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DECISION MAKING UNDER UNCERTAINTIES FOR ADAPTING TO CLIMATE CHANGE IN PROJECT ENVIRONMENTAL ASSESSMENTS

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ABSTRACT

This report presents concepts and methodologies for helping project proponents make decisions on how to adapt to climate change given the uncertainties about the degree of climate change during project planning. A survey of 15 recent EAs for various types of projects found that, while the majority refer to the potential impacts of climate change on their respective projects, most do not deal with it in a systematic manner. Recent literature pertaining to how uncertainty can be addressed in decision making, such as classical decision models (maximin, minimax regret, etc.) and Bayesian analysis were reviewed. The report then explains and illustrates the use of these methods, together with adaptive management for single- and multiple-attribute problems. Guidelines for incorporating this research into EA practice are suggested.

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Abbreviations

GC	Government of Canada
GHG	greenhouse gas(es)
EA	environmental assessment
FPTC	Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment
IPCC	Intergovernmental Panel on Climate Change
NPV	net present value

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Executive Summary

A broad consensus has emerged that climate change will impact human activity in a number of spheres, though its precise effects are still highly uncertain. The Canadian Environmental Assessment Agency has funded this study in order to further develop and adapt approaches for incorporating climate change uncertainties into project-level environmental assessments (EAs).

The research investigates alternative criteria and approaches for decision making under uncertainties, including well-established approaches such as minimize the maximum regret, maximize the minimum outcome, and expected value. These approaches allow for the incorporation into decision making attitudes toward risks and uncertainties and assumptions about the likelihood of future scenarios. In addition, adaptive management, in which flexibility to adjust to changing climate, is considered as a means of addressing the uncertainties.

In considering these issues, this report includes the following four components, the first two of which provide background for the third component, which is the primary purpose of the report:

i) a review of how recent Canadian project EAs addressed uncertainties associated with climate change (Section 5);
ii) a review of selected literature on methodologies for incorporating uncertainties into decision making (Section 6);
iii) an explanation and discussion of the use of these methods for decision making about adaptation to climate change (Section 7); and
iv) suggestions of how this work can inform the drafting of guidelines for accounting for climate change uncertainty in project EAs (Section 8).

The report presents a review of how climate change was considered in Canadian EAs. Specifically, information was sought on how each of the EAs addressed not only the potential impacts of climate change on the project, but also which adaptation measures were considered and how these were determined. Fifteen EAs from 2000 to 2009 were reviewed from various industrial sectors including hydroelectric, mining, drilling, remediation, pipeline, nuclear and wind farm projects, in which climate change was expected to be an issue. Of these, only two made no mention of climate change. Although the majority of the 15 EAs in this current study referred to the potential impacts of climate change on the project, they generally concluded that these consequences will have little effect on project design or operations. Two explanations were commonly provided: the impacts of climate change will occur after the lifespan of the project and/or there is simply too much uncertainty in predicting climate change to incorporate it adequately into the project's design and conception. Because of the complexity of climate change and difficulties in predicting what the future climate will be, project proponents tended to favour more research, monitoring and adaptation as the most practical strategies. Methods for choosing adaptation strategies are therefore needed as there remain significant limitations on the ability of project developers to

address climate change and its uncertainties adequately. There is also a need for methods to help identify the preferred strategy given the uncertain future scenarios.

Relevant literature was reviewed with respect to methods for decision making in the face of climate change uncertainty, both with and without estimates of the probabilities of future climate scenarios. Most of the standard methods for evaluating project alternatives, such as benefit-cost analysis and mutli-attribute analysis, suffer from their inability to meaningfully address uncertainties, which are a defining feature of climate change. However, there are a number of classical methods for explicitly incorporating attitudes toward risks and uncertainties into decision making. While there is a significant body of literature on these methods, that which has been applied to climate change is comparatively narrow and largely presents very limited examples and explanations.

The report then develops the application of these decision methods for the evaluation of adaptation measures with climate change uncertainty. Criteria that are considered include: maximin/minimax, maximax/minimin, minimax regret, Hurwicz alpha, and expected value. These offer potentially useful tools for comparing alternatives to adapt to climate change given the significant uncertainties.

These methods can also be used to compare adaptive and non-adaptive strategies. Adaptive management (such as “real options”) can require an extra initial cost to “buy” the flexibility to permit future actions to adapt to climate change as climate data emerge, in essence paying to reduce uncertainty. It can perform well as a risk-averse strategy, though its appeal depends on how much is paid to permit future changes.

The methods are illustrated through a hypothetical case of a hydroelectric project for both single- and dual-attribute problems as well as qualitative and quantitative measures. The first examples deal with only one attribute in order to illustrate the different criteria. They then become more complex by adding another attribute. The examples show that these methods can provide valuable information for decision making by requiring alternative future scenarios be considered explicitly and identifying how attitudes toward risks and uncertainties affect the preferred choice. The results are transparent and can be relatively simple to interpret, thereby facilitating discussions about tradeoffs in the face of the uncertainties.

Implementation of these methods requires the choice of appropriate sets of scenarios and adaptation options, the assessment of the impacts of the combinations of options with the future climate scenarios, an understanding of the attitudes of the decision maker and other stakeholders toward risks and uncertainties, the application of corresponding decision rules, and effective communication of the results to address conflicts and tradeoffs.

Guidelines can help proponents address these issues, as well as assist reviewers in judging whether the issues were treated adequately. Based on the research reported here, the following is a list of suggested general guidelines on the choice and use of methods for making decisions about adaptation to climate change and its uncertainties. The proponent should explicitly:

i) identify and scope whether and how future climate change may affect the project, directly and/or indirectly,

and, for each of these project vulnerabilities,

ii) identify the potential range of future climate change, and select climate change scenarios that adequately capture this range and the timing of effects,
iii) identify design options, including adaptive management strategies, to adapt the project to the future climate scenarios,
iv) estimate the level of the effect for each design option under each scenario,
v) identify, and justify the choice of, an appropriate decision making method(s) for comparing the design options on the basis of the estimated effects and the decision maker's attitudes toward risks and uncertainties, and
vi) communicate the results of the analysis such that the decision maker and stakeholders can understand the implications of the uncertainties and tradeoffs among the alternative design options.

Each of these general guidelines should be developed into more detailed guidelines with input from relevant proponents, agency reviewers, consultants, and non-governmental organizations interested in climate change. The discussion and explanations in this report can provide useful advice for developing more thorough guidelines.

1. Introduction

A broad consensus has emerged that climate change – predominantly global warming, caused by growing concentrations of greenhouse gases (GHG) in the atmosphere – will impact human activity in a number of spheres, though its precise effects are still highly uncertain. The Canadian Environmental Assessment Agency has identified the need for environmental assessment (EA) practitioners to address climate change in the planning of projects that can affect, or be affected by, climate change.

The 2003 Guidelines of the *Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment* (Canada FPTC 2003) take an important step forward in clarifying the importance of climate change considerations in project-level EAs by explaining the value of addressing climate change and offering generalized advice for doing so. The guidelines propose two broad practical approaches: 1) Identify sources of project-related GHG emissions and estimate their magnitude (GHG considerations); and 2) Determine how climate change may affect a proposed project (impacts considerations). This study focuses on the latter. Among the recommended actions that proponents can take at the project level are the "identification of project sensitivities to climate parameters and variability" and making public interest decision makers "aware of the climate change context within which a project is being proposed" (Canada FPTC 2003, 2). This study aims, in particular, at facilitating these two actions. Moreover, the guidelines go on to say:

> "Where the risks associated with the impacts of climate change on a project are of a private sector nature alone (for example, affecting the long-term profitability of the project), the proponent can choose to absorb this risk. However, if climate change risks extend beyond the project itself to potentially affect the public or the environment, this information must be factored into an informed decision by relevant authorities." (Canada FPTC 2003, 13)

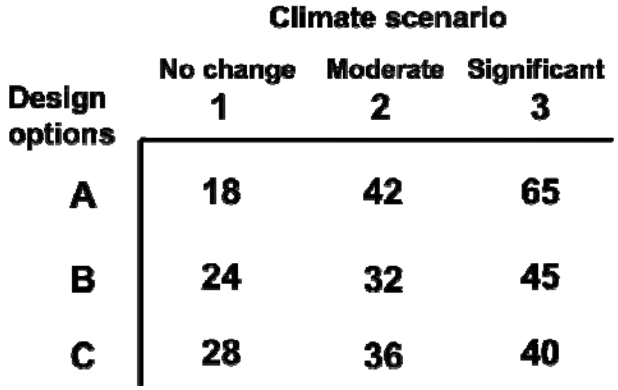
While the FPTC guidelines offer generalized advice and function as a useful starting point, they do not provide information on specific techniques for dealing with uncertainty in the proponent's decision making process. The uncertainty inherent in climate change poses serious challenges in EAs. Project proponents face the difficult task of deciding from among possible design alternatives in the face of climate change uncertainty. The scrutiny of a particular project in an EA must be undertaken in a limited time frame and using existing resources (Paoli 1994) in order to be useful. Addressing uncertainty through a combination of methods and variety of tools can lead to better decisions today about things we will observe only tomorrow.

The Agency has funded this study in order to further develop and adapt approaches for incorporating climate change uncertainties into project-level EAs. This research project builds upon a previous report for the Agency by Byer et al. (2004), which examined the use of scenario analysis, probabilistic analysis and sensitivity analysis as ways of estimating the effects of climate change uncertainty on project performance. Scenarios analysis and computer simulation can help analysts devise representative scenarios that can be used to generate synthetic data sets of relevant variables (temperatures, streamflows, power generation, flooding, etc.) in order to test project performance under uncertain future conditions. Probabilistic analysis can be used to estimate the likelihoods of those variables. Sensitivity analysis can aid in identifying the key variables most affected by climate change.

