 1999). There is still considerable debate over the rate of local isostatic readjustment in the Georgia Strait, with estimates ranging from none to 2 or 3 mm/year. Even with a readjustment rate of –2.5mm/year, sea level in the Georgia Basin can still be expected to rise anywhere from –2.5 to +41.0 cm by the year 2040. Wind, current, and tectonic effects in the Georgia Strait are not expected to be substantial, but may contribute up to 2 mm/year (Beckmann et. al., 1997). Storm surges (from intense, low pressure weather systems) ranging from 1 to1.5 m are also possible in the Georgia Strait, and magnify the impacts of sea level rise.

Using ArcView, a DEM (digital elevation model) of the Georgia Basin was used to isolate areas of the basin that lie below 1 meter in elevation. Although a sea level rise of this magnitude is highly unlikely to occur in the next 40 years, it offers a useful estimate of vulnerable areas in a worse-case scenario of sea level rise combined with high tides and a significant storm surge. In addition, it is entirely possible for a rise of this magnitude to occur over the next couple of centuries, and the long life span of many infrastructure/development projects requires developers to be aware of longer-term impacts as well. For more discussion on the effects of data uncertainty on a sea level rise analysis in the Greater Vancouver Regional District, see the executive summary contained in Appendix 1 at the back of this report.

Spatial Distribution of Impacts

Table 1 shows the area of each land use category in the GB that occupies land with an elevation of less than 1 m above the current sea level. Values are reported in hectares, and as a percentage of the total area in that particular land use category. Nearly all of these lands lie in the Fraser delta. Areas in the remainder of the basin are almost invisible on a basin-wide map, so an enlarged section of the Fraser River delta region is shown in Figure 3.

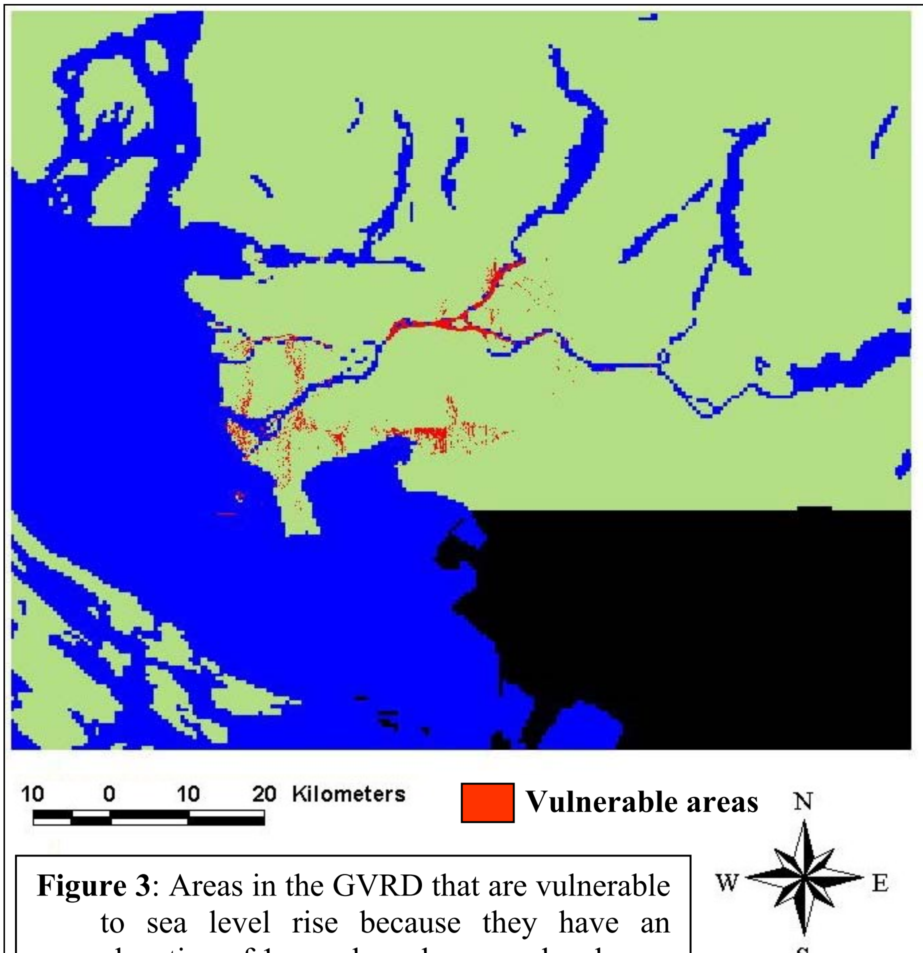


Figure 3: Areas in the GVRD that are vulnerable to sea level rise because they have an elevation of 1 m or less above sea level.

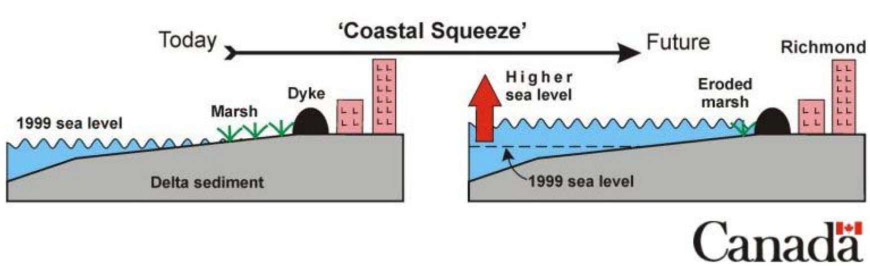
Table 1. Vulnerable areas in the Fraser River Delta, (by land use)

Land Use	Area (hectares)	Percentage of Total Area
Urban: Industrial	1550	9.21
Urban: Residential/Commercial	1125	1.56
Rural	3200	3.66
Protected Areas	850	0.13
Unprotected, Natural Area	18850	0.53
Agriculture	4675	2.38
TOTAL	**30250**	**0.66**

Environmental Impacts

Under a one-meter sea level rise, 850 hectares of protected areas and 18,850 hectares of unprotected natural areas are considered vulnerable to inundation unless they are protected by the dyke system. Much of this area is likely beach or estuarine wetland/marsh. If there is upland area for the wetlands to migrate, the effect of sea level rise will merely be a migration of the ecosystem. In many cases, however, developments and dykes will prevent wetland migration, and “coastal squeeze” will occur (See Figure 4 below). When they cannot migrate, coastal wetlands will be subjected to complete inundation and increased erosion. Freshwater delta estuarine wetlands will see a replacement of freshwater habitat with saltwater habitat, and the plant and animal species distributions will shift toward salt-tolerant ones. Overall, significant shrinkage of wetland area will likely be observed (Beckmann et. al., 1997).

Figure 4: Coastal Squeeze
[Source: GVRD Temperature Rising Website]



Areas of the Nanaimo lowland near Comox, B.C. (along the east coast of Vancouver Island) will also be increasingly subjected to flooding and/or inundation. Breaching, overwashing, and migration of spits will become increasingly common as the sea level rises (Shaw et. al., 1998a). Increases in organic material and sedimentation can be expected in the intertidal areas of the Fraser River delta as a result of increased precipitation in winter, and these will combine with rising seas, warmer coastal waters, and changes in upwelling patterns and sea level differentials to result in significant changes in marine and estuarine ecosystems.

Socio-economic Impacts

With a one-meter sea level rise, 4675 hectares of agricultural land will be below sea level and may become inundated if not protected. Salinization from periodic inundation of fields, or contamination of groundwater with salt water, can substantially reduce the productivity of these agricultural lands (Beckmann et. al., 1997). In addition, many areas of the Fraser Valley rely on groundwater supplies that may be subjected to saltwater intrusion from the rising water table (Beckmann et. al., 1997).

Considerable areas of urban land also face the risk of inundation, and will likely require protection (See Table 1 for a summary of areas). In addition, both light and heavy density industrial land are highly vulnerable, with 800 and 750 hectares (respectively) resting on elevations below the new sea level. BC Hydro has many major hydroelectric installations that are critical nodes in the power distribution system, which are dependent on protection by the current dyke system. Moreover, the electrical power for southern Vancouver Island crosses the delta plain will also be affected (Shaw et. al., 1998b). Groundwater areas in parts of Richmond will be brought to the surface and additional funds will need to be spent on pumping (Clague, 1989). In addition, developments at Goose Spit near Comox will be susceptible to more frequent flooding/inundation, posing safety concerns.

Much of the vulnerable low lying areas in the Fraser River floodplain and delta are currently protected from inundation and flooding and by an extensive system of dykes which has been designed to withstand a 1-in-200-year flood event (MELP, 2001). Many of the dykes in the Boundary Bay/Crescent Bay area are subject to problems with the current sea level, and building specifications do not take climate change considerations into account. In addition, it is likely that extreme flood events and storm surges will occur more often under the climate scenarios, increasing the possibility of breaching, and additional damage to the dykes (from surges, waves, and log debris) (Wodtke, 2001; personal communication.). Many of the dykes will need to be upgraded and/or extended to prevent damage to human activities and the built environment. Furthermore, the risk of dikes being over topped is compounded by the hazard of seismic activity that exists in the Georgia Basin.

5.3 Adaptation Options:

The following list of adaptation options was created to reduce the key climate change impacts and vulnerabilities listed above. These potential options were evaluated and compared by experts and stakeholders in the basin.

1. **Do Nothing –** do nothing in developed areas as the sea level rises; do not upgrade and/or maintain any existing dikes.

2. **Prevent Further Development** - through legislation and regulation, prohibit future development in sensitive areas; ensure new developments are set back from the shore and do not infringe on wetland's ability to retreat.
3. **Public Repurchase -** governments or organizations repurchase vulnerable land and structures.
4. **Rolling Easements** - incorporate rolling easements into the deeds of coastal property, converting land ownership to a temporary or conditional interest that expires when the sea inundates the property. Essentially, development has to make way for migrating ecosystems.
5. **Protect Development** - upgrade and/or maintain the current dike system, and expand to protect other vulnerable developed areas.
6. **Protect Ecosystems** - build protective barriers, breakwaters, etc. to protect natural ecosystems and wetlands.
7. **Research** - conduct further research (e.g. inventories, biological impact studies, etc.) to identify vulnerable natural areas suitable for preservation; continue to invest in sea level monitoring.

6. Energy

6.1 Impacts and Vulnerabilities

In general, the impacts of climate change on the energy sector of the Georgia Basin are not well studies. The impacts on energy use and energy production are expected to be greatest for the production of hydroelectricity, and some changes in demand for heating and cooling are also expected, due to warming temperatures.

Demand modelling for BCHydro, the Georgia Basin's primary electricity provider, is only projected on very short time-scales (week/month) and does therefore not include shifts in climate over the long term. Thus the expected decrease in demand for heating in winter months as well as the increase in demand for cooling in summer months can not be projected with any accuracy.

Use/Demand

Expected decrease in demand in winter months for heating
Expected increase in demand in summer months for cooling (How big? Unknown)
Transportation sector demand will increase based on population growth, which will drive energy prices and increase pollution.

Supply/Production

<u>Hydro</u>
- Under warmer temps, reduced snowpacks – lower reservoir levels, less hydro generation
- Under increased precip – additional hydro capacity – benefit in winter

<u>Wind</u>
- Less reliable wind energy production due to shifting wind directions

Natural Gas

- More exposed pipelines due to washout
- Increased smog

Solar

- Variable impacts depending on cloud conditions

Power Lines

- Vulnerable to sea level rise for lines reaching Vancouver Island

Socio-economic

Fluctuating prices (mostly increases, depending on NA markets) for consumers.

6.2 Adaptation Options

The following list of adaptation options was created to reduce the key climate change impacts and vulnerabilities listed above. These potential options were evaluated and compared by experts and stakeholders in the basin.

1. **Local energy sources** – increase locally generated energy to meet demand
2. **More fossil-fuel energy -** increase thermal or other fossil fuel-based generation to meet demand
3. **More alternative energy** – increase non-fossil fuel based (e.g. solar, wind, biomass, tidal) generation to meet demand.
4. **More hydro energy** – increase hydro-power generation to meet demand (i.e. build more dams)
5. **Island self-sufficiency** – encourage energy self-sufficiency for Vancouver Island .
6. **Conservation programs** – increase energy conservation education and incentives for energy end-users.
7. **Monitor and forecast -** Integrate climate change monitoring and forecasting into planning and operations.
8. **Rely on market** – rely more heavily on import/export of energy and take advantage of market prices (e.g. selling rather than storing seasonal surpluses).

7. Impacts on Human Health

Increased air pollution, heat stress, and the spread of disease are the expected impacts on human health due to climate change in North America. The degree to which these impacts will be felt in the Georgia Basin is dependent upon regional synoptic weather conditions, the increase of pollutants due to population and industry growth, and conditions that promote the spread of disease and its vectors. In general, the Georgia Basin will suffer relatively minor impacts in air pollution and heat stress (Thomson, 1997). No regional-based studies have been done on vector-borne diseases.

While air pollution in the Georgia Basin is expected to increase due to climate change, the effects on health, hospitalizations or mortality, have not been quantified. The effects do appear to be less severe than in other non-coastal Canadian cities. In summer, air pollution and ground level ozone in particular is expected to increase due to a combination of increased traffic and increased air temperatures (Thomson, 1997). In winter, increased precipitation is expected to enhance deposition of airborne particles, and warmer temperatures may mean less winter fuel usage and therefore less pollution (Thomson, 1997).