These approaches can provide valuable information about potential impacts under various future climate change assumptions. For example, Byer et al. (2004; 2009) and Byer and Yeomans (2007) showed that a hydroelectric project designed on the basis of historical streamflow could produce less electricity and result in more flooding than if it were designed on the basis of increased streamflow variability due to climate change. If one were certain of the extent of increased streamflow variability, the project's design could be altered on that basis (by expanding the reservoir volume, including additional turbines, modifying the spillway, establishing a different release policy, etc). However, there are many possible future climate scenarios, and we do not know which one to design for.

To illustrate the challenge, consider an abstract example (Table 1.1) in which a decision maker must select the appropriate design of a project on the basis of one impact in the face of climate change uncertainty. Three possible future climate scenarios are deemed to be representative of the range of uncertainty the project would encounter. These are: (1) persistence of the current climate, (2) a moderate degree of climate change, and (3) more significant climate change. Based on these scenarios, three project designs (A, B and C), each developed for a particular climate scenario (1, 2 and 3, respectively), are presented to the decision maker. The project design is matched to the corresponding scenario in order to realize the lowest adverse impact (the values in the table). For example, if Design B is chosen and Scenario 2 (moderate change) occurs, the project will result in an impact level of 32.

Table 1.1 Adverse impacts for alternative designs and climate scenarios



	Climate scenario		
Design options	No change 1	Moderate 2	Significant 3
A	18	42	65
B	24	32	45
C	28	36	40

The best design alternative depends on which climate scenario eventually materializes. If we knew which scenario will occur, then we would know which design to select. For example, if it is Scenario 1, Design A should be chosen because it would result in the lowest impact (18); if Scenario 2, Design B because it has the lowest impact (32); and if Scenario 3, Design C with an impact of 40. If the proponent ignores climate change and designs for “no change,” the result would be Design A. However, if climate change occurs, then there is the cost of increased impacts, in this case an increase from 18 to either 42 or 65.

An approach that is taken by some jurisdictions and project planners is to assume a particular future scenario and design for that: for example, to design a stormwater management system assuming a particular increase in storm intensities. But we do not know which scenario will be realized, and we may choose a design that is not best once we see how climate change unfolds. Thus, if Design C were selected but climate change turned out to be moderate (Scenario 2), the impact would be worse than it might have been (36 instead of 32). Even if there is reason to favour one scenario (e.g., Scenario 3) over the others, there still remains the possibility that one of the other scenarios will occur, and all of this should be factored into decision making. This report examines how decisions might be made in such circumstances.

2. Research Methodology and Structure of the Report

In advancing the work of the previous report, this research investigates alternative criteria and approaches for decision making under uncertainties, including well-established approaches such as minimize the maximum regret, maximize the minimum outcome, expected utility (Grima et al. 1986; Kassouf 1970; Keeney and Raiffa 1976; Lifson 1972; Welch 2002) and newer approaches such as “real options” analysis (de Neufville 2004). These approaches allow for the decision making to incorporate attitudes toward risks and uncertainties and assumptions, at least implicitly, about the likelihood of future scenarios. The use of real options in which the design builds in flexibility to adjust to changing circumstances is a form of adaptive management. This is a promising approach for responding to uncertainties about climate change.

The applicability of these approaches to specific projects will depend on a number of factors, including

- whether the impacts can be quantitatively or qualitatively estimated;
- whether the analysis must address a single objective (e.g., economic costs) or multiple objectives (e.g., costs and lives); and
- whether flexibility can be built into the project to permit future adaptation measures (e.g., designing a flood wall in a manner that permits subsequent height extensions).

In considering these issues, this report includes the following four components. The first two provide background for the third component, which is the primary purpose of the report.

i) a review of how recent Canadian project EAs addressed uncertainties associated with climate change (Section 5);
ii) a review of selected literature on methodologies for incorporating uncertainties into decision making (Section 6);

iii) an explanation and discussion of the use of these methods for decision making in relation to adaptation to climate change (Section 7); and
iv) suggestions of how this work can inform the drafting of guidelines for incorporating climate change uncertainty in project EAs (Section 8).

Through these steps, this work aims to introduce established decision making models to a wider EA community in a manner that is relatively straightforward.[1]

3. Uncertainty

Project planners face uncertainties[2] related to climate change from two interrelated sources: uncertainties about the future state of the climate, and uncertainties due to modelling of the climate to the local project area. Negotiating these uncertainties presents a significant challenge; however, rather than explicitly address climate change uncertainty in their decision frameworks, project planners often assume project robustness or planning horizons short enough that climate will remain stable during the project's lifetime. The EAs reviewed in Section 5 exhibit this tendency.

It can be complex to develop useful future scenarios according to which project planners can make key decisions. Climate change scenarios are typically computer-simulated realizations of the possible future climate in terms of different statistical parameters of climate-relevant variables (e.g., mean daily maximum temperature or monthly precipitation, etc.). Scenario output depends on numerous variables and assumptions including model scope and sophistication, (for example, the processes covered by a General Circulation Model and how they are represented mathematically), regional downscaling and numerical grid resolution.

In the past, project planners could base their designs on the historical climate conditions. They could assume that climate variability (e.g., frequency and intensity of storms) was *stationary*; that is, the probability distributions of temperature, precipitation, etc., would not change. Climate change will modify the amplitude and/or shift in the climate variability, which means that historically observed statistical parameters may no longer be a good basis for design.

Byer et al. (2004) illustrated how scenario analysis can be an important tool for considering climate change uncertainty in project EAs. By focusing scrutiny on a discrete subset of scenarios that encapsulates the likely range of possible climate change that the project will encounter, this approach renders the problem computationally more tractable. Representative scenarios facilitate the decision

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[1] To obtain advice on this work, a one-day workshop was held on April 27, 2010, at the University of Toronto. The authors presented preliminary results to approximately 20 people involved in project EAs and/or climate change. The workshop schedule and list of participants appear in Appendix 1 (Section 9.1). The participants confirmed the potential value of the concepts and methods that were presented.

[2] The Intergovernmental Panel on Climate Change (IPCC) defines uncertainty as "an expression of the degree to which a value is unknown." Uncertainty "can result from lack of information or from disagreement about what is known or even knowable" and "may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology …" (IPCC 2007, 882).

models featured later in this report. The critical issue is to determine which scenarios are meaningful and actually do capture an appropriate range of likely effects.

4. Adaptation

Mitigation and adaptation are two generalized strategies to address climate change. Mitigation directly attempts to reduce GHG emissions and slow the rate of climate change through various approaches such as substituting fossil fuels with renewable energy or forest replanting to boost carbon assimilation. It aims to reduce the severity of climate change with the hope of preventing some degree of avoidable warming, and retarding the progression of unavoidable warming. Mitigation alone appears insufficient to prevent at least some climate perturbation, leaving adaptation, a form of risk management, as an indispensable approach for reducing the vulnerability of projects to climate change (Stern 2007; IPCC 2007).

Adaptation is the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007, 869).[3] It is based on the premise that, by now, some degree of climate change is underway, or imminent, and that various associated impacts are unavoidable, with several already having been documented (Canada GC 2007). As such, it has become increasingly common for climate change to be integrated into policies and projects in terms of both mitigation and adaptation; this is especially critical for ventures whose time horizon is long (IPCC 2007).

Adaptation and mitigation can sometimes be interrelated. For example, observation of more frequent and intense heat waves that have put the electrical grid in precarious situations due to large cooling demand may lead a provincial energy authority to promote the development of more wind farms, other renewable energy and expanded lake water cooling systems for office buildings. These measures respond to warming that is already experienced, and hence they are adaptive. They may also happen to reduce overall GHG emissions if they substitute for some of the current generation based on fossil fuels and thus may mitigate further climate change. Adaptation measures can serve a dual purpose: to build adaptive capacity, or flexibility, into projects, or to deliver adaptive action (Willows and Connell 2003).

Adaptation measures can assume diverse forms, such as a physical adjustment, technological change, or regulatory and behavioural alteration. These measures may occur at the individual, community, or government scale (Auld 2008; Auld, MacIver and Klaassen 2007; Canada GC 2007). Time-scale considerations are also

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[3] The IPCC offers some useful definitions pertaining to adaptation. This can be classified into *anticipatory adaptation* (or proactive adaptation), which takes place before impacts of climate change are observed, and *planned adaptation.* The latter is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state. *Adaptation benefits* are "the avoided costs, or the accrued benefits, following the adoption and implementation of adaptation measures," while *adaptation costs* are "the costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs" (IPCC 2007, 869).

significant, in that adaptation responses may be influenced by actual changes in climate or by the modelled scenarios of anticipated changes (Canada GC 2007).

Anticipatory adaptation tends to result in a reduced long-term cost; conversely, reactive approaches may result in higher costs and may be particularly ineffective and detrimental especially when damages are irreversible. A case in point would be the extinction of a species or loss of alpine glaciers (IPCC 2007). Currently, various anticipatory forms of adaptation initiatives are being undertaken to reduce the severity of climate change across the globe. In Canada, several examples of anticipatory forms of adaptation measures are being taken. For instance, Inuit hunters use global positioning systems to aid in navigation during unpredictable weather; ski resorts develop alternative activities in order to diversify their economic base; the Quebec government has introduced regulations to limit development along coastal zones; and in Saskatchewan, water conservation measures have been implemented (Canada GC 2007).

It is important to distinguish between adaptation and *adaptive capacity*. Adaptive capacity[4] is the ability of the individual, community, industry or country to implement adaptation measures to climate change. Adaptive capacity is influenced by institutional structures, access to education, technological capabilities and financial resources (IPCC 2007) as well as the effectiveness of decision making frameworks (the focus here). Canada is considered to have a high adaptive capacity, whereas many developing countries tend to have a low adaptive capacity (Canada GC 2007). Likewise, the adaptive capacity may differ within the same country between rural and urban areas, and segments of the population, exemplified in the Canadian context between Aboriginal and non-Aboriginal groups. Having a high adaptive capacity does not necessarily imply that appropriate or essential adaptation measures will be implemented.

For some countries and industrial sectors the degree of adaptive capacity may constrain implementing sufficient adaptation measures to cope with climate change. An additional, and significant, limitation is related to the decision support tools available for choosing appropriately among adaptation initiatives. Decision making regarding adaptation strategies for climate change is a considerable challenge because the uncertainties are substantial and the potential for misapplying resources is great. In deciding which adaptation options are most viable, multiple factors need to be considered, such as the likelihood of the expected impact and the means (technological or financial) for implementing the strategy. Incorporating adaptation measures into project design and operations may attenuate long-term costs associated with climate change and may even reveal areas of opportunity. Conversely, overestimating the actual impacts may have the outcome of augmenting project costs (Canada GC 2007).

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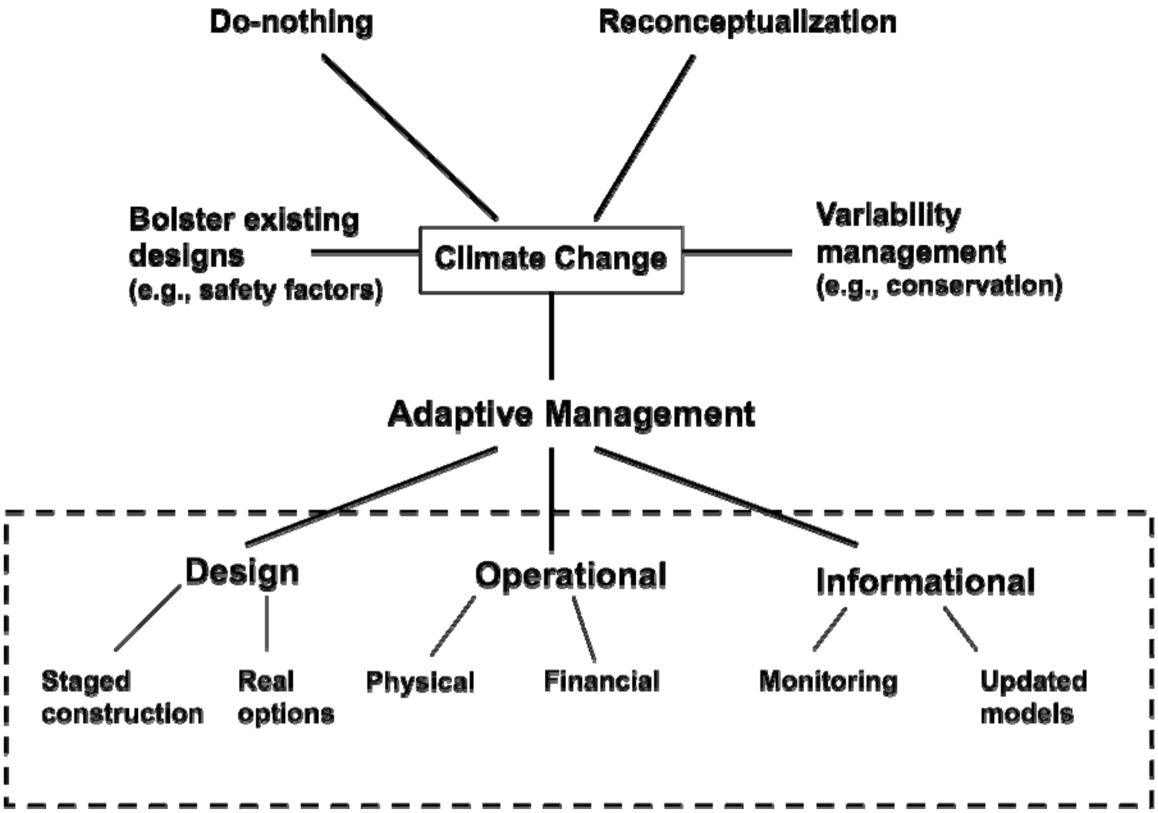
[4] The IPCC also defines it as “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences” (IPCC 2007, 869).

Figure 4.1 classifies anticipatory adaptation approaches for how a project proponent might attempt to adapt to climate change. Each of these approaches is discussed in the following subsections.

Figure 4.1 Broad approaches for adapting to climate change in project design and operation.



4.1 Do-nothing

Doing nothing in this context refers to project design that is not influenced by climate change considerations. While not an actual adaptation method, it is always a possible course of action. Inability to predict future climate scenarios, lack of confidence in climate models, gaps in knowledge of climate processes, and the expectation that climate change impacts will be felt mostly after the project's life all can encourage this choice.

4.2 Bolstering existing designs

It is general practice in engineering to design for larger than normal loads or conditions (e.g., applying *safety factors*). This can be useful for protecting against system failure, especially when uncertainty is not easy to characterize or quantify. For example, the supporting piers of the Confederation Bridge were designed for a 1-m rise in sea levels to specifically accommodate climate change concerns.

4.3 Variability management

Climate change is expected to increase the variability of certain parameters (e.g., the intensity of storms). Variability management involves design and operational measures that augment the capacity of the project to accommodate the increased variability. For example, a hydroelectric reservoir could be designed to handle larger inflows resulting from more intense storms. As another example, more frequent and prolonged hot spells would cause increased variability in electric power demands, which could be satisfied with extra peak generating capacity. In contrast to augmenting the project's ability to handle increased climate variability, it may be possible to modify the effects of the variability on the project. Implementing conservation measures (e.g., installing more efficient cooling systems or increased prices) could reduce the effects of the increased variability (e.g., lower average and peak demands).

4.4 Project reconceptualization

This entails rethinking the way a project is conceived, built and operated in order to significantly reduce a project's vulnerability to climate by considering hitherto unknown or unusual design elements. An example of reconceptualization is the shift away from traditional means of air conditioning for cooling office towers to deep-lake water recirculation and/or architectural changes such as green roofs. Reconceptualization may offer promise, especially in the medium to long term.

4.5 Adaptive management

An additional adaptation strategy, commonly applied in the natural resource sector, is *adaptive management*. The fundamental premise of adaptive management is flexibility. Because knowledge and information, in this case about climate change, are lacking, the appropriate adaptation strategy may be difficult, costly and impractical to devise and implement. The premise is that once sufficient experience is generated through "learning while doing" then the necessary measures can be taken (Lee 1999). Adaptive management may be particularly useful in the context of climate change because the uncertainty in predicting climate scenarios and outcomes is significant (Hauser and Possingham 2008). Alternatively, adaptive management has been viewed as a way to defer the problem to a later date (Lee 1999). As shown in Figure 4.1, it can be divided into three subclasses: informational, operational and design.

Informational flexibility

Monitoring is a deliberate strategy of obtaining data in order to observe how climate-induced changes are occurring. This is a prerequisite for most flexibility approaches. Modular design and staged construction (described below) rely on acquired data before new components are added and project phases are initiated. Monitoring can also provide valuable data for informing a project's operations, such as a reservoir release policy at a dam, based on both upstream and downstream needs (water supply, power, navigation, irrigation, etc.), climate and local hydrology. Decision models can also be updated (especially scenarios and the probability of their occurrence) with such information. The survey of EAs in this study indicates that proponents often planned to rely on monitoring to address climate change. A meaningful wait-and-see approach requires, as a minimum, good data collection and interpretation.

Operational flexibility

Operational flexibility puts the emphasis of project-level climate change adaptation on the post-construction phase. There are two broad categories: flexibility in the operations of physical elements (machinery, throughput handling, worker shifts, etc.) and financial instruments.

Flexibility in operations relates to how project assets are used and the decision rules governing their use. For example, the Lower Churchill Hydroelectric Generation Project (2009) proposed adapting to flow variation through operational modifications such as more frequent use of a spillway or running the turbines at greater capacity in the case of increased precipitation.

Financial instruments reassign the monetary risk of a project in order to protect a project's financial health. Protecting a project's bottom line from some degree of climate-related losses can help proponents and stakeholders adapt to new scenarios by ensuring adequate financial resources to undertake potentially costly retroactive measures at such time as they become urgently necessary.

Insurance is a traditional way of negotiating certain risks, essentially by passing them off to another party in exchange for a premium. For example, insurance might be purchased to cover potentially larger losses for existing risks (e.g., building collapse due to heavier wind loads) or new risks created by climate change (e.g., oil spill due to a ruptured pipe from thawing permafrost).

Financial derivatives such as options and swaps are essentially risk management tools that can help shift risk to those with a greater appetite for it, typically commodity market investors. They are commonly employed in the energy sector by both generators and consumers to circumvent exaggerated price dips or spikes when volatility is expected to be high. The California Energy Crisis of 2000–2001 provides an example of how system robustness, climate and financial hedging came together to create a particularly acute situation as the state embarked on its nascent deregulation. Hot summer weather combined with drought in the Pacific Northwest led to a high power demand and compromised supply. In a tight market, prices climbed, and some of the utilities, forced to pay high spot prices for natural gas, quickly became insolvent. If they had signed long-term gas purchase contracts or possessed gas market hedging instruments, they might have been able to resist bankruptcy.

Designed flexibility

Flexibility-oriented design requires a conscious upfront effort, with its associated cost, to design the project for potential future modification as climate change unfolds. An example is flood control embankments constructed with foundations so that retaining walls can later be added as flood intensity and frequency increase over time. This is essentially the notion behind *real options*. As the name suggests, there is a resemblance to options in the financial sector whereby an investor buys the right, but not the obligation, to buy or sell a particular security at a given price (on, or by, a certain date). The idea of a call option, for example, is that the holder of the option may purchase the stock at a set (strike) price per share on a specific date. If the market price of the stock is above the strike price, it will be attractive to exercise the option and then sell the stock at the higher market price. If the market price remains below the strike price, the option is not exercised. Dobes (2008) offers several examples of real options in the context of climate change.

In the context of engineered projects, a real option is the ability to build extra capacity or undertake some other design modification as conditions change and new information becomes available. The option allows the decision maker to avoid or put off some commitments now and wait to see what final investments are appropriate. Phased capacity expansion is a common example for engineering projects.