To examine the impacts of temperature change on the air quality in the Lower Fraser Valley (LFV), three simulations were performed to test the effects of increased temperature on ozone levels in the LFV. The concentration of ozone was used as a surrogate for deteriorated air quality in general and no attempt was made to model particulates or other regulated species. The simulations were performed on a day conducive to deteriorated air quality and hence are an attempt to quantify climate change impacts on air quality episodes. The simulations included a baseline run, a run with a 2 °C temperature rise and a 5 °C temperature rise (Figure 5). The two runs with increased temperature differed from the baseline runs only in the prescribed hourly temperature. For simplicity, the temperature rise was assumed to be a constant value for each hour of the simulation.

The simulations where performed using the OZIPR (Gery and Grouse, 1989) model. This is a box model with a comprehensive chemical mechanism. The model allows for time varying meteorological conditions (mixing height, temperature, etc.) and time varying emissions for a parcel of air following a fixed trajectory. The meteorology, chemical mechanism, emission and trajectory used in the simulations were based on work by the National Research Council (NRC). Specifically, the meteorology was based on simulations by the NRC of a summer ozone episode in the LFV (Hedley and Singleton, 1997; Hedley et al., 1997). The chemical mechanism was modified by the NRC to match the LFV emission profiles (Jiang et al., 1996). An episode specific emission inventory was prepared for the simulations (MacLaren et al., 1996). The trajectory for the box model simulations was identical to the one outlined by Jiang et al. (1996). It was chosen so that the parcel of air passed over the Vancouver downtown core during the morning rush hour before continuing on a generally easterly trajectory.

Since the simulations were intended as a rough measure of climate change impacts on the air quality in the region, no effort was made to quantify the effects of the increased daytime temperature on the mixed layer depth or parcel trajectory. In addition, no changes were made to the emissions inventory or the chemical mechanism. It is believed that these factors are controlled by a variety of processes and the neglect of temperature effects should not significantly alter the general simulation trends.

Heat stress is not likely to have any significant impact in the Georgia Basin. At present, there is no significant relationship between heat and mortality in Vancouver. A study done in Seattle, however, suggests that stressful weather (consecutive hot days) has a greater impact on acute mortality than high pollution concentrations (Kalkstein, 1993). Climate models indicate that Victoria will go from having 3 days per year recording a temperature over 30^{o}C to 13 under a 2xCO_2 scenario (Last et. al., 1998) (please see Figure 6).

Figure 5. Maximum Ozone Concentrations versus Time for 3 Different Temperature Scenarios

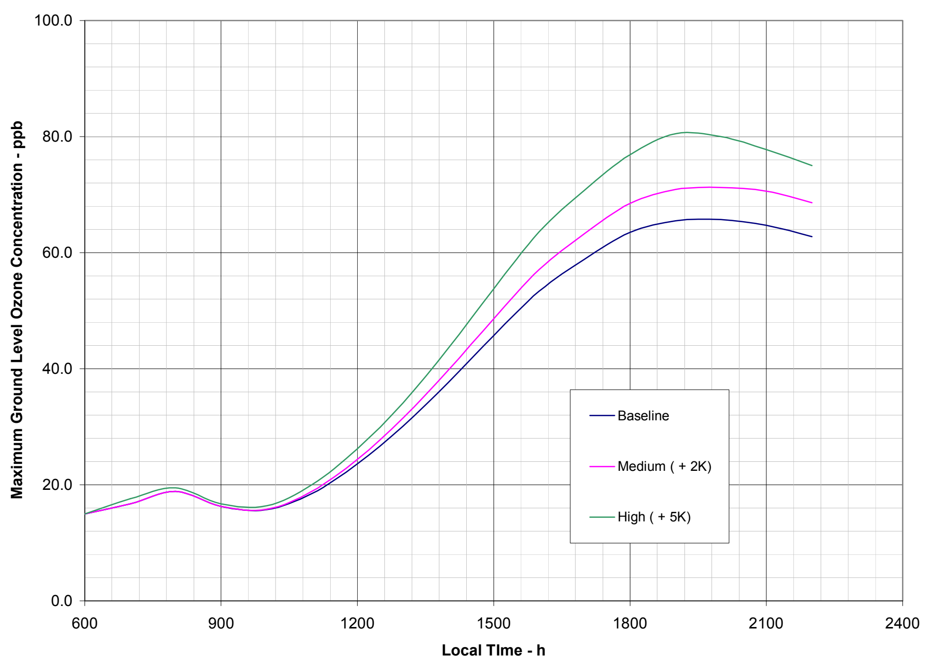
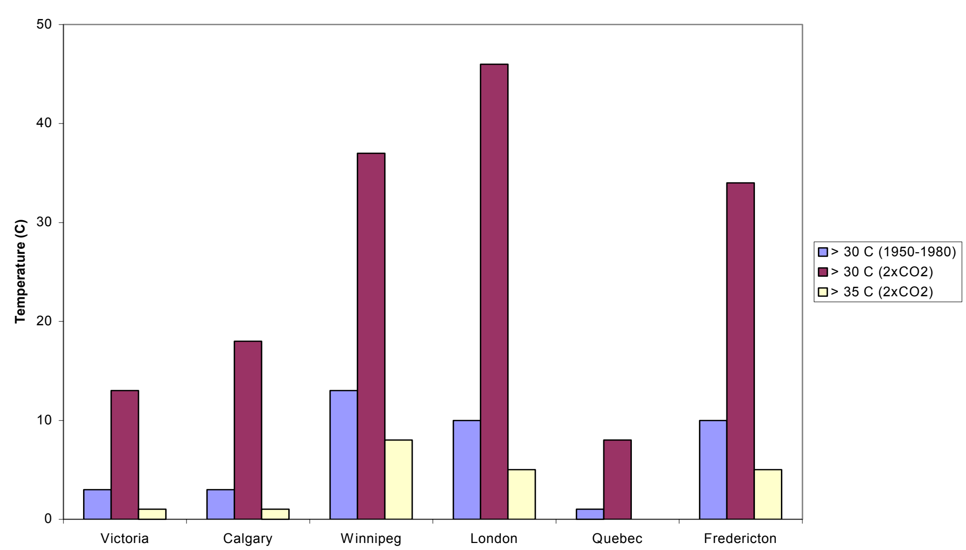


Figure 6. Number of days above 30 C in Canadian cities: current and under 2xCO2 scenarios



Due to the expected minimal impact of climate change on human health in the Georgia Basin, adaptation options were not examined in this study.

8. Fisheries

8.1 Environmental Impacts

The impacts of climate change on fish species and the fishing industry in the Georgia Basin are confounded by natural variations in ocean temperatures, large-scale atmospheric circulation, food availability, as well as the effects of fishing and fisheries management. While increasing ocean temperatures are known to have an impact on the physiology and behaviour of fish, there are also carrying capacities of aquatic ecosystems and species interrelationships to consider. Ocean temperatures off the coast of British Columbia are expected to rise by approximately 1-2^{o}C in the next 50 years, combined with a possible reduction in winds and a resultant decrease in coastal upwelling of nutrients (Beamish et al, 1997). Modelers can use the temperature information to model the thermal limits of a certain species of fish, but must speculate what additional co-limitations are experienced by the fish due to natural fluctuations and fishing effects. Evaluating changes in freshwater streamflow and temperature is also a critical part of understanding the impacts to Georgia Basin fisheries, particularly for the Fraser River. A study on the upper thermal limits and ocean migration of sockeye salmon showed that under a 2xCO_2 scenario, the area of acceptable thermal habitat in the North Pacific is predicted to decrease to zero in summer and decline sharply (to the Bering Strait) in winter (Welch and Ishida, 1998)

The impact on most of the commercially valuable species of fish in the Georgia Basin is summarized in Table 2.

8.2 Socioeconomic Impacts

While no published studies on the anticipated economic losses to the fishing industry in the Georgia Basin exists, unpublished estimates range from over half a billion for the species-specific fishing industry, to over 1 billion for the sport fishing industry. Unemployment in the commercial fishery, decreased revenue for the sport fishing industry, and less supply and choice, and an increase in prices for certain species for the consumer are all potential socio-economic impacts that may result from climate change and a decrease in the number and diversity of fish in the Georgia Basin.

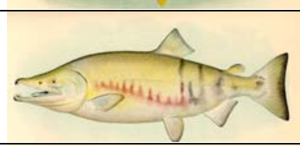
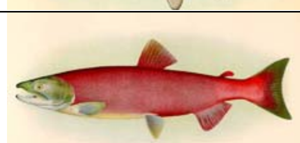
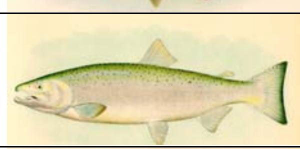
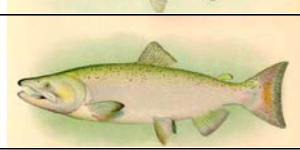
8.3 Adaptation Options

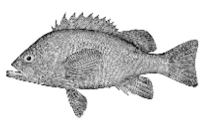
The following list of adaptation options was developed to reduce the key climate change impacts listed above. These potential options were evaluated and compared by experts and stakeholders in the basin.

1. **Monitoring & assessment** – increase research and monitoring of fish species to identify and assess those "at-risk".
2. **Increase aquaculture** – expand the aquaculture/fish farming industry while implementing fish health protection regulations.

3. **Sustained harvest reductions** – reduce the number of fish being harvested for at-risk species on a permanent or semi-permanent basis.
4. **Habitat protection & conservation –** expand in-river programs, reduce physical barriers to migration/spawning, reduce pollution, etc.
5. **Negotiate** - Integrate climate change impacts into international treaties (i.e. Pacific Salmon Treaty).
6. **Inter-regional communications** – spread knowledge about fisheries and fish species from historical fishing regions (and associated fisheries) to future fishing regions where fish migrate in response to thermal and/or habitat limitations.
7. **Community programs** – increase programs in fisheries-based communities to restructure the economy and ownership of resource-based assets.
8. **Do Nothing –** maintain status quo with respect to fisheries management.

Table 2. Impacts of climate change on various species of fish

Fish Species		**Impact**	**Specific Climate Change Impacts**
Pink **Salmon**		✘	Decreased Fraser River stocks, but stocks in the north not seriously affected. Natural fluctuations may predominate.
Chum **Salmon**		✘	Declining productivity due to changes in productivity/temp. of Strait of Georgia.
Sockeye **Salmon**		✘	Most affected of Pac. Salmon. Decreased stocks. Large areas of the N. Pacific would be unable to support growth.
Coho **Salmon**		=	Follow fluctuations in abundance similar to last 20 years.
Chinook **Salmon**		✘	Large and abrupt fluctuations, near 1980s levels. Changes in % of life history types surviving to spawn.
Steelhead		=	Possible reduce abundance – not severe. Under 2xCO_2 scenario, would move north due to thermal limitations.

Pacific **Herring**		=	No significant change
Pacific **Halibut**		✘=	Larval and juvenile fish affected.
Sablefish		=	Mature fish not affected in 50 years
Pacific **Cod**		✘	Reduced abundance – may no longer be commercially fished
Lingcod		=	No significant change
Pacific **Hake**		✓	No change, possible increase
Sole		=	Distributional shifts may occur, with some increase in abundance, and some decrease.
Rockfish		=	Distributional shifts may occur.

Source of data: (Beamish et al., 1997); Source of images: http://www.fishbase.org

9. Forestry

9.1 Impacts and Vulnerabilities

In general, the impacts of climate change on forests and the forest industry are not well studied in the Georgia Basin. Most forested ecosystems including those in coastal British Columbia will experience a northward and upslope migration of tree and forest types under a warming climate. It is possible that some forests, especially those at upper elevations, will see increased productivity due to warmer temperatures and the CO_2 fertilization effect. Laboratory studies have shown that increased CO_2 concentrations enhance photosynthesis and improve water use efficiency (Spittlehouse, 1999). Some species that grow only at high elevations currently (i.e. Yellow Cedar (Cypress)), however, may be lost completely if the climate continues to warm.

Moisture conditions play a primary role in determining distribution and productivity of tree species in British Columbia. In the Georgia Basin, warmer and drier summers will be more stressful and may affect the growth of many tree species such as Douglas-fir and Western Red Cedar. The BC Ministry of Forests has used the Table Interpolation Program for Stand Yield (TIPSY) to show that there is a relationship between summer water availability and economic return of Douglas-fir forests.[1] Ignoring compensating factors, a 10 – 20% decrease in summer water availability will adversely affect the growth and yield of these forests, and their economic value may decrease by up to $1150 - $2250/ha. It is important to keep in mind that this estimate is a worst-cast scenario that ignores compensating factors (such as warmer temperatures, CO_2 fertilization), and Spittlehouse (1999) notes that this scenario is highly unlikely. Soil moisture deficits will likely have the largest effect on seedling growth and survival.

In the Georgia Basin, the proposed climate scenario should result in a climate that is still within the range hospitable to most of the tree species. In this area of western North America, under a $2xCO_2$ climate scenario, plant distribution models predict very little change in spatial distribution of most dominant tree species (Sitka Spruce, Western Red Cedar, and Western Hemlock). Forest retreat and the disappearance of some Douglas-fir ecosystems may be observed in regions of already warm and dry climate such as the southeastern portion of Vancouver Island (Hebda, 1995; Thompson et. al., 1998). In some areas of North America, a warmer climate may affect the ability of Coastal Western Hemlock and Coastal Douglas-fir forests to meet their winter chilling requirements, however, this is unlikely to be a major concern as far north as the Georgia Basin (Spittlehouse, 1996).

Trees and forest ecosystems may face an increased risk of disturbance as a result of projected changes in climate. Scientists and meteorologists are expecting that the frequency and intensity of storm events could increase thereby increasing the potential that more trees could be broken or uprooted by the wind. Greater precipitation over the winter months may also damage forest species by increasing the occurrence of high flows and debris avalanches. Warmer conditions are perceived to be generally more favourable for pests and more stressful for trees, thus placing forest ecosystems at a greater risk of damage from insects. In addition, warmer

[1] The TIPSY model uses growth and yield information generated by the Tree And Stand Simulator (TASS), a biologically-oriented and spatially explicit individual tree model that produces potential growth and yield tables for even-aged stands. It is a component of a larger system that evaluates the effects of Silviculture Treatments on Yield, Lumber Value, and Economic Return (SYLVER) (Spittlehouse, 1999). Please see Spittlehouse (1999) for a more detailed explanation of the models and results.

temperatures year-round will almost certainly lead to a longer fire season and an increase in the frequency and intensity of forest fires (Spittlehouse, 1999).

The forests in the Georgia Basin are already managed for loss of timber. In many cases, the impact of climate change will merely be a greater economic cost to society as management activities must become more extensive. For example, a longer fire season and an increase in forest fire frequency will require fire crews and equipment to be active more often (Spittlehouse, 2001 personal communication). For forest companies, more precipitation in the winter months will also affect factors such as runoff, erosion, and sedimentation, and will likely increase the maintenance cost for roads. Given the budgetary constraints of governments and other stakeholders, trade-offs will need to be made between different management strategies. The climate change adaptation options in this sector reflect this situation, rather than trying to mitigate possible impacts and vulnerabilities that are not well known or studied in this region.

9.2 Adaptation Options

The following list of adaptation options was created to address forest management concerns associated with the impacts and vulnerabilities listed above. These potential options were evaluated and compared by experts and stakeholders in the basin.

1. **Maintain Healthy Forests** – promote climate change awareness, and improve overall forest management strategies to maintain healthy forests under changing climate conditions (control vegetation that competes for soil moisture; fertilize and/or irrigate to improve seedling survival)
2. **Fire Protection** - invest heavily in fire protection programs (high quality forest fire monitoring and attack capabilities, fuel management techniques and prescribed fire)
3. **Pest & Disease Protection** – improve disease detection and response rate, and improve integrated pest management
4. **Site-level Adjustments** – modify harvesting and site prep. practices and scheduling to protect site productivity, minimize erosion, etc.; adjust planting and regeneration activities to reflect climate changes (plant drought-resistant stock/species; select species appropriate to both present and likely future conditions; consider multi-species mixes)
5. **Accelerate R&D** – develop drought-resistant stocks and stocks that utilize CO2 enrichment, to increase adaptive capability
6. **Manage Ecological Landscapes** – manage landscapes to protect biodiversity and allow them to evolve naturally (leave migration corridors and reserve areas)
7. **No Change** – maintain current forest management policies/practices

10. Water

10.1 Impacts and Vulnerabilities

The projected impacts on water use and quality in the Georgia Basin is based on a scenario of warmer winter and summer temperatures, with increased precipitation in winter, and decreased precipitation in summer. This would mean that in general, fresh water quantity would not likely be a problem in winter, spring and early summer, but may pose a problem in late summer and early fall (Hii, 1997). Increased precipitation may also mean problems with drainage in urban areas, although the intensity and frequency of future precipitation events under climate change are not known. A study done in the Greater Vancouver Regional District (GVRD) indicates an increasing trend in high-intensity events, which may be related to large-scale circulation patterns (heat island effect is negligible) (Dunkley, 2000).

The supply of drinking water for the GVRD is vulnerable to both increasing temperatures and decreased snow-pack. A modelling scenario using present values for water demand indicated that a noticeable impact on water supply would be felt in the region by 2050 (Taylor and Langlois, 2000). This model did not take future demand due to increasing temperatures, autumn rain variability or increasing populations into account, all of which add to the water supply vulnerability. The modelling scenario output has been used, however, to shape the long-term (100 year) plan for water management in the GVRD. Vulnerability to water pollution will likely be managed with more chlorination, should bacteria density increase in summer waters of the Capilano, Seymour or Coquitlam reservoirs.

Stormwater infrastructure is significantly vulnerable in the GVRD because of potential increased runoff and high intensity rainfall events. The time scale for changes to stormwater management is based on the lifecycle of the drainage infrastructure, and is therefore vulnerable to changes in runoff that occur before the infrastructure can be altered. Therefore there is potential for increased flooding of roads and buildings if changes in climate occur more rapidly than stormwater management infrastructure can be changed.

Water quality and quantity issues in other areas such as the Capital Regional District (CRD) and the Abbotsford aquifer are influenced by other factors than those in the GVRD. The CRD reservoirs are fed by rainwater only and are not reliant on snow-pack. Therefore, an increased vulnerability of drinking water supply to climate change is a valid concern. For the Abbotsford aquifer, reduced groundwater recharge may impact late summer and early fall water quantities, while demand rises due to increases in population and higher temperatures. While the supply is not expected to diminish completely, the larger problem resulting from lower water levels is the increase in pollutant concentrations from agricultural runoff because of less dilution (Hii, 1997).

The socio-economic impacts of climate change on water supply and quality will likely include increased health problems associated with decreased water quality. Economically, water prices are expected to increase, and competing demands for water (fisheries, electrical production) may be affected by the increased demand for water as a source for drinking water.

10.2 Adaptation Options

The following list of adaptation options was created to reduce the key climate change impacts and vulnerabilities listed above. These potential options were evaluated and compared by experts and stakeholders in the basin.

1. **Increase storage** – increase the number of local or regional water storage reservoirs to offset summer losses.
2. **Water quality monitoring** – increase the level of water quality monitoring for urban reservoirs and rural wells and aquifers.
3. **Improve drainage infrastructure** – improve urban drainage infrastructure to accommodate increase in precipitation.
4. **Demand management** – increase conservation awareness, encourage water saving technologies and practices for the end-user
5. **Restrict water export** – reduce vulnerability by restricting the export of water via interbasin transfers.
6. **Reduce system losses** – reduce losses in urban pipe and storage systems, as well as in rural areas (including unintended losses from irrigation)
7. **Usage fees** – implement a system-wide water metering program.
8. **Reduce water pollution** – place restrictions on industrial and agricultural practices that contribute to water pollution in water storage reservoirs.
9. **Encourage research** – encourage research to improve operations in weather forecasting, warnings, and controlling reservoir releases.

12. Application of the Multi-criteria Adaptation Measures Evaluation System

12.1 The AHP Method and the Internet Adaptation Option Survey

The next stage of the project is to involve multiple stakeholders in a multi-criteria evaluation of adaptation options. One of the major components of this project was the design and creation of an internet website on the World Wide Web (WWW). Summaries of the climate change impacts were coded into HTML and presented on the web, and a series of online surveys were created to involve experts and stakeholders in the evaluation. Having a copy of the survey available online enabled it to be quickly and easily distributed (electronically via email) to a wide range of individuals, and it presented a convenient way for stakeholders to respond to the survey questions on their own time. Readers are invited to visit the website at URL address: http://www.sdri.ubc.ca/aos to find more detailed information about the survey. The website also provides information about the AHP method and the computer software. A paper copy of the survey was also created so it could be administered in one-on-one interviews and in small group/workshop settings.

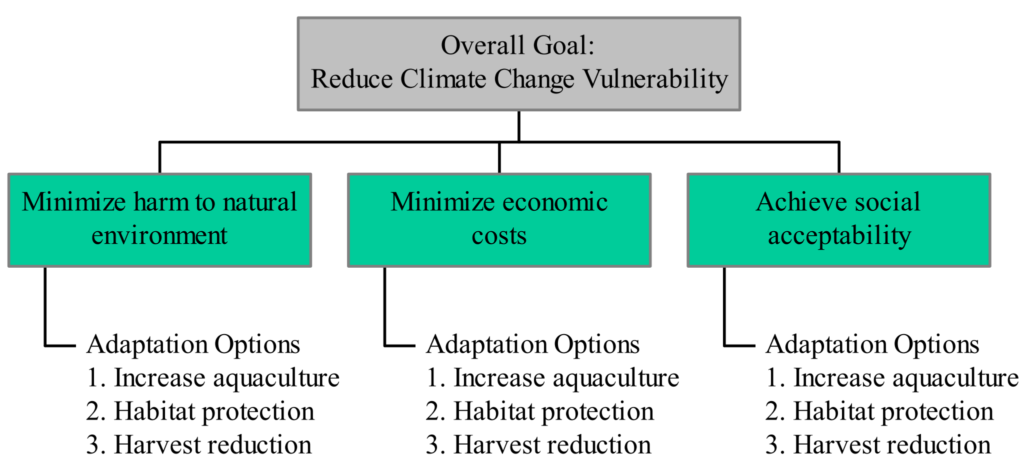
The multi-criteria adaptation measures evaluation system outlined above involves use of AHP to conduct a multi-criteria evaluation. The Expert Choice (EC) 2000 software package was used to facilitate the application of AHP in this study. Survey questions were designed according to the principles of AHP so that the responses could be input into the software program for compilation and analysis. EC is able to synthesize or combine the priorities for each part of a problem (in this case, the relative importance of three goals) to determine overall priorities and ranks for the alternatives (adaptation options). Conducting a *Distributive Synthesis* provides an overall score for each alternative option by distributing the importance of the goals among the adaptation options, thereby dividing each goal's priority into proportions relative to the percentage of alternative. In addition, EC provides measure of the logical inconsistency of a respondent's judgments with an inconsistency ratio, and it can also be used for sensitivity analysis.

In order to conduct a multi-criteria AHP evaluation, it is first necessary to specify certain criteria (or goals) against which the relative effectiveness of the adaptation options can be judged. In this study, the overall goal is to reduce climate change vulnerability in the GB within the context of achieving coast regional sustainability. Three broad sustainability goals were therefore chosen to act as criteria in the AHP evaluation: one goal to represent each of the three core components of sustainability. They include:

1. Minimize harm to the natural environment
2. Minimize economic costs to society
3. Achieve social acceptability

With these three goals, and a set of adaptation options to compare, a decision hierarchy model was created for each sector. Figure 7 shows an example decision hierarchy for the fisheries sector. This decision hierarchy is quite simple because it includes a single overall goal, with two levels below it in the hierarchy: a set of criteria/goals (green boxes), and a list of alternative adaptation options (only the lowest level of the hierarchy differs between sectors; the sustainability goals and the overall goal remain the same). One of the reasons why AHP is such a powerful tool is because it allows you to add sub-criteria into additional levels in the hierarchy. Once the relative importance of individual criteria and sub-criteria is determined, decision-makers need only think about the preference of each alternative adaptation option in terms of achieving a single criterion.

Figure 7. AHP decision hierarchy for fisheries sector



Because there are only two levels in this decision hierarchy, only two sets of comparisons need to be made. First, the three broad sustainability goals (green boxes) need to be compared in a pair-wise manner to determine their relative importance with respect to achieving a goal of reducing climate change vulnerability. Secondly, individual adaptation options need to be pair-wise compared to determine their relative effectiveness at achieving each of the three goals.

The survey, which is different for each sector (because there are different adaptation options), was designed as a series of tables. Respondents were given a pair of goals or a pair of options, and asked to compare them using a numerical sliding scale. The comparison scale ranged from 1 to 5, with 1 representing options that are equally effective (or goals that are equally important), and 5 representing options where one is extremely more important than the another. A sample survey question is contained in Figure 8 below.

To target experts and stakeholders who were potential respondents, an email invitation with the website address (URL) of the survey was sent out over various climate change and sustainable development email lists compiled from past workshops and conferences. Some individuals responded to the invitation and completed the survey online and submitted their responses to an email server electronically. In addition to the internet survey, to improve sampling size, a series of small expert/stakeholder group meetings or workshops were organized, and survey responses were collected from the attendees.

Figure 8. AHP comparison table: agriculture sector

Indicate the relative effectiveness of the following adaptation options to achieve the goal of ***minimize harm to the natural environment*** *in the agriculture sector:*

	Relative Effectiveness Scale									
Adaptation Option	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**Adaptation Option**
Farm-level adjustments								x		Organic methods
Farm-level adjustments			x							Intensive modern methods
Farm-level adjustments						x				Efficient irrigation technologies
Farm-level adjustments					x					Water management techniques
Farm-level adjustments			x							Government relief programs
Farm-level adjustments						x				Research and education
Farm-level adjustments			x							Greenhouse agriculture
Farm-level adjustments			x							Land conversion

Note the relative effectiveness scale: 1 – equally effective; 2 – marginally more effective; 3 – moderately more effective; 4 – strongly more effective; 5 – very strongly more effective.