Incremental design allows investors to engage fewer capital resources in the project at any moment, rendering project financing easier (and perhaps ensuring the project's feasibility). It minimizes expenses that might subsequently prove to have been unnecessary. However, it may also involve upfront costs (essentially the option price) for extra design consideration and component retrofit capability and a potential loss in economy-of-scale benefits should full capacity eventually be realized. From an environmental perspective, incremental design may also be beneficial: if construction occurs only when needed, unnecessary construction and its associated waste (materials and energy consumption, GHGs, etc.) may be reduced. De Neufville (2002) describes the economic analysis of tradeoffs involved in real options to reflect the time value of money.

5. Review of Canadian Project EAs

This section of the report reviews how climate change was considered in 15 Canadian environmental assessments (EAs) conducted between 2000 and 2009. Specifically, information was sought on how each of the EAs addressed not only the potential impacts of climate change on the project, but also which adaptation measures were considered and how these were determined. The EAs were drawn from various industrial sectors in which climate change was expected to be an issue. These included hydroelectric, mining, drilling, remediation, pipelines, nuclear and wind farm projects. This review builds on a similar review by Lalani (2003) of 11 EAs from 1992 to 2000, which Byer et al. (2004) summarize. The 15 EAs that were reviewed are as follows:

Hydroelectric projects

- Lower Churchill Hydroelectric Generation Project (2009)
- Waneta Hydroelectric Expansion Project (2007)
- Romaine Hydroelectric Complex Project (2007)

- Glacier Power Ltd.'s Dunvegan Hydroelectric Project (2006)

Pipeline projects
- Emera Brunswick Pipeline Project (2007)
- Mackenzie Gas Project (2004)

Mining, drilling and remediation projects
- Prosperity Gold-Copper Mine Project (2009)
- Encana Shallow Gas Infill Project (2007)
- Kearl Oil Sands Project (2007)
- Sydney Tar Ponds and Coke Ovens Sites Remediation Project (2006)
- Cheviot Coal Mine Project (2000)

Nuclear project
- Bruce Power Project (2008)

Wind projects
- Summerside Wind Farm Project (2008)
- Wolfe Island Wind Farm Project (2007)
- Melancthon Grey Wind Project (2005)

Of these, only two EAs made no mention of climate change: the Cheviot Coal Project (2000) and the Emera Brunswick Pipeline Project (2007). This shows significant improvement from what Lalani (2003) observed, in which 6 of 11 EAs made no reference to any aspect of climate change. Although most of the 15 EAs in this study referred to the potential impacts of climate change on the project, they generally concluded that these consequences will have little effect on project design or operations. Two explanations were commonly provided: the impacts of climate change will occur after the lifespan of the project and/or there is simply too much uncertainty in predicting climate change to incorporate it adequately into the project's design and conception.

The following subsections outline how these sector-specific EAs addressed climate change adaptation and, where applicable, how decisions regarding adaptation were made.

5.1 Hydroelectric projects

The impacts of climate change on hydroelectric projects depend on where in Canada the venture is located. The Canadian climate is generally predicted to become warmer, and precipitation patterns are expected to change, ultimately affecting river flows and lake levels (Canada GC 2007). These changes will affect the production or supply of hydropower and will be magnified by alterations on the demand side. For example, meeting peak energy demand in Western Canada may become more problematic as glaciers retreat and constrict fluvial discharge. This may be exacerbated by an increase in the number and magnitude of heat waves, and hence, the demand for electricity for air conditioning (Canada GC 2007). Climate change can affect the design, operation and maintenance of hydroelectric facilities in several ways including a change in storage and supply, flooding, a change in the flow rate (may be higher or lower), and changes in the ice regime, all factors that EAs should now consider (IPCC 2001; Glacier Power 2006).

The four EAs on hydroelectric projects that were reviewed all addressed climate change, its impacts and how the venture contributes to reducing GHG emissions. The reports often dismissed the severity of the consequences of climate change on the project either because of the high degree of uncertainty associated with future climate predictions or because the project proponents claimed that the outcomes of climate change simply would not affect the venture. For example, a common sentiment found throughout the reports was exemplified by the Romaine Hydro EA, which stated that because of large uncertainties it was “premature to establish strategies” (2007, Vol. 7, Sec. 49, p. 9). Regardless, the reports yield several lessons on how an EA may incorporate climate change and adaptation measures into the assessment of hydroelectric projects.

A major concern for hydroelectric projects is to maintain storage or supply capacity. Both the IPCC (2001; 2007) and the GC (2007) propose that the best adaptation measure is to expand the reservoir capacity by increasing the storage area and volume or by building an additional storage unit. For instance, the GC (2007) explains that increased winter snow melt in northern Canada may reduce the natural snow storage held in the reservoir, and so the storage capacity will need to be extended. The GC’s recommendation is to either raise the height of the dam or, if this is unfeasible, then to construct an additional storage unit. The EAs reviewed discussed similar adaptation strategies. The Glacier Power EA called for a reservoir to store at least 1.5 years’ flow, claiming that this should be sufficient (2006, Vol. 2, Sec. 14). This may prove inadequate, in that the GC (2007) recommends redefining the inflow design flood, that is, the most severe flood that the facilities are designed to handle. Enhanced forecasting and management operations may incorporate additional adaptation methods for ensuring the supply of energy. For example, the Romaine Hydro Project aimed to adapt to changes in storage through improving the forecasting of the supply and demand for energy and improving knowledge about changes in precipitation and temperature. The Romaine Hydro EA further asserted that, as knowledge about climate change improved, adaptation strategies would be adopted (2007, Vol. 7, Sec. 49).

Flooding is always a concern for hydroelectric projects and, in a changing climate, the frequency and intensity of extreme weather events are expected to increase. Adaptation strategies proposed by the IPCC (2001; 2007) include raising the flood protection levees, building a catchment source control to reduce discharge, and designing systems to meet the extreme 5-year flood event. Similarly, the GC (2007) suggests the need to redefine the inflow design flood for which a dam and its facilities are designed and constructed to withstand. All the reviewed hydroelectric EAs addressed flooding, but not necessarily in reference to climate change. The Waneta Hydro Project was designed for a 1-in-200-year flood event, and stated that in an “extreme event the power house may be flooded but not compromised” (2007, Part E, Sec. 1, p. 161). The Lower Churchill EA applied the PMF (probable maximum flood) in its design of the generation facilities. The dam was specified to withstand, but also surpass, the PMF and was designed to meet over three times the maximum flow ever recorded over a 28-year period. Hence, the authors of the Lower Churchill EA were confident that its facilities were designed to cope with any future climate changes that might have implications for flooding (2009, Vol. 1, Part A, Sec. 10.5.1.2). Finally, the Romaine Hydro EA claimed that the current flood design standards required in Quebec already protected it against extreme flood events so that changes in climate would have negligible effect (2007, Vol. 7, Sec. 49).

Variations in flow regime have the potential to affect hydroelectric generation and, in turn, could compromise reliably meeting electric power demand; adaptation measures are critical to ensuring a continued supply of energy. The IPCC (2007) states that an improvement in seasonal forecasts can facilitate offsetting some of the hydrologic changes associated with climate change. This in turn would allow management entities to better anticipate changes in flow. Although the EAs recognized that changes in flow are likely to occur, they tended to be optimistic. For example, Waneta Hydro EA referred directly to alterations in flow due to climate change. It maintained that changes in the hydrologic regime will result in earlier peak spring flows, longer low flow periods and increased winter flows, ultimately affecting power production. Nonetheless, it claimed that “this will not necessarily mean, however, that project viability will be affected because the climate change effects will be system-wide and under such conditions the price of power will likely increase” (2007, Part E, Sec. 1, p. 161). Consequently, no adaptation measures were considered. Glacier Power acknowledged fluctuations in flow (not necessarily due to climate change) and designed its headworks to handle the PMF and low flow conditions (2006, Vol. 3, Sec. 3.2.2). Finally, the Lower Churchill EA proposed to adapt to flow variation through “adaptive management.” For example, it proposed that an increase in flow due to increased precipitation may require the spillway to be used more frequently or the turbines to be operated at a greater capacity (2009, Vol. 1, Part A, Sec. 10.5.1.6).

Addressing the effects the project will have on the river ice regime is an EA requirement because it constitutes a valued environmental component (VEC) (Glacier Power 2006). Glacier Power evaluated in depth how the project would affect the ice regime and reviewed various future climate scenarios to determine the implications for changes in ice cover. It limited its assessment to alterations in air temperature, deeming future precipitation changes too uncertain. The following climate scenarios were considered: years 2020, 2050, 2080, and varying temperatures by 1 to 2°C for the short term and 3 to 5°C for the long term. It concluded overall that there would be no significant differences in ice regime with or without the project (2006, Vol. 4, Sec. 4.7.5.11). The EA concluded, “A change to a warmer climate will affect the ice regime on the Peace River but this change is not expected to affect project operations” (2006, Vol. 3, Sec. 3.11.4, p. 54).

Finally, all EAs except that for Waneta Hydro featured an extensive section on climate change and its potential effect on the environment and project. The Glacier Power EA recognized that a warmer climate accompanied by an increase in precipitation can influence the river flow and ice regime yet claimed that these changes would not affect the operation of the project, primarily because of the storage capacity of nearby Williston Lake (2006, Vol. 2, Sec. 14). In the Romaine Hydro EA, 25 different future climate scenarios were used (up to the year 2050) with temperature changes from 1 to 4°C (spring, summer and fall) and 2 to 7°C for winter. Incorporated into the models were alterations in precipitation ranging from −10% to +30%. The project developers concluded that, because of the wide range of future climate and hydrology estimations, it is too complex to establish adaptation strategies under such high uncertainties. Hence, they proposed that as knowledge about climate change increases, adaptation strategies will be adopted, essentially adopting a strategy of reactive adaptive management (2007, Vol. 7, Sec. 49).

Similarly, the Lower Churchill EA utilized several model simulations to assess the effect of climate change on the river with an increase of 0.5 m sea-level rise. Under each scenario, mean river flow increased. Regardless, it concluded that "the current project design adequately accounts for climate change and the overall economic feasibility of the project will not be affected" (2009, Vol. 1, Part A, Sec. 10.5.1.6, p. 319). Also, because of uncertainty, the proponents maintained that it is unfeasible to implement additional adaptation measures. They argued that the incorporation of climate change into their management and operations procedures would be sufficient to adapt to any climatic scenarios (2009, Vol. 1, Part A, Sec. 10.5.1.6).