12.2 Preliminary Results and Discussion of the AHP Analysis

To date, (45) survey responses have been received from individuals affiliated with the federal, regional and municipal governments, academia, First Nations, and Non-Governmental Organizations (NGOs). Six of the seven sectors were surveyed (as mentioned above, the climate change impacts on the health sector are not well studied, and are not anticipated to be very severe), with different number of responses in each individual sector.

Using the EC software package, each respondent's comparison choices were input into the computer for analysis. By calculating a series of matrices, EC assigns an overall priority or score to each adaptation option based on the pair-wise comparisons made among the goals and the adaptation options. In each sector, the individual respondents' overall scores were then combined by taking an average across the sector.

The next section provides a brief summary and interpretation of the survey responses in each sector. The graphs present an overall average of all the responses to the six sectors. This type of synthesis is not an ideal method to combine results that are sometimes very different, and it can often result in a loss of important information and details. However, we have chosen to do so anyways in order to provide an indication of which options are generally preferred, and which ones are not as popular. A complete summary of each stakeholder's responses and their inconsistency ratio is contained in Appendix 2. The vast differences in responses in the appendix illustrate the complexity of climate change and sustainability issues, and the varying results that come as a result of different values, backgrounds, affiliations, and knowledge/expertise.

Sector 1: Agriculture

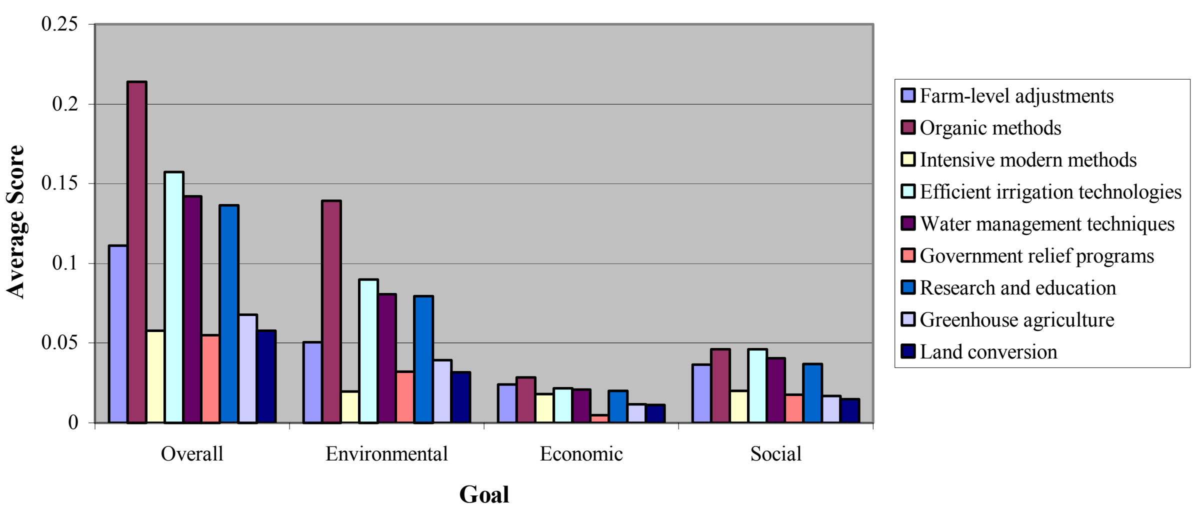
Table 3. Overall ranks and scores of adaptation options in the agriculture sector

Rank	Overall Score	Adaptation Option
1	0.214	Organic methods
2	0.157	Efficient irrigation technologies
3	0.142	Water management techniques
4	0.137	Research and education
5	0.111	Farm-level adjustments
6	0.068	Greenhouse agriculture
7	0.058	Land conversion
8	0.058	Intensive modern methods
9	0.055	Government relief programs

Ten survey responses were received for the agriculture sector, most of which came from individuals representing academia in the Greater Vancouver Regional District (GVRD). No responses were received from the Fraser Valley, one was from Vancouver Island (Capital Regional District (CRD)), and only one response came from outside of academia and government. Respondents were, on average, fairly consistent in their judgements (average inconsistency ratio = 0.15), but the magnitudes of the overall scores for the adaptation options were quite varied (see individual scores in Appendix 2).

There are, however, some general trends in the responses. Overall, *Organic methods* option was judged to be the most effective one for all three goals (environment, economic, and social), and was the most preferred overall by a fairly large margin (see Table 3). Its score of 0.214 is largely a result of its strong performance with respect to the environmental goal, and is substantially larger than that of the next option: *Efficient irrigation technologies* (0.157). *Water management techniques* and *Research and education* options also scored fairly high. The importance of the three broad sustainability goals does not appear to substantially affect the participants' overall preference of adaptation options, with the first four options in Table 3 consistently appearing in respondents' top choices. In addition, the bottom four options (*Government relief programs, Intensive modern methods, Land conversion,* and *Greenhouse agriculture)* are generally not preferred, regardless of a respondent's affiliation or importance of goals. *Government relief programs* scored especially poorly with respect to the economic goal. The adaptation options' overall scores closely resemble their scores for the environmental goal (see Graph 1) because the environment was rated the most important by all but one respondent.

Graph 1. Average scores for adaptation options in the agriculture sector



Sector 2: Coastal Regions

Eight responses were received for the Coastal Regions sector, from respondents affiliated with academia, First Nations, and various levels of government. All except for one are stakeholders in the GVRD region of the GB, which isn't surprising given the nature of the impacts in this sector. The average inconsistency ratio among the respondents was moderately high (0.21), with two individuals having a ratio of 0.35 or greater.

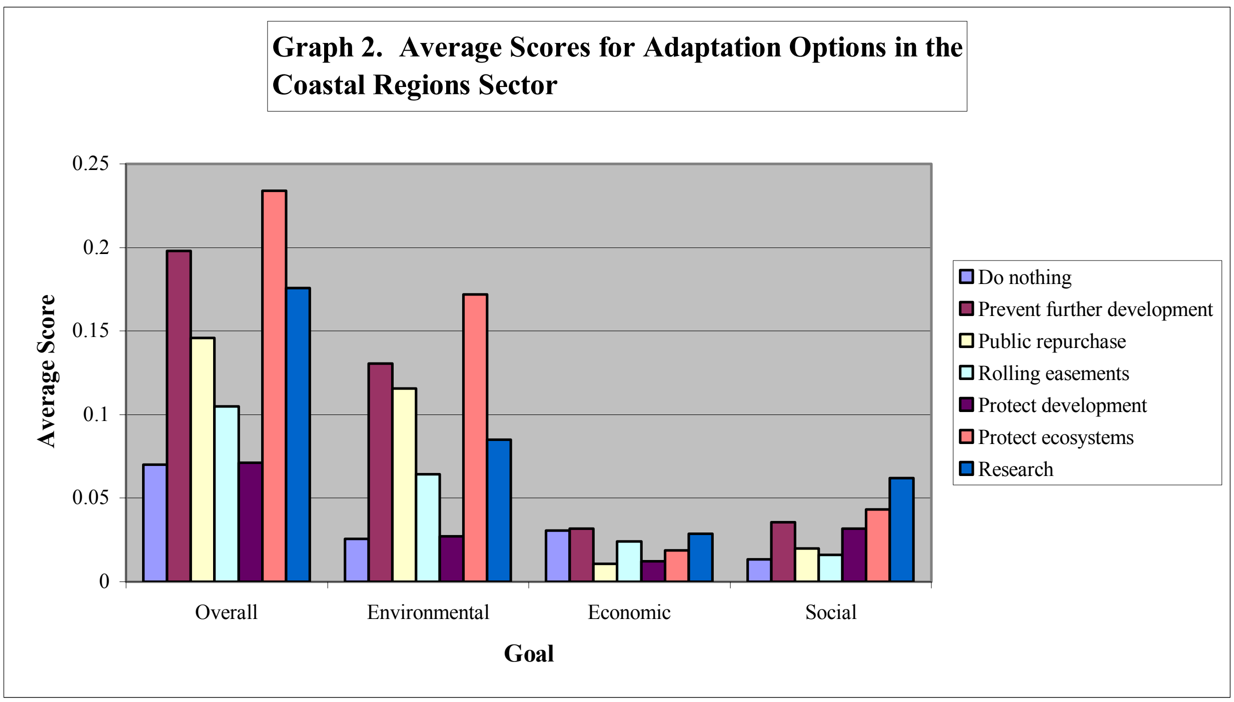
Protect ecosystems was the most desirable adaptation option for Coastal Regions, with *Prevent further development* and *Research* options scoring fairly high as well (see Table 4). Once again, the respondents' personal goal preferences and their affiliations did not appear to significantly affect their overall ranking of the adaptation options. *Public repurchase* option scored fourth overall, however, it was judged to be the most ineffective option from an economic perspective, and it was ranked considerably lower overall among those respondents favouring the economic goal. The cores for *Research* option were highly variable with no observed trend, but

Table 4. Overall Rank and Score of Adaptation Options in the Coastal Regions Sector

Rank	Overall Score	Adaptation Option
1	0.234	Protect ecosystems
2	0.198	Prevent further development
3	0.176	Research
4	0.146	Public repurchase
5	0.105	Rolling easements
6	0.071	Protect development
7	0.070	Do nothing

Protect development and *Do nothing* options scored near the bottom of the list for most participants (especially from an environmental perspective) and are not considered to be very desirable adaptation options. Once again, the adaptation options' overall scores closely resemble their scores for the environmental goal (see Graph 2) because the environment goal was rated the most important by all but one respondent.

There seemed to be some confusion among participants about the logistics of implementing a *Rolling easement* option, and another respondents suggested that "protect future ecosystems that would be encroached by a retreating population" could also be included in a list of potential adaptation options.



Sector 3: Energy

The sample of respondents in the Energy sector includes four from academia and three from municipal government in the GVRD. No employees from the BC Hydro (the Georgia Basin's primary energy provider) responded to the survey invitations. The average inconsistency ratio among respondents was 0.19.

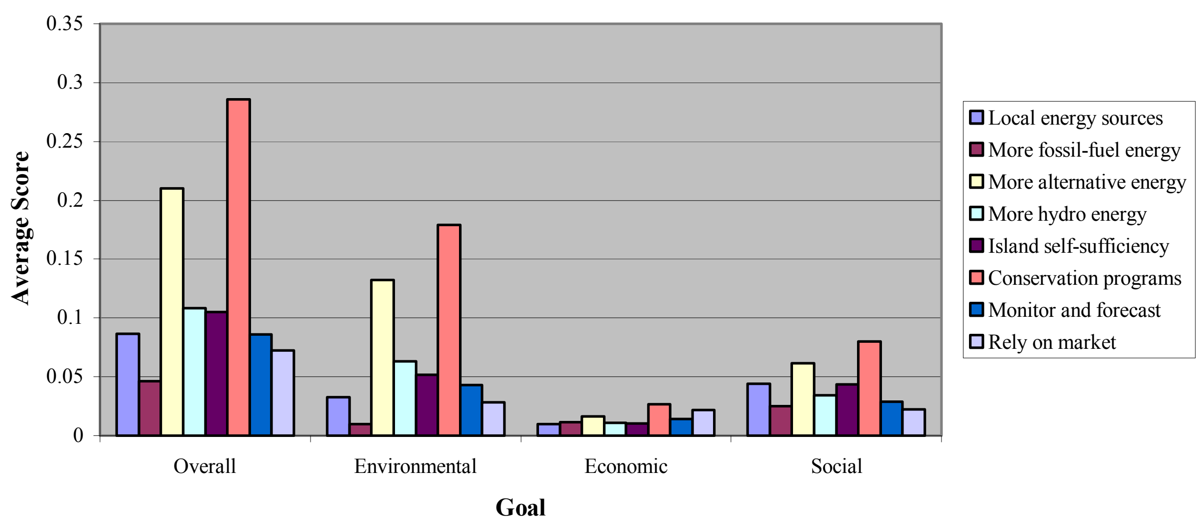
Table 5 shows overall ranks and scores for adaptation options in the energy sector. *Conservation programs* option was ranked the highest with respect to all three goals (see Graph

3) to achieve an overall score of 0.286 - substantially higher than *More alternative energy* option, its next closest rival and the only other highly-desirable option. Both were judged very high from an environmental perspective by respondents regardless of their goal preference and affiliation. *More fossil fuel energy* scored especially low under the environmental goal, and thus achieved a low score overall. One respondent commented that *Island self-sufficiency* is difficult to compare with some of the other options, and implementation of this may in fact include the use of some of the other options (such as *Alternative energy*, *Hydro energy*, etc.).

Table 5. Overall Rank and Score of Adaptation Options in the Energy Sector

Rank	Overall Score	Adaptation Option
1	0.286	Conservation programs
2	0.210	More alternative energy
3	0.108	More hydro energy
4	0.105	Island self-sufficiency
5	0.087	Local energy sources
6	0.086	Monitor and forecast
7	0.072	Rely on market
8	0.046	More fossil-fuel energy

Graph 3. Average Scores for Adaptation Options in the Energy Sector



Sector 4: Health

No survey was conducted in the health sector as mentioned earlier.

Sector 5: Fisheries

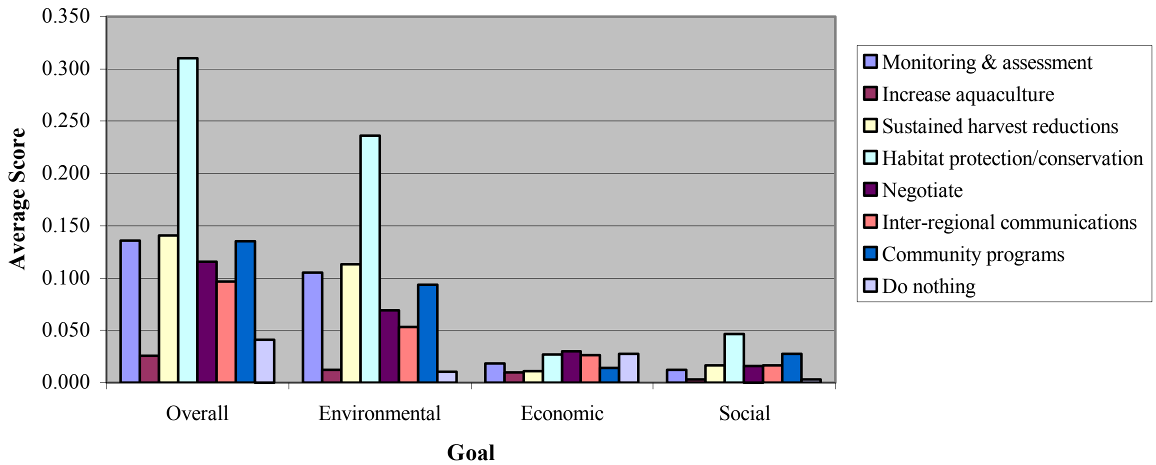
Table 6. Overall Rank and Score of Adaptation Options in the Fisheries Sector

Rank	Overall Score	Adaptation Option
1	0.310	Habitat protection/conservation
2	0.141	Sustained harvest reductions
3	0.136	Monitoring & assessment
4	0.135	Community programs
5	0.116	Negotiate
6	0.097	Inter-regional communications
7	0.041	Do nothing
8	0.025	Increase aquaculture

It was difficult to obtain responses in the Fisheries sector, and only four were received: two from academia, one from First Nations, and one from an NGO. The average inconsistency ratio was fairly high (0.23), reflecting contradictory judgements in many of the comparisons. The environmental goal was rated the most important by all four respondents, and *Habitat protection and conservation* option was the most desirable one overall by a very large margin (It received an especially high score of 0.489 by the NGO representative.). The NGO and First Nations respondents ranked *Community programs* as their second choice, whereas the academics preferred other options such as *Sustained harvest reductions* and *Monitoring and assessment*. *Do nothing* and *Increase aquaculture* options were given low scores for each of the goals and are thus not very desirable alternatives.

One respondent suggested that *Increase aquaculture* should be separated into endemic and non-endemic species because the two choices have very different implications for the fisheries sector. Another one suggested that *Sustained harvest reductions* could be re-written as “Sustainable harvest levels” to remove ambiguity between the title and description of the option.

Graph 4. Average Scores for Adaptation Options in the Fisheries Sector



Sector 6: Forestry

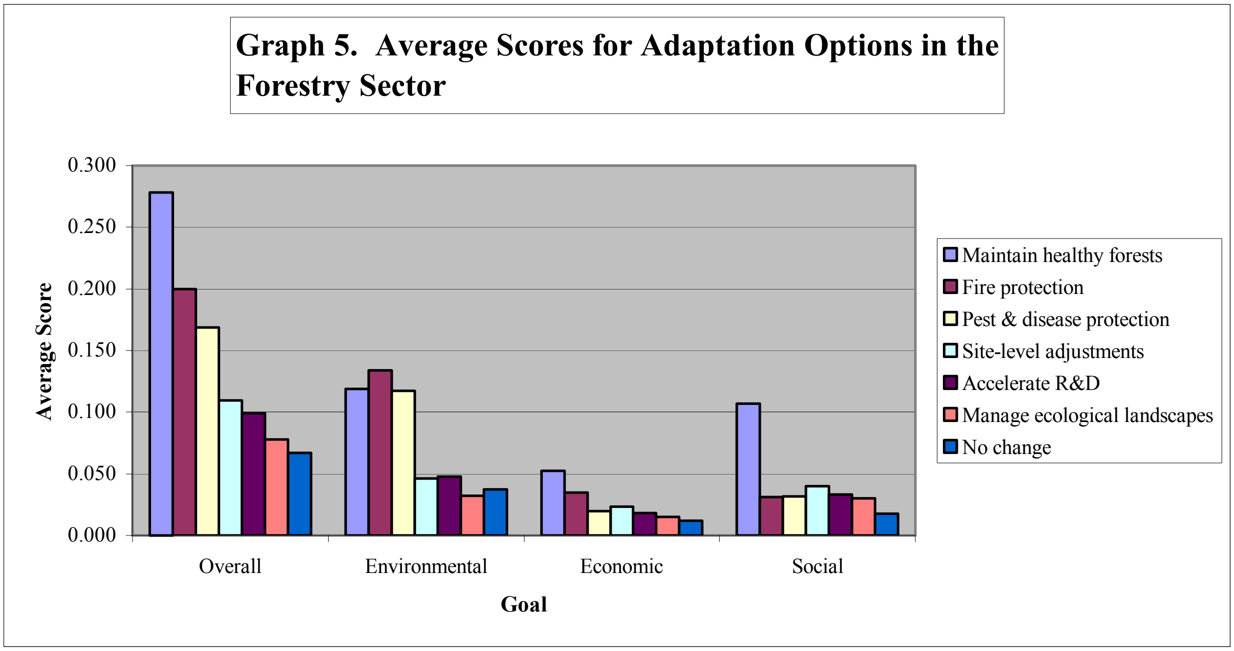
Table 7. Overall Rank and Score of Adaptation Options in the Forestry Sector

Rank	Overall Score	Adaptation Option
1	0.238	Manage ecological landscapes
2	0.203	Maintain healthy forests
3	0.169	No change
4	0.107	Site-level adjustments
5	0.102	Fire protection
6	0.095	Pest & disease protection
7	0.085	Accelerate R&D

The Forestry sector was also not well represented in the survey, with only four individuals providing responses. Two respondents were from academia and two were from government, and they had an average inconsistency ratio of 0.28. A ratio of 0.51 by one individual illustrates the complexity of the AHP pair-wise comparison methodology.

It is useful to mention a few trends exist in the four responses. Manage ecological landscapes was rated the most desirable in three out of four surveys, and No change was listed as the number two choice by three respondents as well. As shown in Table 7, maintaining healthy forests is also a desirable option. No choices received a really poor score overall, and thus none of the adaptations are highly undesirable.

Some respondents commented that there was ambiguity in the definition of *Maintain healthy forests*, and it was hard to compare with many of the other options. It was suggested that perhaps this option is redundant, and is covered by the other choices.



Sector 7: Water

Fourteen responses were received in the Water sector, most of which came from the academics and government (federal and regional) employees in the GVRD. In addition, one NGO completed the survey. The overall inconsistency ratio among respondents in the water sector was reasonable at 0.15.

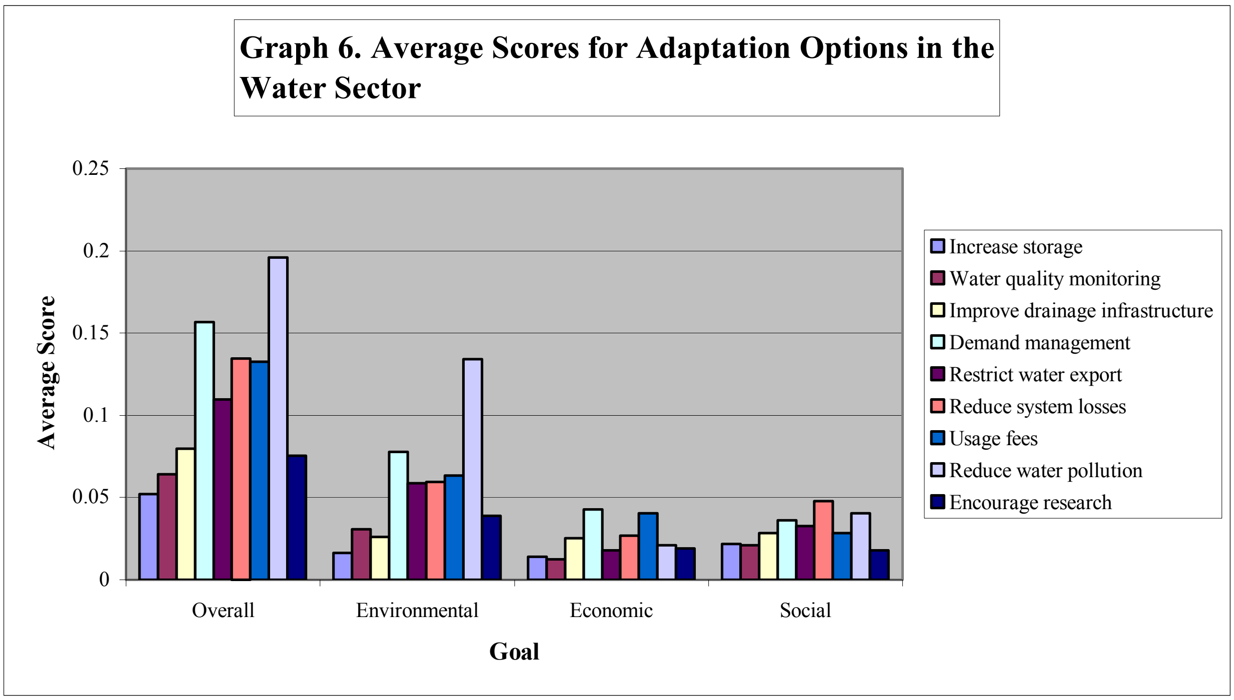
Table 8. Overall Rank and Score of Adaptation Options in the Water Sector

Rank	Overall Score	Adaptation Option
1	0.196	Reduce water pollution
2	0.157	Demand management
3	0.134	Reduce system losses
4	0.132	Usage fees
5	0.109	Restrict water export
6	0.080	Improve drainage infrastructure
7	0.076	Encourage research
8	0.064	Water quality monitoring
9	0.052	Increase storage

The goal of minimizing economic costs was considered more important in the water sector than in any others, largely at the expense of the environmental goal. Overall, however, the environmental goal was still the most important and options that were effective at achieving this goal scored well overall. *Reduce water pollution* option received the highest score overall (0.196), followed by *Demand management* (0.157). As expected, *Reduce water pollution* was especially popular among respondents who valued the environment the most, and was not as desirable for those who favoured the economic and social goals. *Demand management* was desirable for almost all the participants, and especially those affiliated with government (it scored in the top three choices of every single government respondent.). *Water quality monitoring* and *Increase storage* options were generally among the least popular choices.

Many comments about the adaptation options list were received from respondents in the water sector. Some of the concerns expressed included ambiguity in the meaning of certain options such as *Restrict water export* and *Increase storage* (which could imply constructing new dams to form lakes, or adding a tank within the current system). In addition, some options that might have been considered include:

-statutory provisions to protect or give priority to community drinking water
-limit urban growth with water as a limiting factor
-recycling water systems and/or mandatory water purification in the industrial sector
-charge more for water to discourage wasteful consumption
-land use planning for flood damage reduction (design for extreme water events)



12.3 Overall Discussion

Many difficulties were encountered in the application of the IA approach in the Georgia Basin. A lack of background information and a complex research methodology combined with time constraints has made the initial application of this approach a challenge. Given these circumstances, it would be difficult to obtain a reasonable representation of the many different stakeholders and experts in any context.

Climate change and its effects on coast regional sustainability are a relatively new topic on the research agenda. To date, very few scientific and technical studies have been performed in the GB, and the impacts of and vulnerabilities to climate change in this particular region are not well known. Although this report describes in general some of the vulnerabilities that may be expected in seven key sectors, it illustrates the need for further scientific research and modelling in this region.

The IA approach has never been applied in the GB for the purpose of evaluating adaptation options to reduce climate change vulnerability. The methodology is difficult to implement, and the multi-criteria adaptation measures evaluation system is complex. The approach requires multi-stakeholder participation, and thus numerous methods were employed to involve multiple stakeholders and experts in the evaluation process. It was expected that an internet website with email advertisements would be an effective way to reach a large number of potential stakeholders in a relatively short time. Having the survey online offers a convenient way for the stakeholders to respond the survey questions on their own time, and eliminates the substantial time lag that would be incurred if the surveys had to be mailed out. Email advertisements were sent out to personal contacts and on many different climate change email lists, with second and sometimes third reminders. The response rate was not as high as expected. This could be attributed to a very short time of the project.

Most of the survey respondents were not familiar with the analytic hierarchy process, and the entire survey (which takes up to half an hour to complete) appears daunting to potential respondents. It seems that many of the targeted experts and researchers are very busy individuals and the AHP methodology makes the survey too time consuming to complete. Other stakeholders have found the methodology unfamiliar, complex, and confusing, and chose not to participate in the study.

Only 22 people responded to the survey online, and to improve the response rate, numerous individuals were contacted individually and asked to complete the survey in a one-on-one interview or in a small group workshop-type setting. This approach proved to be much more effective, and suggests that the methodology is not too complex if the participants are given a brief overview of the study and the IA approach, and are permitted to ask questions to clarify their concerns and confusion. One-on-one interviews have been used by the researchers in previous studies (Yin and Cohen, 1994), and have once again proven to be an effective means for targeting potential respondents.