All the hydroelectric EAs addressed climate change in some manner. The EAs discussed how the project will help mitigate climate change by producing energy from a clean renewable source. They also described what the predicted changes in the given region were likely to be and how these would affect the project. Three out of the four EAs provided a detailed summary of the climate models used to predict future changes. The general consensus was that climate change would have little impact on the projects and that the projects were designed adequately to accommodate any such changes. Additionally, the EAs stipulated that through continued research and monitoring the impacts of climate change could be better understood and incorporated into project management and operations, which might form part of an adaptation strategy.

5.2 Pipeline projects

Climate change is expected to have impacts on other infrastructure such as pipelines, especially in northern regions where changes in the cryosphere (permafrost, snow and ice) are expected to be pronounced (Canada GC 2007). A warming climate will cause the permafrost to thaw and, as a result, the soil to subside, augmenting risk to the structure and stability of pipelines. An increase in the number and severity of extreme events such as floods and heavy rainfall may also cause erosion and rupture of the pipeline (IPCC 2007). These potential impacts could affect the design and maintenance of pipeline projects.

Two pipeline project EAs, for the Mackenzie Gas Project (2004) and the Emera Brunswick Pipeline Project (2007), were reviewed. The Mackenzie Gas EA contained an in-depth analysis on climate change and how the project would likely be impacted by future alterations. Conversely the Emera Brunswick Pipeline document made no reference to climate change. The Mackenzie EA applied several climate scenarios to assess the impacts on the project's design and operations. A multi-stakeholder workshop with experts in the field determined the most appropriate scenarios to use. The Mackenzie EA concluded that the outcomes of climate change over the lifespan of the project would not be significant and could be dealt with through monitoring and management. Nonetheless, the report identified several design and operation adaptation measures, specifically regarding thaw settlement, erosion and extreme events such as flooding.

The IPCC (2001; 2007) does not provide significant details on adaptation measures for infrastructure projects such as pipelines; it simply suggests that such structures should be designed differently. The GC (2007) presents several recommendations, especially in reference to thaw settlement, that is, primarily to avoid thaw-sensitive soils and, secondly, to design the infrastructure to preserve permafrost. Permafrost preservation may be achieved by adding insulation, inducing artificial cooling using a thermosyphon or ensuring the ground remains frozen by incorporating air convection embankments. Alternatively, it also suggests that the permafrost be removed and replaced with thaw-stable material prior to constructing the pipeline or to begin the construction after the vegetation has been removed and the ground has settled (Canada GC 2007). The Mackenzie EA addressed thaw settlement in several ways in relation to climate change. For example, in order to ensure that pipeline operating temperatures not cause thaw along the structure, it was located north of Inuvik, where the temperature is expected to remain at −1°C or colder. Additional measures included constructing the facilities on piles and insulated pads to reduce the possibility that the building heat will melt the surrounding permafrost (2004, Vol. 5, Part F, Sec. 14.1.2).

Erosion from extreme events such as flooding, strong winds or water can increase the risk that the pipeline will rupture or malfunction. The Mackenzie EA outlined several measures to reduce the pipeline's susceptibility to erosion including constructing the pipeline 1.2 m or more deeper to prevent water and ice scour at the crossing locations, ensuring that the pipeline is placed far enough from the river bank to reduce exposure at crossings, and implementing erosion control measures such as revegetating the soil and diverting surface water off the right-of-way with cross ditches (2004, Vol. 5, Part F, Sec. 14.1.2).

Adaptation initiatives taken to address flooding included constructing the production facilities 2 to 3.5 m above ground using pads or elevated platforms and designing the barge-based gas-conditioning facility to accommodate a 5- to 6-m rise in water level. Extreme runoff and heavy precipitation can also adversely affect such a project. To protect against this hazard, both surface and subsurface control devices were located along the right-of-way to manage runoff, and culverts were designed to withstand 150% of the maximum expected flow (2004, Vol. 5, Part F, Sec. 14.2).

The Mackenzie EA evaluated potential impacts of climate change on the project using a combination of 29 different model simulations and incorporating several future predictions of GHG emissions as outlined in the IPCC reports. It held a stakeholder workshop attended by specialists from Environment Canada, non-governmental organizations and northern native groups to establish several possible climate scenarios. These scenarios indicated future temperature changes from 3 to 6°C and an increase in precipitation by as much as 11.8% over the 30-year lifespan of the project. Based on these projections, the EA considered groundwater, hydrology, water quality, fish and fish habitat, soils, landform and permafrost, and vegetation and wildlife. The report concluded: "Although some uncertainty exists, and climate change could affect the northern environment, over time, it is unlikely that the effects of climate change over the life of the project will change baseline conditions to such an extent that the assessment of the potential effects of the project will change" (2004, Vol. 5, Part F, Sec. 11.1.2, p. 1). This conclusion was challenged by Environment Canada (2005), which argued that the EA did not adequately address climate change and climate variability. Specifically, Environment Canada voiced concerns that the EA overlooked the consequences of climatic extremes, such as the impacts of several warm years in succession. The response of the proponents was that the model simulations and the design and construction of the pipeline sufficiently considered these issues and that monitoring and adaptive management would be used to reduce any risk or damage to the pipeline in the future (Canada Environment Canada 2005).

5.3 Mining, drilling and remediation projects

Mining, drilling and remediation projects will be impacted by climate change in varying degrees depending on the stage of the project – during exploration, operation or site reclamation – which occur at different time scales. For instance, in northern Canada, changes in ice cover and permafrost will affect the timing and location of oil exploration (Canada GC 2007). During mining operations in the north, the stability of waste rock piles and tailing ponds will require monitoring as they rely on frozen ground conditions. Both drought and extreme precipitation can have implications for mining infrastructure. For instance, tailing ponds are often kept topped with water to prevent oxidation; in the case of heavy precipitation these may overflow causing a release of contaminants. Tailing ponds may also be impacted by an increase in temperature and evaporation, which could expose the raw tailings and increase their vulnerability to weathering (Canada GC 2007).

Five EAs were reviewed in these sectors: the Cheviot Coal Mine Project (2000), Sydney Tar Ponds and Coke Ovens Sites Remediation Project (2006), Encana Shallow Gas Infill Project (2007), Kearl Oil Sands Project (2007) and the Prosperity Gold-Copper Mine Project (2009). With the exception of the Cheviot Coal Mine EA, all addressed the issue of climate change to some degree. The EAs for both the Sydney Tar Ponds and Coke Ovens Sites Remediation Project (2006, Sec. 5.8) and the Encana Shallow Gas Infill Project (2007, Vol. 3, Sec. 9.4) asserted that the impacts of climate change were considered, yet, because of the duration of the project, the potential effects are expected to be minimal. The reports from the Kearl Oil Sands

Project and the Prosperity Gold-Copper Mine Project provided more in-depth analyses and offered suggestions for adaptation measures to climate change.

Mining operations generally have an impact on hydrology and groundwater; these changes are expected to be magnified because of alterations in climate. The GC (2007) recommends reducing the intake of water during operations, recycling processed water and establishing infrastructure to move water from tailing ponds and quarrels for use underground. The Prosperity Mine EA (2009, Vol. 1, Sec. 9) proposed a channel to divert water north of the open pit to cope with reduced hydrologic yield. Extreme events such as flooding, precipitation, snowstorms and droughts must be considered in the design and operation plans of mining, oil and gas projects. The Sydney Tar Ponds and Coke Ovens Sites Remediation EA (2006, Sec. 5.8) asserted that extreme weather has been addressed by situating operations outside any potential flooding area and that all structures would be built to withstand hurricane force winds. The Encana Shallow Gas Infill EA (2007, Vol. 3, Sec. 9.2) stated that it will adapt to an increase in the number and magnitude of extreme events through the suspension or modification of activities during such occurrences.

Providing a more detailed analysis, the Prosperity Mine EA (2009, Vol. 1, Sec. 18) outlined several adaptation measures for extreme events. For excessive precipitation, the project design incorporated an inflow design flood volume for a 72-h storm event, which was considered sufficient to manage any net increase in precipitation due to climate change. Water management structures such as ditches and ponds were designed to withstand a return period longer than the duration of the mine operation (>20 years). The effect of climate change on the duration curves would be evaluated and the new values applied to the water management system. In considering drought, the EA maintained that the tailings storage facility (TSF) would have a minimum volume with an operating buffer under average conditions. Strong winds and excess water can cause waves in the TSF and, as such, the structure was developed to withstand a 1-m high wave above the pond. Finally, in relation to snowstorms and heavy ice loads, the building was designed to meet building code requirements to support roof loading from snow and associated rain events (based on a 1-in-50-year snow load).

An important component of mining and oil projects is the end phase of the activity, which requires site reclamation. Since this stage comes at the very end of the project it is critical that climate change be accounted for. The Kearl Oil Sands EA made a considerable attempt at incorporating future climate change into the reclamation activities (2007, Vol. 7, App. 3). Based on a review of relevant literature, results from climate-soil modeling and studies on interpretations related to soil reclamation, the report highlights how future changes in climate will affect soil composition and distribution, and hence reclamation activities. Modeling the future impacts on soil composition and distribution involved the use of various models (i.e., the Hadley Centre Coupled Model), the upper bounds for temperature, the lower and upper bounds for precipitation, combined with various IPCC emissions scenarios in order to produce the results and recommendations. The Kearl Oil Sands EA proposed limiting the effects of soil dehydration by using fine textured organic materials in the first 1-m level of the ground (2007, Vol. 7, App. 3) to reduce the potential for soil drying and promote healthy forest growth. Reclamation is meant to re-establish the pre-project natural ecosystems; however, it was recognized that with a changed climate this may not be possible. As such, the report stated that the vegetation would be adapted to the climate of the time (2007, Vol. 7, App. 3).

Three of the four EAs addressed climate change. Particularly, the Kearl Oil Sands EA (2007, Vol. 4, App. 2B) presented a detailed analysis on climate change, the project's contribution to GHG emissions and the likely impacts of future changes on the venture. It used numerous models and emission scenarios as outlined by the IPCC which, in turn, were ranked using a multi-stakeholder consultation process. In the end, nine models and scenarios illustrating the upper bounds of temperature and the lower and upper bounds for changes in precipitation were utilized (2007, Vol. 4, App. 2B, Sec. 1.3). Using these nine models, the EA concluded that climate change will not have a significant impact and that, through continued monitoring and revision of management plans, any unforeseen outcomes would be mitigated. Similarly, the Prosperity Mine EA (2009, Vol. 1, Sec. 18) concluded that the project's sensitivity to climate change during all phases (construction, operation and closure) would be nil to low.

5.4 Nuclear project

Nuclear power facilities and operations may expect several impacts associated with climate change. The IPCC (2007) identifies melting permafrost and soil subsidence as a risk to nuclear facilities in northern regions which could potentially lead to structural failures. Other negative outcomes may be the complete failure to produce electricity, exemplified in France in the summer of 2003 during a severe heat wave that eventually led to a power failure. This derived from a combination of factors including the increased demand for electricity for air conditioning and augmented river temperatures that reduced the cooling efficiency of the nuclear power plants (IPCC 2007).

The Bruce Power EA (2008) was reviewed to provide an example of how nuclear power projects address climate change. A general problem for nuclear activities is the impact that the venture will have on the hydrology and water quality of the area, which may be exacerbated with climate change; this is a concern for both facility operation and environmental integrity. The project, located on Lake Huron, acknowledged that changes in precipitation and temperature are likely to have consequences for lake conditions and water levels. Yet the report claimed that increased evaporation due to higher temperatures would likely be offset by increased precipitation and so no adaptation measures were required (2008, Vol. 1, Sec. 6.6.2). With respect to severe weather events, the report asserted that it had taken into consideration the effects of such occurrences in the project's design and that climate change should not involve further additional impacts (2008, Vol. 1, Sec. 6.6.2).

During the public consultation process several issues regarding climate change were raised. Apprehension was voiced in reference to the cooling option and whether climate change would be considered in the choice of methods available. The report's response was that a warming climate would increase lake temperatures and so cooling towers might be the most appropriate adaptation measure to incorporate into the project (2008, Vol. 3, App. D).

The report extensively considered climate change; the project's GHG emissions, its mitigation potential, and the effects climate change might have on the project (2008, Vol. 2, Sec. 11). It also considered the project's impacts on the valued environmental components (VECs) and reevaluated the VECs in the context of a changed climate. It then considered how the project would likely impact the VECs under a different climate scenario. Despite such an in-depth analysis, in every case the assessment concluded: "no different or changed effects of the Project on the predicted future environment are expected based on the modelled climate change scenarios compared with those predicted in the assessment of the Reference Project and Alternative Project Scenarios" (2008, Vol. 2, Sec. 11, p. 11.5). Consequently, the EA dismissed any negative outcomes and provided limited adaptation strategies. It further concluded that over the 60-year lifespan of the project there would be no additional negative effects of climate change on the project and its operations.

5.5 Wind farm projects

Growing concerns about climate change and energy use have sparked greater interest in renewable forms of energy, such as wind power. While wind farm projects are a climate mitigation strategy in that they represent a shift away from GHG-producing energy generation, their design and operation must also address the effects of climate change on their structural stability and power generating capacity. The IPCC (2007) claims that, in particular, wind farms must consider the location of the facilities as the variability of climate may alter wind patterns.

Three wind farm project EAs were reviewed: the Melancthon Grey Wind Project (2005), Wolfe Island Wind Farm Project (2007) and the Summerside Wind Farm Project (2008). Each discussed climate change, the mitigation potential of the project and also how the venture would likely be impacted by climate change. The greatest apprehension regarding climate change and wind farm activities tended to be focused on extreme weather events.

The Melancthon Grey EA addressed extreme events and claimed that the blades, nacelle and tower would be constructed to withstand the impacts from extreme and heavy hail events. Also the blades would shut down in the occurrence of heavy ice loads or speeds greater than 25 m/s (2005, Sec. 7.18). The Wolfe Island EA specifically stated that future climate predictions of increased temperature and precipitation would likely be accompanied by increased wind speeds. Taking these predictions into consideration, the project designed its blades to pitch out of the wind during strong winds in order to maintain the structural integrity of the turbine (2007, Sec. 7.21). Addressing sea-level rise, the Summerside EA recognized that assets may be adversely affected by increased erosion, yet no adaptation measures were put forward. The report maintained that a research and monitoring program would be established so that adaptation strategies might be properly incorporated at a later time when its full complexities are better understood (2008, Sec. 6.2).

5.6 Concluding remarks from the review

The review of the fifteen EAs from various sectors reveals that thirteen addressed climate change to some degree and several (such as the Kearl Oil Sands EA) provided an extensive analysis in which models and predictions were used to evaluate their project. A general conclusion in the EAs was that the potential impacts of climate change on the project would be minimal. (McBeath (2003) had similar findings with respect to transportation infrastructure systems in Alaska.) For instance, the Melancthon Grey Wind Project EA (2005, p. 117) concluded, "The potential impacts of the climate on the Project are expected to be limited to levels well below those that could cause significant negative net effects" (see also Encana 2007, Vol. 3, Sec. 9.4, p. 9-3; Glacier Power 2006, Vol. 4, Sec. 4.7.5.2.11, p. 190; Waneta 2007, Part E, Sec. 1, p. 161).

There are two reasons that may explain why project proponents commonly arrived at this conclusion. One is that the lifespan of the proposed activity would end before the impacts of climate change are expected to materialize, as exemplified in the Sydney Tar Ponds and Coke Ovens Sites Remediation Project EA:

> "Because of the relatively short construction and operation period involved STPA does not foresee climate changes having any significant effect upon the Project as a whole or the incinerator in particular (2006, Sec. 5.8, p. 91)."

Similarly, the Mackenzie Gas Pipeline Project EA stated:

> "The conclusion is that although some uncertainty exists, and climate change could affect the northern environment, over time, it is unlikely that the effects of climate change over the life of the project will change baseline conditions to such an extent that the assessment of the potential effects of the project will change (2004, Vol. 5, Part F, Sec. 11.1, p. 11-1)" (see also Bruce Power 2008, Vol. 2, Sec. 11, p. 11-22).

Secondly, project proponents maintained that there was either a lack of information concerning changes in climate or significant uncertainties with the modeled predictions. For instance, the Romaine Hydro Project EA maintained,

> *« On ne peut pas établir clairement de stratégie d'adaptation sur la base de projections climatiques incertaines…* »
> "We cannot clearly establish adaptation strategies on the basis of uncertain climatic projections…" (2007, Vol. 7, Sec. 49, p. 9).

In a similar vein, the Kearl Oil Sands report asserted,

> It is not possible to reliably predict any future hydrologic effects due to climate change or variability forward in time for any environmental impact assessment, since the linkage between changes in air temperature and precipitation, and changes in streamflows in the oil sands region can not be established on the basis of available data (2007, Vol. 4, App. B, p. 47).

Because of the complexity of climate change and difficulties in predicting what the future climate will be, project proponents tended to favour more research, monitoring, and adaptation as the most practical strategies.

Methods for choosing scenarios and adaptation strategies are needed, as there remain significant limitations on the ability of project developers to address climate change adequately. There are no clear guidelines indicating which scenarios project developers should consider, nor are there guidelines to help the decision maker use this information in determining the best adaptation strategy, particularly in the face of the uncertainties associated with the scenarios.

6. Decision Making with Climate Change Uncertainty: A Literature Review of Approaches

The review of Canadian EAs in the previous section reveals that project proponents in Canada are paying increasing attention to climate change. This development is positive but remains hampered by unsystematic approaches. The main goal of this report is to help guide such varied efforts toward a more structured approach for making decisions about adaptation to climate change at the project level. To this end, relevant literature was reviewed with respect to methods for decision making in the face of climate change uncertainty. This section summarizes that review. In Section 7, the more promising of these approaches are illustrated and developed for use as tools for project-level EAs.

The United Nations Framework Convention on Climate Change (UNFCCC 2008) and Feenstra et al. (1998) present compendia of tools and methods for decision making and adaptation to climate change including benefit-cost analysis (BCA), cost effectiveness analysis, adaptation decision matrix (ADM), tools for environmental assessment and management (TEAM), etc. Benefit-cost analysis, for example, evaluates alternatives in terms of economic efficiency (i.e., best monetary-equivalent return for a given financial investment). Uncertainty about the future can be incorporated into BCA by increasing the discount rate to reduce the present value of future unknown benefits and costs, though this would be inadequate for evaluating adaptation alternatives for climate change. Multi-attribute methods such as TEAM estimate the various attibutes and apply weights according to their relative preferences. UNFCCC (2008) presents these tools in a standardized bibliographic manner, describing their appropriate use, scope, key inputs and outputs, required training, computer needs, application cost estimates and references to documentation for further reading. Feenstra et al. (1998) similarly evaluate the tools in terms of level of precision, ability to address uncertainties, input needed and resource requirements. These tools address uncertainties primarily in the context of sensitivity analysis applied to the values assumed in the analysis (e.g., benefits, costs, weights) rather than explicitly and directly address uncertainties about the future climate. These and similar methods have been discussed by numerous authors including de Bruin et al. (2009a, 2009b), Qin et al. (2008), Bell et al. (2001, 2003), Janssen (2001) and Steele et al. (2009).

Other methodologies have been developed that can explicitly incorporate uncertainties into decision making, perhaps in combination with methods such as BCA. These can be classified according to whether probabilities are assigned to potential future climate scenarios. The various methods, each of which reflects a different attitude toward risks and uncertainties, are discussed below. To the extent that climate change uncertainty shares characteristics with other forms of uncertainty, general decision making techniques that deal with uncertainty are potentially useful in project EAs.