Perhaps a website-based survey is easier to administer for short and simple methodologies, or for projects of a longer duration. Although the funding for this particular project has expired, the survey website will remain active in the future, and hopefully stakeholders will continue to visit the website (URL: http://www.sdri.ubc.ca/aos) and respond to the survey questions. Moreover, the website can be used as a training tool for researchers and professionals who are interested in climate change impact assessment and adaptation evaluation studies. It is a particularly useful tool for the C-CIARN Network.

13. Conclusions

Although the project has been completed, it is expected that many of the lessons learned during this study will play a significant role in future research activities on climate adaptation evaluation. This project is part of a larger evolution of the PI's research, and has been built on many years of research experience of the investigators in integrated climate change impact and adaptation studies in the Georiga Basin, the Mackenzie River Basin, and Great Lakes Basin in Canada, and the Yangtze Delta in China. The project has appropriately developed a broader research effort that includes improved understanding of how climate change might affect the region's ecological systems and the human societies that are dependent upon ecosystems. The project has made useful scientific data and information more broadly available for public and private stakeholders by establishing an internet based adaptation option evaluation survey.

Enhancing the region's capacity to manage its ecosystems would promote sustainable development in the region. Capacity building of the project has included providing training to enable graduate students to undertake the impact assessment and adaptation evaluation (e.g., data collection, climate modeling, impacts modeling, adaptation tool designing) themselves. Those graduate students will be in a position to continue research and participate in future assessments. With improved knowledge and skill of the ecological conditions and adaptation options, the region can make more sustainable decisions in the future.

To accomplish more on climate change research, we must further improve our capabilities for conducting integrated assessment of climate change and its potential consequences on regional sustainability. Our current level of understanding shows us that climate change and its impacts will vary by sector and region, but our knowledge of specific regional and sectoral effects remains limited. We also need to improve our knowledge on the interactions of variability, climate change, and other human-induced changes in the region including environmental pollution, land-use change, resource depletion, and other unsustainabilities. In addition, we need to achieve a better understanding not only of vulnerabilities of the ecological and human systems to climate change, but also of their implications for societal sustainability.

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Appendix 1: Uncertainty and Sea Level Rise in the GVRD
Executive Summary

For a full version of this report, please visit the following website:
http://www.geog.ubc.ca/courses/klink/g472/class00/ajdownie/index.html

Background Information

Global warming is predicted to have many different effects around the world. One of the major impacts is expected to be a global rise in sea level due to thermal expansion of the oceans and the melting of polar glaciers and ice caps. The Intergovernmental Panel on Climate Change (IPCC) has used a model to estimate a series of sea level rise scenarios that might occur as a result of rising temperatures. Ignoring any local or regional effects such as isostatic readjustment, they predict the global sea level to rise anywhere from 0.22m to 1.24m in the next 100 years.

Permanent inundation of low-lying and intertidal areas is a primary concern in areas such as the Greater Vancouver Regional District (GVRD), and the economic, social, and environmental implications of sea level rise in this region are substantial. Not only will sea level rise likely result in the permanent flooding and alteration of coastal wetlands, but it also poses a threat to human activities. As the climate warms, it is increasingly important for developers and government policy-makers to consider the implications of sea level rise in their decision-making processes.

To estimate the impacts of sea level rise, it is necessary to develop techniques that allow us to model the process. Geographical Information Systems (GIS) can be a useful tool to do this, however, many individuals who have used GIS acknowledge that there are problems accommodating uncertainties in both the input elevation data, and the magnitude of sea level rise that is applied. Uncertainty is an important consideration in the decision-making process because of its relationship to decision risk. An Idrisi software manual predicts that in the future there will be a movement away from the traditional 'hard' decisions, to procedures dominated by 'soft' decisions. In other words, there will be "talk not of whether an area does or does not have a problem, but of the 'likelihood' that it has a problem." Then, based on the level of risk one is willing to assume, a 'hard' decision can be developed.

There are two main types of GIS uncertainty described in the literature: *database uncertainty* and *decision rule uncertainty*. In the case of modeling sea level rise, *database uncertainty* is derived primarily from measurement errors in the elevation values contained in a digital elevation model (DEM). The variability of recorded values around their true value can be described using probability theory, and the error can be quantified as a root-mean square (RMS) error. *Decision rule uncertainty* exists because of uncertainties in the magnitude of sea level rise that should can be expected. The latter type of uncertainty will not be examined in this project.

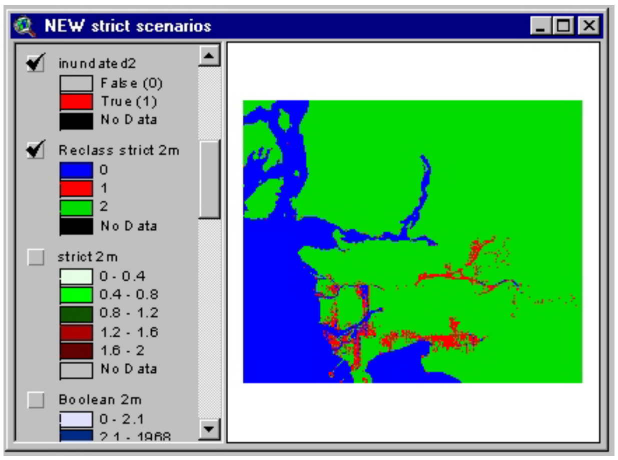
Many GIS software packages have already incorporated procedures for analyzing different kinds of uncertainty. ArcView version 3.2 does not, however, have this capability. The goal of this project is to develop a procedure in ArcView that is similar to the one in Idrisi's PCLASS module, which can be used to incorporate *database uncertainty* into a sea level rise analysis. The project illustrates how a continuous probability map can be generated to show the probability of inundation given a specific scenario, based on the RMS error inherent in the original DEM. In the case of sea level rise, successful handling of uncertainty allows us to generate useful impact estimates despite a lack of concrete data. Knowledge of possible impacts is important for planning future developments, and for considering adaptation options to cope with global warming and sea level rise.

Part 1

In Part 1 of this project (which does not recognize any uncertainty), two sea level rise scenarios (1.0 and 2.0 meters) were examined. The analyses were carried out using elevation data for the GVRD obtained from the Province of B.C.'s gridded DEM. A series of RECLASS and OVERLAY operations were used to isolate vulnerable areas in the GVRD. Figure 1 is a map of the GVRD, reclassified into three categories after a 2.0-meter sea level rise. The area is broken down into: existing water (blue), areas newly inundated under the sea level rise scenario (red), and areas that remain dry (green). Because the DEM data is only available to the nearest meter, there was no point in doing any analyses for scenarios that aren't on 1-meter intervals.

This operation neglects inherent error in the DEM data. A very large portion of the GVRD has reported elevation values of 3 meters or less, so an RMS error of 6.10 meters is certainly quite substantial. Maps and statistics produced in this way are likely of little use to developers and planners.

Figure 1:
ArcView Screen-shot of GVRD land reclassified for 2.0m rise



Part 2:

Part 2 of this project incorporates *database uncertainty*, and examines three sea level rise scenarios. Two were taken from the IPCC's projections: 0.22 meters representing a conservative estimate based on a low emissions scenario, and 1.24 meters representing a high emissions scenario. A third scenario of 2.0 meters was also chosen. Although this estimate is considerably higher than the IPCC's, it is not uncommon in the literature, and can represent a possible scenario where sea level rise is accompanied by high tide and a significant storm surge.

The GVRD DEM lists its elevation values to the nearest meter, and was created from a 1:20,000 scale TRIM map. According to the "Gridded DEM Specification Release 1.1", the data conforms to the 1:20,000 TRIM accuracy standard, whereby 90% of all points interpolated from the TRIM DEM shall be accurate to within 10 meters of their true elevation. Assuming that the data is not biased (the error is uniform), the standard deviation of the map should be equal to its root-mean square error. Thus, the RMS of the DEM is 6.10 meters.

From a statistical point of view, individual elevation values in the DEM should be normally distributed. Any quoted elevation value therefore falls somewhere under a normal curve characterized by a mean of the true value, and a standard deviation or RMS of 6.10 meters. The probability of a cell value falling at any given location can be computed as a z-score:

$$z = (y - m)/s$$

where z is the z-score; y is the observed value; m is the mean value; and s is the standard deviation, or RMS.

A z-score was computed in ArcView for the entire DEM using the following formula:

[zscore] = (2.0 - [DEM]) / 6.10

Figure 2 shows the z-score map for a 2.0m sea level rise in the GVRD.

The z-score values were then RECLASSIFIED according to a set of chosen probability ranges that are likely of interest to decision-makers. The ranges are shown in Table 1.

Numerous OVERLAY and RECLASSIFICATION operations were then used to convert the z-score map into a probability map, and to isolate areas that are already underwater. Figure 3 shows the soft probability map calculated for the 0.22-meter scenario.

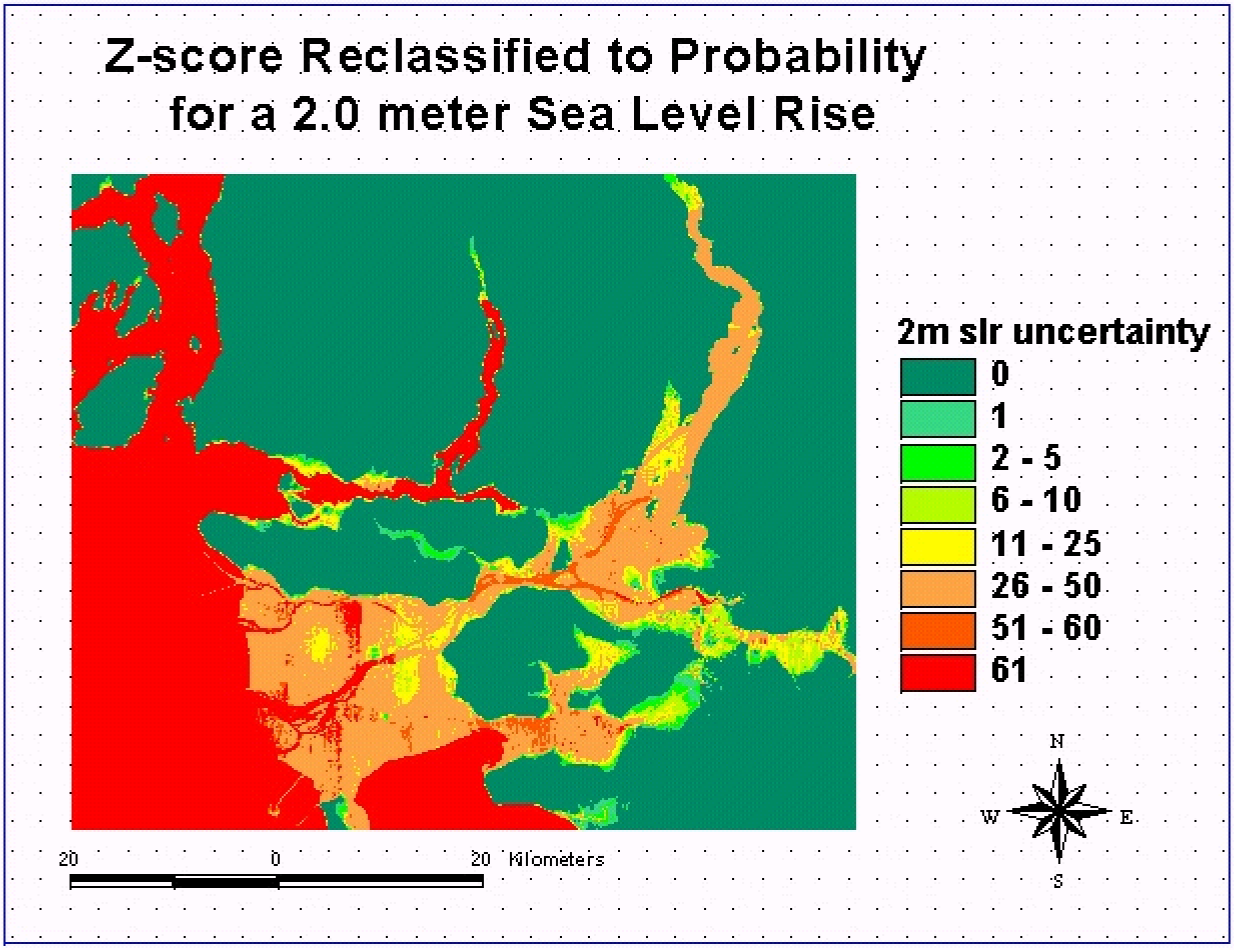
The impacts were then quantified in various ways using a GVRD land use map. Using ArcView features including MAP QUERY, SUMMARIZE ZONES, and TABULATE AREAS, numerous statistics were extracted from the GVRD land use data to determine the sea level rise impact on various sectors. Some highlights are shown in Table 2, and all the results are given in the online version of this report, available at:
http://www.geog.ubc.ca/courses/klink/g472/class00/ajdownie/index.html

Table 1: Z-Score values and associated probability ranges

Z-Score	Probability
-322.295 - -3.091	0
-3.091 - -2.325	< 1 %
-2.325 - -1.644	2 – 5 %
-1.644 - -1.281	6 – 10 %
-1.281 - -0.674	11 – 25 %
-0.674 - 0.001	26 – 50%
0.001 – 0.254	51 – 60%
> 0.254	> 61%

Table 2. Land with >25% risk of inundation

	2.0 meter scenario	0.22 meter scenario
Resid. Single Family		
Area inundated (km^2)	42.339	30.596
Percentage of total	12 %	8 %
Industrial		
Area inundated (km^2)	29.702	15.883
Percentage of total	40 %	22 %
Trans./Comm./Utilities		
Area inundated (km^2)	27.250	19.728
Percentage of total	67 %	49 %
Agriculture		
Area inundated (km^2)	257.211	172.333
Percentage of total	55 %	37 %


Z-score Reclassified to Probability
for a 2.0 meter Sea Level Rise
2m slr uncertainty
0
1
2 - 5
6 - 10
11 - 25
26 - 50
51 - 60
61
N
W
E
S
20
0
20 Kilometers

Conclusion:

Despite the relatively long time horizon of the projections (100 years), results such as these have substantial implications for developers and planners. In many cases, even a 25% probability represents a very high risk, and perhaps a 5 or even 1% probability is more realistic when considering multi-million dollar developments and infrastructure projects.