6.1 Methods using probabilities

Methods in this category are based on the analyst being able to assign subjective probability values to different future climates. For example, if three future climate scenarios are being considered, the first scenario may be perceived as 30% likely, and the second and third scenarios as 10% and 60%, respectively. These probabilities are combined with project outcomes (benefits and costs) under the different scenarios to compare the alternatives (e.g., their expected values or expected utilities). One approach, Bayesian analysis, updates probabilities according to new information, rendering it also a tool for adaptive management.

Dessai and van der Sluijs (2007) suggest Bayesian analysis is a potentially useful method for analysing climate change uncertainties pertaining to various infrastructure systems and projects. One of the main advantages derives from the ability of Bayesian analysis to estimate the expected value of perfect/imperfect information about climate change.

Hobbs (1997) provides a thoughtful summary of the value and challenges of employing Bayesian analysis for improving decision making when faced with climate change uncertainty. He confronts the major issues of inference, subjective assessment and updating models given new information. He also describes a framework based on a Bayesian Monte Carlo analysis for updating models of sea level rise. Hobbs et al. (1997) applied decision trees and Bayesian analysis to assess the value of incorporating climate change uncertainty into decisions about water resources infrastructure; specifically, they applied the approach to an example of water level regulation and breakwaters for shoreline protection on Lake Erie. The authors note that accounting for climate change uncertainty can help protect against significant opportunity losses and that, just as real options are used in a variety of contexts, the decision making methodologies are no different in a context of climate change than for other forms of uncertainty commonly encountered in engineering projects. Their analysis also provides estimates of the value of waiting for better information on climate change before making a decision.

As explained by Hobbs (1997), the decision maker’s attitude toward risk can be incorporated into Bayesian analysis through the use of utility functions (Keeney and Raiffa 1976).

6.2 Methods without probabilities

This category is applicable when probabilities cannot be assigned to the various future climates because no reasonable subjective estimates are available or agreed upon. It includes classical decision rules such as maximin and minimax regret (Kassouf 1970; Lifson 1972) which have been applied in various contexts such as water resources planning (Maass et al. 1962). Their application to decision making under climate change uncertainty has been discussed by several authors, including Bretteville (1999), Clarke (2008), and Willows and Connell (2003), as summarized below.

Bretteville (1999) showcases the classical decision rules applied at the policy level to climate change, offering a simplified example in which damage due to climate change with or without policy action is assumed known, as is the cost of implementing the policy. A payoff matrix is constructed to which the various decision criteria (i.e., maximax, maximin, minimax regret, expected payoff, etc.) are applied to two policies: one based on the precautionary principle and the other on do-nothing. Three scenarios were considered: insignificant damage from climate change, damage resulting from climate change when the policy is effective, and damage resulting when the policy is ineffective. Bretteville shows that the preferred policy choice depends on the choice of decision criterion, the magnitude of costs and the framing of the issue of uncertainty. The study also addressed the distinction between risk and uncertainty, where risk implies knowledge of the probabilities for an event, while uncertainty indicates an inability to assign meaningful probability values. Expected utility-based methods can be appropriate where probabilities and outcomes are reasonably known. Since this is not the case with climate change, Bretteville concluded that non-probabilistic decision criteria might therefore be more suitable.

Willows and Connell (2003) provide a simple hypothetical example of the use of decision rules (maximax, minimax and minimax regret) for adaptation to climate change. In their example, they structure a payoff matrix based on the degree of climate change that eventually materializes (rapid, little and no climate change) and the investment in adaptation (no, low, medium and high).

Clarke (2008) applies the decision rules to assess the “social insurance” of policies in minimizing regret and worst case outcomes (the precautionary principle) and evaluates the role of “all weather” and mixed policies. Specifically, he accounts for the role of potentially high policy conception and implementation costs, ineffective policy, climate change costs that are less than anticipated, opportunity costs and returns from policy initiatives regardless of ultimate climate scenario. Adaptive management is featured in an example of policy related to a river basin with two attributes (agricultural output and biodiversity); the policy integrates the classical rules with utility theory in order to construct a payoff matrix having values deriving from a social welfare function based on the two attributes.

6.3 Adaptive management and flexibility

As described earlier (Section 4), adaptive management is a general approach for responding to uncertainties about climate change by deferring certain decisions. Adaptive management alternatives can be compared with non-adaptive alternatives using the methods with and without probabilities described above. With respect to climate change, the literature on decision making about adaptive management has focused on Bayesian analysis (Hobbs 1997; Hobbs et al. 1997) as described above. More recently, Yang et al. (2008) provide a sophisticated mathematical approach to real options for scrutinizing investment decisions in electric power production in the face of regulatory uncertainty pertaining to prices of carbon emissions. The premise is that regulation in several jurisdictions is still evolving but is bound to affect, directly or indirectly, the price of carbon emissions and that such uncertainty in emissions price affects the selection of energy production technology, facility operating expenses and investor funding decisions. The real option relates to the flexibility that companies have to time their investments in the face of regulatory uncertainty and exploit a wait-and-see stance. In order to assess the value of waiting, the authors employ a dynamic programming model that compares the expected value of an upfront investment with one that is delayed until the timing is optimal.

6.4 Literature review conclusions

Most of the standard methods for evaluating project alternatives, such as benefit-cost analysis and multi-attribute analysis, suffer from their inability to meaningfully address uncertainties that are a defining feature of climate change. This section has therefore focused on classical decision rules for dealing with uncertainty and Bayesian analysis for risks. While there is a significant body of literature on these methods, that which has been applied to climate change is comparatively narrow and largely presents very limited examples and explanations. The next section describes the most promising of these techniques through examples.

7. Decision Models for Project-Level EAs

This section develops the application of decision models for the evaluation of adaptation measures with climate change uncertainty. The models are illustrated through a hypothetical example of a hydroelectric project. Adaptive management is brought into the framework of these decision models. Initially, these methods are used for single-attribute problems and are then expanded to consider dual-attribute problems.

7.1 Application of classical decision rules under uncertainty

Byer et al. (2004), in a research report to the Agency, presented methods that EA practitioners could employ to estimate the impacts of climate change on a project under different future scenarios. Choosing the scenarios to consider is challenging. The IPCC (2001) recommended that "users should … apply multiple scenarios … [that] span a range of possible future climates, rather than designing and applying a single ‘best guess’ scenario.” The Canadian Institute for Climate Studies (CICS) recommended that “specific scenarios should be selected that represent the extreme ranges of the key variables required in the analysis, as well as a more moderate, intermediate scenario” (CICS 2003). The relevant climate variables, such as precipitation, will depend on both the type of project and the impacts of concern. “Archetype” scenarios can be developed to provide information suited to the needs of specific sectors and types of projects. The Canadian Climate Change Scenarios Network (CCCSN) provides scenario information for decision making and policy development, including models for the construction of scenarios and downscaling. Scenarios are provided from numerous international research centres, as is output from the Canadian Regional Climate Model (CCCSN 2010).

Assuming that appropriate scenarios can be devised, and their impacts for different design alternatives can be estimated, various decision models can be applied. Making project design choices for established scenarios that have no known associated probabilities constitutes decision making under *uncertainty*. When subjective probabilities (derived from a Monte Carlo simulation or expert opinion, for example) can be assigned to the scenarios, decision making is under *risk*.

In setting up the decision making framework, different design options can be matched to different scenarios. For example, in the case of a hydroelectric facility, the design options may be different reservoir capacities that would accommodate different streamflow scenarios. In the case of a subarctic oil pipeline, the different design options may be pipes with differing support and bedding characteristics (amount of insulation, for example), reflecting different severities of climate warming (and thus varying needs to protect an already fragile permafrost). Because the scenario of interest (e.g., degree of thaw) would materialize and become apparent only in the future after key decisions are made, there is a chance that project design may at some point become “mismatched” to the eventual scenario (and in hindsight would be regretted).

The application of the classical decision rules is illustrated through an example of a hypothetical hydroelectric project with five design options and three potential climate scenarios, for which there are no probability estimates. For illustrative purposes, the example starts with simplified (and unrealistic) assumptions. These are progressively relaxed to permit more realistic, but complicating, factors. The project is expected to last at least 60 years. Table 7.1 shows the project’s upfront cost and the overall net financial return (in terms of present values[5] in millions of dollars) for each combination of scenario and design option. The cost of each design option (25, 40, 62, 51 and 68) is independent of the scenarios. The benefits (i.e., project revenues) could be determined from coupling the results of a scenario analysis with hydrologic watershed and facility hydraulic models in order to assess energy production. The design options represent different capacities to accommodate the streamflows associated with different climates (1 being the current climate, 2 representing a moderate change in

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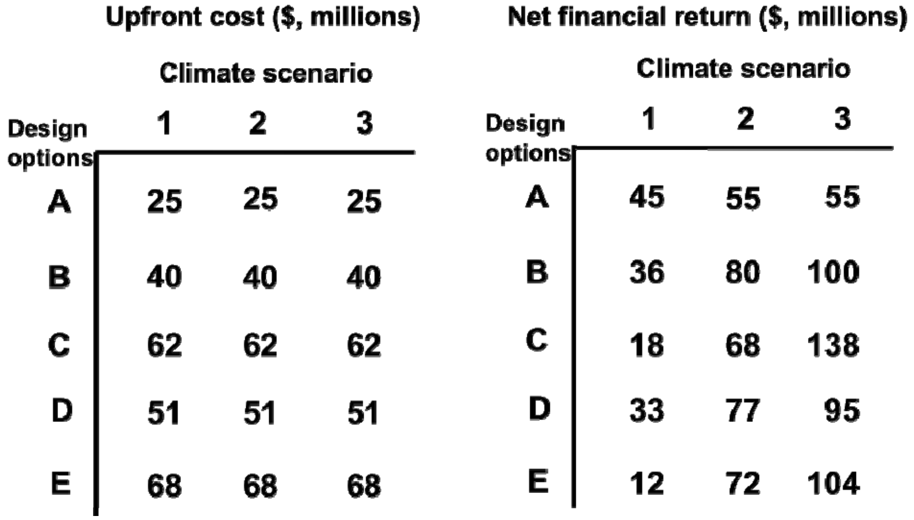
[5] The net present values (NPVs) are obtained by using standard economic procedures that convert future amounts to present values by discounting.

streamflow, and 3 being the most extreme departure from current climate). In this example, the payoffs are financial, but the decision models could be applied to other single metrics of interest to EA practitioners. For example, they could be the estimated number of hectares of arable land affected by a project, probability of flooding, wildlife disruption, etc.