The scope of this project was limited to examination of database uncertainty; however, there are many other sources of uncertainty that should be addressed in sea level rise modeling efforts. The areas of global warming and sea level rise are plagued with a lack of concrete data, but with careful consideration of the many types of uncertainty involved, it should be possible to generate useful impact estimates**.**

Appendix 2: Individual survey responses for each sector, arranged by Survey ID

Survey results for each respondent

SURVEY ID: AGR1

	Overall	Environment	Economic	Social
Farm-level adjustments	0.096	0.060	0.029	0.007
Organic methods	0.418	0.269	0.114	0.035
Intensive modern methods	0.094	0.060	0.028	0.006
Efficient irrigation technologies	0.100	0.065	0.028	0.006
Water management techniques	0.122	0.087	0.028	0.006
Government relief programs	0.021	0.014	0.006	0.002
Research and education	0.040	0.023	0.013	0.003
Greenhouse agriculture	0.098	0.064	0.028	0.005
Land conversion	0.012	0.008	0.003	0.001

SURVEY ID: AGR2

	Overall	Environment	Economic	Social
Farm-level adjustments	0.145	0.034	0.059	0.052
Organic methods	0.185	0.066	0.059	0.060
Intensive modern methods	0.060	0.015	0.018	0.027
Efficient irrigation technologies	0.061	0.016	0.014	0.032
Water management techniques	0.240	0.092	0.068	0.080
Government relief programs	0.037	0.015	0.010	0.013
Research and education	0.170	0.069	0.082	0.019
Greenhouse agriculture	0.069	0.014	0.013	0.042
Land conversion	0.034	0.014	0.010	0.009

SURVEY ID: AGR3

	Overall	Environment	Economic	Social
Farm-level adjustments	0.106	0.014	0.061	0.031
Organic methods	0.123	0.012	0.037	0.074
Intensive modern methods	0.088	0.006	0.039	0.043
Efficient irrigation technologies	0.238	0.034	0.049	0.155
Water management techniques	0.103	0.019	0.011	0.074
Government relief programs	0.064	0.007	0.010	0.047
Research and education	0.178	0.032	0.044	0.101
Greenhouse agriculture	0.066	0.007	0.024	0.035
Land conversion	0.033	0.003	0.006	0.024

SURVEY ID: AGR4

	Overall	Environment	Economic	Social
Farm-level adjustments	0.126	0.063	0.023	0.040
Organic methods	0.258	0.214	0.004	0.040
Intensive modern methods	0.055	0.016	0.023	0.017
Efficient irrigation technologies	0.111	0.049	0.023	0.039
Water management techniques	0.058	0.039	0.004	0.015
Government relief programs	0.039	0.027	0.004	0.009
Research and education	0.056	0.039	0.004	0.013
Greenhouse agriculture	0.176	0.151	0.019	0.007
Land conversion	0.122	0.062	0.054	0.006

SURVEY ID: AGR5

	Overall	Environment	Economic	Social
Farm-level adjustments	0.034	0.024	0.003	0.006
Organic methods	0.287	0.249	0.005	0.034
Intensive modern methods	0.038	0.020	0.008	0.011
Efficient irrigation technologies	0.064	0.036	0.010	0.018
Water management techniques	0.108	0.072	0.009	0.027
Government relief programs	0.096	0.087	0.004	0.006
Research and education	0.271	0.206	0.015	0.049
Greenhouse agriculture	0.056	0.036	0.005	0.014
Land conversion	0.046	0.023	0.005	0.018

SURVEY ID: AGR6

	Overall	Environment	Economic	Social
Farm-level adjustments	0.190	0.067	0.028	0.095
Organic methods	0.185	0.170	0.004	0.011
Intensive modern methods	0.058	0.010	0.013	0.035
Efficient irrigation technologies	0.156	0.098	0.015	0.043
Water management techniques	0.205	0.148	0.030	0.027
Government relief programs	0.022	0.017	0.002	0.003
Research and education	0.094	0.078	0.006	0.010
Greenhouse agriculture	0.045	0.027	0.004	0.014
Land conversion	0.044	0.022	0.003	0.019

SURVEY ID: AGR7

SURVEY ID: AGR8

	Overall	Environment	Economic	Social
Farm-level adjustments	0.074	0.037	0.006	0.031
Organic methods	0.158	0.059	0.020	0.079
Intensive modern methods	0.043	0.037	0.001	0.005
Efficient irrigation technologies	0.205	0.110	0.017	0.079
Water management techniques	0.227	0.097	0.019	0.111
Government relief programs	0.097	0.063	0.003	0.031
Research and education	0.115	0.049	0.005	0.061
Greenhouse agriculture	0.042	0.018	0.004	0.019
Land conversion	0.040	0.017	0.004	0.019

	Overall	Environment	Economic	Social
Farm-level adjustments	0.184	0.122	0.009	0.053
Organic methods	0.369	0.264	0.022	0.083
Intensive modern methods	0.028	0.013	0.007	0.008
Efficient irrigation technologies	0.099	0.065	0.013	0.021
Water management techniques	0.020	0.011	0.005	0.004
Government relief programs	0.029	0.018	0.005	0.006
Research and education	0.153	0.108	0.011	0.035
Greenhouse agriculture	0.070	0.043	0.010	0.018
Land conversion	0.048	0.026	0.006	0.016

SURVEY ID: AGR9

	Overall	Environment	Economic	Social
Farm-level adjustments	0.089	0.068	0.016	0.006
Organic methods	0.075	0.052	0.017	0.006
Intensive modern methods	0.092	0.012	0.040	0.041
Efficient irrigation technologies	0.277	0.224	0.035	0.019
Water management techniques	0.174	0.134	0.020	0.020
Government relief programs	0.114	0.055	0.004	0.054
Research and education	0.086	0.055	0.007	0.024
Greenhouse agriculture	0.039	0.022	0.008	0.009
Land conversion	0.054	0.037	0.009	0.007

SURVEY ID: AGR10

	Overall	Environment	Economic	Social
Farm-level adjustments	0.071	0.018	0.008	0.045
Organic methods	0.082	0.039	0.003	0.039
Intensive modern methods	0.021	0.011	0.002	0.008
Efficient irrigation technologies	0.264	0.202	0.013	0.049
Water management techniques	0.164	0.110	0.015	0.040
Government relief programs	0.027	0.019	0.002	0.006
Research and education	0.204	0.135	0.014	0.055
Greenhouse agriculture	0.020	0.011	0.002	0.007
Land conversion	0.148	0.106	0.013	0.029

SURVEY ID: CST1

	Overall	Environment	Economic	Social
Do nothing	0.089	0.006	0.019	0.064
Prevent further development	0.237	0.009	0.044	0.185
Public repurchase	0.055	0.005	0.025	0.025
Rolling easements	0.134	0.026	0.059	0.050
Protect development	0.088	0.003	0.022	0.063
Protect ecosystems	0.063	0.005	0.011	0.046
Research	0.334	0.013	0.039	0.282

SURVEY ID: CST2

	Overall	Environment	Economic	Social
Do nothing	0.053	0.012	0.038	0.002
Prevent further development	0.156	0.099	0.041	0.016
Public repurchase	0.132	0.122	0.005	0.005
Rolling easements	0.106	0.094	0.008	0.003
Protect development	0.061	0.052	0.004	0.004
Protect ecosystems	0.416	0.370	0.011	0.034
Research	0.077	0.017	0.049	0.011

SURVEY ID: CST3

	Overall	Environment	Economic	Social
Do nothing	0.128	0.026	0.100	0.002
Prevent further development	0.134	0.072	0.059	0.003
Public repurchase	0.073	0.057	0.007	0.009
Rolling easements	0.127	0.062	0.049	0.015
Protect development	0.059	0.014	0.010	0.035
Protect ecosystems	0.372	0.329	0.014	0.029
Research	0.108	0.077	0.019	0.012

SURVEY ID: CST4

	Overall	Environment	Economic	Social
Do nothing	0.052	0.039	0.007	0.006
Prevent further development	0.425	0.387	0.029	0.008
Public repurchase	0.119	0.103	0.005	0.011
Rolling easements	0.170	0.145	0.009	0.016
Protect development	0.071	0.010	0.001	0.059
Protect ecosystems	0.045	0.014	0.002	0.029
Research	0.119	0.037	0.004	0.078

SURVEY ID: CST5

	Overall	Environment	Economic	Social
Do nothing	0.041	0.028	0.003	0.010
Prevent further development	0.105	0.061	0.014	0.030
Public repurchase	0.286	0.242	0.009	0.034
Rolling easements	0.089	0.078	0.005	0.006
Protect development	0.028	0.017	0.002	0.010
Protect ecosystems	0.297	0.201	0.028	0.067
Research	0.155	0.105	0.020	0.030

SURVEY ID: CST6

	Overall	Environment	Economic	Social
Do nothing	0.072	0.064	0.005	0.003
Prevent further development	0.090	0.075	0.005	0.010
Public repurchase	0.161	0.119	0.005	0.037
Rolling easements	0.044	0.031	0.003	0.010
Protect development	0.055	0.011	0.004	0.039
Protect ecosystems	0.142	0.098	0.005	0.039
Research	0.435	0.364	0.020	0.052

SURVEY ID: CST7

	Overall	Environment	Economic	Social
Do nothing	0.049	0.017	0.015	0.016
Prevent further development	0.183	0.139	0.030	0.013
Public repurchase	0.065	0.030	0.024	0.011

SURVEY ID: CST8

	Overall	Environment	Economic	Social
Do nothing	0.078	0.015	0.060	0.003
Prevent further development	0.254	0.204	0.030	0.020
Public repurchase	0.277	0.248	0.004	0.025

	Overall	Environment	Economic	Social
Rolling easements	0.072	0.023	0.036	0.013
Protect development	0.141	0.077	0.048	0.016
Protect ecosystems	0.350	0.222	0.071	0.057
Research	0.139	0.048	0.065	0.026

	Overall	Environment	Economic	Social
Rolling easements	0.096	0.058	0.024	0.015
Protect development	0.068	0.033	0.007	0.028
Protect ecosystems	0.187	0.135	0.007	0.045
Research	0.040	0.021	0.012	0.007

SURVEY ID: ENR1

	Overall	Environment	Economic	Social
Local energy sources	0.115	0.026	0.003	0.086
More fossil-fuel energy	0.028	0.006	0.006	0.016
More alternative energy	0.164	0.088	0.002	0.074
More hydro energy	0.059	0.039	0.003	0.017
Island self-sufficiency	0.077	0.036	0.001	0.040
Conservation programs	0.384	0.222	0.010	0.151
Monitor and forecast	0.079	0.011	0.019	0.050
Rely on market	0.094	0.028	0.046	0.020

SURVEY ID: ENR2

	Overall	Environment	Economic	Social
Local energy sources	0.044	0.031	0.007	0.006
More fossil-fuel energy	0.015	0.010	0.003	0.002
More alternative energy	0.263	0.188	0.039	0.035
More hydro energy	0.048	0.035	0.009	0.004
Island self-sufficiency	0.051	0.036	0.007	0.007
Conservation programs	0.457	0.351	0.087	0.020
Monitor and forecast	0.090	0.065	0.014	0.011
Rely on market	0.032	0.022	0.005	0.005

SURVEY ID: ENR3

	Overall	Environment	Economic	Social
Local energy sources	0.108	0.058	0.009	0.040
More fossil-fuel energy	0.014	0.008	0.001	0.005
More alternative energy	0.195	0.144	0.012	0.038
More hydro energy	0.189	0.144	0.012	0.033
Island self-sufficiency	0.138	0.078	0.011	0.049
Conservation programs	0.277	0.164	0.021	0.092
Monitor and forecast	0.059	0.037	0.004	0.018
Rely on market	0.022	0.015	0.001	0.005

SURVEY ID: ENR4

	Overall	Environment	Economic	Social
Local energy sources	0.049	0.022	0.006	0.021
More fossil-fuel energy	0.023	0.011	0.001	0.011
More alternative energy	0.327	0.259	0.025	0.043
More hydro energy	0.169	0.117	0.009	0.043
Island self-sufficiency	0.096	0.064	0.008	0.023
Conservation programs	0.205	0.189	0.002	0.014
Monitor and forecast	0.072	0.062	0.005	0.006
Rely on market	0.060	0.030	0.007	0.023

SURVEY ID: ENR5

	Overall	Environment	Economic	Social
Local energy sources	0.077	0.008	0.028	0.041
More fossil-fuel energy	0.132	0.015	0.020	0.097
More alternative energy	0.069	0.017	0.012	0.039
More hydro energy	0.079	0.014	0.016	0.049
Island self-sufficiency	0.139	0.064	0.027	0.048
Conservation programs	0.169	0.068	0.028	0.072
Monitor and forecast	0.158	0.068	0.037	0.053
Rely on market	0.177	0.064	0.053	0.060

SURVEY ID: ENR6

	Overall	Environment	Economic	Social
Local energy sources	0.127	0.050	0.005	0.071
More fossil-fuel energy	0.066	0.010	0.038	0.018
More alternative energy	0.242	0.096	0.008	0.138
More hydro energy	0.105	0.028	0.017	0.059
Island self-sufficiency	0.132	0.032	0.007	0.093
Conservation programs	0.223	0.082	0.010	0.131
Monitor and forecast	0.057	0.015	0.008	0.035
Rely on market	0.049	0.010	0.018	0.021

SURVEY ID: FOR1

	Overall	Environment	Economic	Social
Maintian healthy forests	0.220	0.183	0.004	0.033
Fire protection	0.047	0.027	0.007	0.013
Pest & disease protection	0.065	0.043	0.006	0.016
Site-level adjustments	0.059	0.022	0.017	0.020
Accelerate R&D	0.059	0.019	0.017	0.024
Manage ecological landscapes	0.293	0.214	0.006	0.072
No change	0.256	0.206	0.010	0.040

SURVEY ID: FOR2

	Overall	Environment	Economic	Social
Maintian healthy forests	0.265	0.187	0.018	0.060
Fire protection	0.106	0.059	0.004	0.043
Pest & disease protection	0.111	0.068	0.010	0.033
Site-level adjustments	0.144	0.109	0.015	0.020
Accelerate R&D	0.116	0.091	0.013	0.012
Manage ecological landscapes	0.104	0.078	0.015	0.011
No change	0.154	0.066	0.081	0.007

SURVEY ID: FOR3

	Overall	Environment	Economic	Social
Maintian healthy forests	0.155	0.082	0.035	0.038
Fire protection	0.137	0.030	0.010	0.097
Pest & disease protection	0.129	0.071	0.018	0.039
Site-level adjustments	0.070	0.029	0.015	0.027
Accelerate R&D	0.066	0.025	0.014	0.027
Manage ecological landscapes	0.225	0.017	0.038	0.170
No change	0.217	0.174	0.013	0.030

SURVEY ID: FOR4

	Overall	Environment	Economic	Social
Maintian healthy forests	0.173	0.090	0.035	0.048
Fire protection	0.120	0.020	0.064	0.035
Pest & disease protection	0.076	0.023	0.025	0.028
Site-level adjustments	0.156	0.095	0.025	0.036
Accelerate R&D	0.097	0.029	0.026	0.041
Manage ecological landscapes	0.329	0.056	0.147	0.126
No change	0.050	0.020	0.011	0.019

SURVEY ID: FSH1

	Overall	Environment	Economic	Social
Monitoring & assessment	0.319	0.312	0.002	0.005
Increase aquaculture	0.015	0.012	0.001	0.003
Sustained harvest reductions	0.180	0.151	0.021	0.008
Habitat protection/conservation	0.183	0.106	0.013	0.065
Negotiate	0.118	0.069	0.007	0.041
Inter-regional communications	0.080	0.037	0.004	0.039
Community programs	0.093	0.027	0.003	0.064
Do nothing	0.012	0.009	0.001	0.002

SURVEY ID: FSH2

	Overall	Environment	Economic	Social
Monitoring & assessment	0.101	0.036	0.053	0.012
Increase aquaculture	0.048	0.008	0.038	0.002
Sustained harvest reductions	0.194	0.175	0.013	0.006
Habitat protection/conservation	0.173	0.125	0.031	0.016
Negotiate	0.165	0.053	0.104	0.008
Inter-regional communications	0.134	0.034	0.088	0.012
Community programs	0.062	0.022	0.033	0.007
Do nothing	0.123	0.013	0.107	0.003

SURVEY ID: FSH3

	Overall	Environment	Economic	Social
Monitoring & assessment	0.041	0.021	0.006	0.015
Increase aquaculture	0.016	0.012	0.001	0.003
Sustained harvest reductions	0.134	0.099	0.006	0.028
Habitat protection/conservation	0.489	0.385	0.022	0.081
Negotiate	0.078	0.065	0.002	0.011
Inter-regional communications	0.070	0.058	0.003	0.009
Community programs	0.157	0.136	0.005	0.016
Do nothing	0.016	0.010	0.001	0.004

SURVEY ID: FSH4

	Overall	Environment	Economic	Social
Monitoring & assessment	0.082	0.051	0.013	0.018
Increase aquaculture	0.023	0.017	0.001	0.005
Sustained harvest reductions	0.056	0.028	0.005	0.023
Habitat protection/conservation	0.396	0.330	0.042	0.024
Negotiate	0.101	0.090	0.006	0.005
Inter-regional communications	0.102	0.085	0.011	0.005
Community programs	0.228	0.189	0.016	0.023
Do nothing	0.012	0.009	0.002	0.002

SURVEY ID: WAT1

	Overall	Environment	Economic	Social
Increase storage	0.073	0.030	0.031	0.011
Water quality monitoring	0.103	0.018	0.041	0.044
Improve drainage infrastructure	0.059	0.018	0.014	0.026
Demand management	0.205	0.057	0.079	0.069
Restrict water export	0.123	0.054	0.033	0.036
Reduce system losses	0.098	0.033	0.018	0.047
Usage fees	0.085	0.036	0.033	0.016
Reduce water pollution	0.123	0.044	0.017	0.062
Encourage research	0.130	0.043	0.067	0.020

SURVEY ID: WAT2

	Overall	Environment	Economic	Social
Increase storage	0.059	0.030	0.001	0.028
Water quality monitoring	0.057	0.018	0.017	0.022
Improve drainage infrastructure	0.225	0.135	0.005	0.085
Demand management	0.148	0.101	0.035	0.012
Restrict water export	0.102	0.070	0.008	0.025
Reduce system losses	0.094	0.038	0.005	0.051
Usage fees	0.097	0.076	0.012	0.008
Reduce water pollution	0.187	0.086	0.015	0.086
Encourage research	0.030	0.011	0.012	0.007

SURVEY ID: WAT3

	Overall	Environment	Economic	Social
Increase storage	0.032	0.001	0.018	0.014
Water quality monitoring	0.024	0.001	0.009	0.014
Improve drainage infrastructure	0.314	0.001	0.237	0.076
Demand management	0.180	0.009	0.150	0.022
Restrict water export	0.102	0.005	0.036	0.062
Reduce system losses	0.114	0.014	0.054	0.046
Usage fees	0.132	0.024	0.105	0.003
Reduce water pollution	0.059	0.012	0.033	0.014
Encourage research	0.042	0.003	0.031	0.007

SURVEY ID: WAT4

	Overall	Environment	Economic	Social
Increase storage	0.021	0.000	0.012	0.008
Water quality monitoring	0.138	0.101	0.012	0.025
Improve drainage infrastructure	0.059	0.049	0.003	0.006
Demand management	0.155	0.105	0.014	0.035
Restrict water export	0.122	0.078	0.003	0.041
Reduce system losses	0.041	0.032	0.005	0.004
Usage fees	0.124	0.097	0.013	0.015
Reduce water pollution	0.249	0.205	0.021	0.022
Encourage research	0.093	0.070	0.010	0.013

SURVEY ID: WAT5

	Overall	Environment	Economic	Social
Increase storage	0.086	0.003	0.035	0.047
Water quality monitoring	0.075	0.009	0.024	0.042
Improve drainage infrastructure	0.042	0.006	0.008	0.027
Demand management	0.113	0.012	0.019	0.082
Restrict water export	0.094	0.009	0.025	0.060
Reduce system losses	0.259	0.026	0.051	0.183
Usage fees	0.242	0.022	0.076	0.144
Reduce water pollution	0.051	0.011	0.011	0.029

SURVEY ID: WAT6

	Overall	Environment	Economic	Social
Increase storage	0.013	0.006	0.003	0.004
Water quality monitoring	0.047	0.015	0.001	0.031
Improve drainage infrastructure	0.021	0.009	0.003	0.010
Demand management	0.181	0.072	0.024	0.085
Restrict water export	0.196	0.149	0.016	0.031
Reduce system losses	0.107	0.044	0.023	0.041
Usage fees	0.176	0.140	0.030	0.006
Reduce water pollution	0.216	0.125	0.030	0.061

Encourage research	0.039	0.007	0.010	0.023

Encourage research	0.043	0.025	0.006	0.012

SURVEY ID: WAT7

	Overall	Environment	Economic	Social
Increase storage	0.032	0.010	0.021	0.001
Water quality monitoring	0.020	0.010	0.008	0.002
Improve drainage infrastructure	0.026	0.018	0.006	0.001
Demand management	0.134	0.090	0.038	0.006
Restrict water export	0.056	0.036	0.012	0.008
Reduce system losses	0.243	0.150	0.082	0.012
Usage fees	0.102	0.056	0.042	0.004
Reduce water pollution	0.362	0.325	0.006	0.031
Encourage research	0.026	0.020	0.005	0.001

SURVEY ID: WAT8

	Overall	Environment	Economic	Social
Increase storage	0.022	0.005	0.010	0.007
Water quality monitoring	0.021	0.006	0.008	0.007
Improve drainage infrastructure	0.024	0.008	0.009	0.007
Demand management	0.241	0.090	0.089	0.062
Restrict water export	0.074	0.020	0.026	0.028
Reduce system losses	0.104	0.032	0.028	0.044
Usage fees	0.207	0.047	0.075	0.085
Reduce water pollution	0.116	0.056	0.031	0.030
Encourage research	0.190	0.069	0.058	0.064

SURVEY ID: WAT9

	Overall	Environment	Economic	Social
Increase storage	0.017	0.007	0.001	0.009
Water quality monitoring	0.128	0.098	0.007	0.022
Improve drainage infrastructure	0.017	0.007	0.001	0.009
Demand management	0.160	0.104	0.017	0.040
Restrict water export	0.101	0.075	0.003	0.023
Reduce system losses	0.193	0.111	0.011	0.070
Usage fees	0.153	0.120	0.017	0.016
Reduce water pollution	0.179	0.099	0.011	0.070
Encourage research	0.050	0.027	0.003	0.020

SURVEY ID: WAT10

	Overall	Environment	Economic	Social
Increase storage	0.064	0.008	0.014	0.041
Water quality monitoring	0.044	0.035	0.003	0.005
Improve drainage infrastructure	0.073	0.012	0.004	0.057
Demand management	0.153	0.118	0.008	0.028
Restrict water export	0.109	0.086	0.002	0.020
Reduce system losses	0.136	0.032	0.021	0.084
Usage fees	0.067	0.013	0.046	0.008
Reduce water pollution	0.302	0.297	0.001	0.003
Encourage research	0.053	0.036	0.005	0.012

SURVEY ID: WAT11

	Overall	Environment	Economic	Social
Increase storage	0.099	0.022	0.019	0.058
Water quality monitoring	0.062	0.023	0.008	0.031
Improve drainage infrastructure	0.036	0.014	0.007	0.016
Demand management	0.204	0.143	0.055	0.006
Restrict water export	0.074	0.046	0.018	0.010
Reduce system losses	0.157	0.111	0.030	0.016
Usage fees	0.103	0.057	0.041	0.005
Reduce water pollution	0.172	0.127	0.006	0.040
Encourage research	0.091	0.058	0.015	0.019

SURVEY ID: WAT12

	Overall	Environment	Economic	Social
Increase storage	0.106	0.053	0.007	0.046
Water quality monitoring	0.081	0.046	0.020	0.015
Improve drainage infrastructure	0.115	0.044	0.027	0.044
Demand management	0.090	0.049	0.020	0.021
Restrict water export	0.146	0.063	0.032	0.051
Reduce system losses	0.102	0.069	0.019	0.014
Usage fees	0.141	0.058	0.026	0.057
Reduce water pollution	0.121	0.034	0.050	0.037
Encourage research	0.098	0.044	0.021	0.033

SURVEY ID: WAT13

	Overall	Environment	Economic	Social
Increase storage	0.052	0.037	0.007	0.009
Water quality monitoring	0.033	0.017	0.006	0.010
Improve drainage infrastructure	0.025	0.016	0.003	0.005
Demand management	0.072	0.060	0.010	0.003
Restrict water export	0.123	0.075	0.020	0.027
Reduce system losses	0.098	0.083	0.006	0.008
Usage fees	0.093	0.078	0.012	0.003
Reduce water pollution	0.408	0.323	0.042	0.043
Encourage research	0.096	0.090	0.004	0.003