Table 7.1 Project costs and overall net financial returns including upfront costs



Design options	Upfront cost ($, millions)			Net financial return ($, millions)		
	Climate scenario			Climate scenario		
	1	2	3	1	2	3
A	25	25	25	45	55	55
B	40	40	40	36	80	100
C	62	62	62	18	68	138
D	51	51	51	33	77	95
E	68	68	68	12	72	104

If we knew which scenario would occur, we would know which design to choose. For example, if we knew it would be Scenario 2, Design B would be selected because it has the best overall net financial return (80 compared with 55, 68, 77 and 72). If Scenario 1, it would be Design A because it has the highest value (45); and if Scenario 3, it would be Design C, with a value of 138. However, we do not know before the decision needs to be made which scenario will, in fact, occur. In order to help us decide, various decision methods can be applied.

As a first step when applying any of these methods, design options should be eliminated if they are dominated by other alternatives. An alternative is dominated by another alternative if, for each of the possible scenarios, the other alternative provides an equal or better payoff. Thus, Design D can be removed from further consideration because it is dominated by Design B (for Scenario 1, 36 > 33; for Scenario 2, 80 > 77; for Scenario 3, 100 > 95). Dominated alternatives are not always apparent (and do not always exist among a set of choices); however, when they are present, removing them simplifies the decision space.

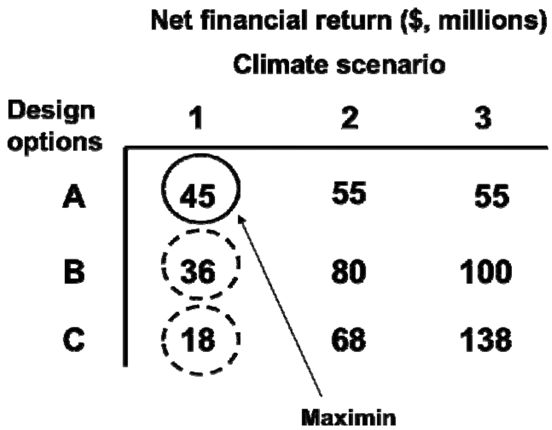
Alternatives should also be eliminated if they do not meet feasibility constraints, or acceptable thresholds. For example, if the project must achieve a net financial return of at least 15, Design E would be removed from further consideration. Constraints could exist for various criteria based on legal, economic, environmental or social acceptability. However, only truly binding constraints should be used because, once applied, potentially promising alternatives could be removed prematurely.

With the three remaining design options (i.e., Designs A, B and C), a variety of classical decision criteria can be applied depending on the decision maker’s attitude toward uncertainties.

Maximin criterion

A risk-averse decision maker would play it safe by paying more attention to the worst outcomes that might occur. In the extreme case, the decision maker would select the alternative with the best of the worst outcomes (i.e., the one that maximizes the minimum payoff deriving from the design options). Hence it is called maximin. This criterion can be perceived as representing a pessimistic outlook. In the example (Table 7.2), the worst possible outcomes are 45 for Design A, 36 for Design B and 18 for Design C. Thus, Design A would be chosen under this criterion since 45 is the highest of these payoffs. Design A is the most conservative option from an economic perspective because it costs the least and does not gamble on obtaining future revenues that may not materialize.

Table 7.2 Maximin, pessimistic criterion



Net financial return ($, millions)

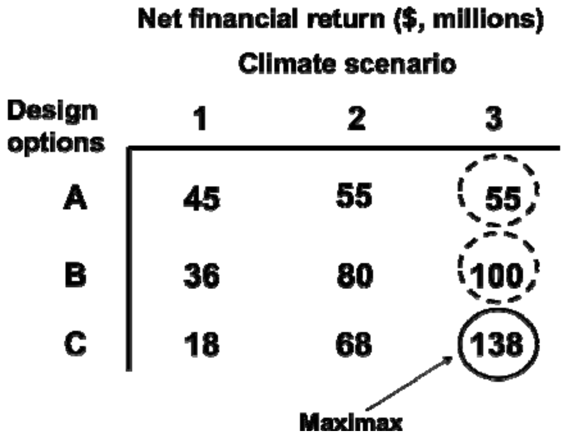
Climate scenario

Design options	1	2	3
A	45	55	55
B	36	80	100
C	18	68	138

Maximax criterion

The opposite criterion to maximin is maximax, representing a risk-prone (optimistic) attitude. In such a case, the decision maker focuses on the best outcomes. The preferred option is the one that maximizes the maximum payoffs of each option, hence maximax. As shown in Table 7.3, the maximum payoffs for Designs A, B and C are 55, 100 and 138, respectively. Hence, Design C would be chosen. This criterion does not, however, reflect the cautious approach generally considered appropriate for climate change.

Table 7.3 Maximax, optimistic criterion



Net financial return ($, millions)

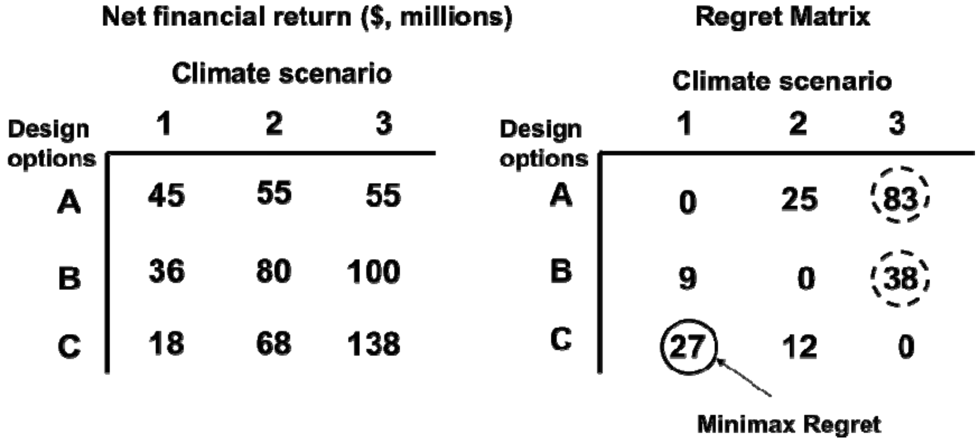
Design options	Climate scenario 1	2	3
A	45	55	55
B	36	80	100
C	18	68	138

Maximax

Minimax regret criterion

A cautious approach that seeks to minimize after-the-fact disappointment, or the tendency to say “If only I had chosen alternative X, I would be better off by amount Y,” is the minimax regret criterion. Its use first requires construction of a regret matrix as shown on the right side in Table 7.4. Evaluating the elements of this matrix is undertaken by first determining the best payoff for each scenario and then referencing (subtracting) the payoffs for each design (under this scenario) from this best payoff value. For example, if Scenario 2 comes about, and Design B had been chosen, there would be no regret (80 − 80 = 0). But, if instead Design A had been chosen, then the project would yield 25 fewer payoff units (80 − 55 = 25).

Table 7.4 Minimax regret criterion



Net financial return ($, millions)

Design options	Climate scenario 1	2	3
A	45	55	55
B	36	80	100
C	18	68	138

Regret Matrix

Design options	Climate scenario 1	2	3
A	0	25	83
B	9	0	38
C	27	12	0

Minimax Regret

Each design option involves some potential regret. The goal of constructing the regret matrix is to show the decision maker the forfeited payoffs that would result if the best design under a given scenario were not chosen.

Under the minimax regret criterion, the decision maker chooses the design that minimizes the maximum regret. The maximum regret if Design A is chosen is 83, for Design B it is 38, and for Design C it is 27. Since the minimum of these maximum regrets is 27, Design C would be chosen.

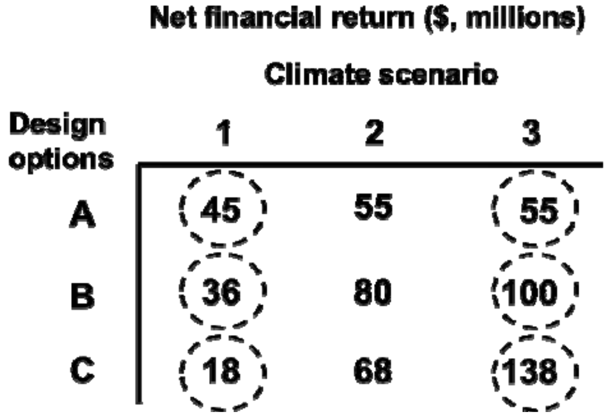
Hurwicz alpha criterion

The decision rules discussed above assume either very optimistic or very pessimistic attitudes toward uncertainties. But a decision maker does not necessarily have such an extreme attitude. The Hurwicz α criterion provides for a mix of optimism and pessimism. The α is an index from 0 to 1 that represents the degree of pessimism of the decision maker (if $\alpha = 1$, the procedure reduces to the maximin criterion and if $\alpha = 0$, it becomes the maximax criterion). It is used to calculate what is known as the Hurwicz value, H, for each alternative:

$$H = \alpha \times \text{minimum payoff} + (1 - \alpha) \times \text{maximum payoff}$$

For the example, Table 7.5 shows the minimum and maximum payoffs for each design.

Table 7.5 Hurwicz alpha criterion



Net financial return ($, millions)

Climate scenario

Design options	1	2	3
A	45	55	55
B	36	80	100
C	18	68	138

If, for example, the decision maker tends more toward pessimism with a corresponding $\alpha = 0.7$, the Hurwicz value for each design is:

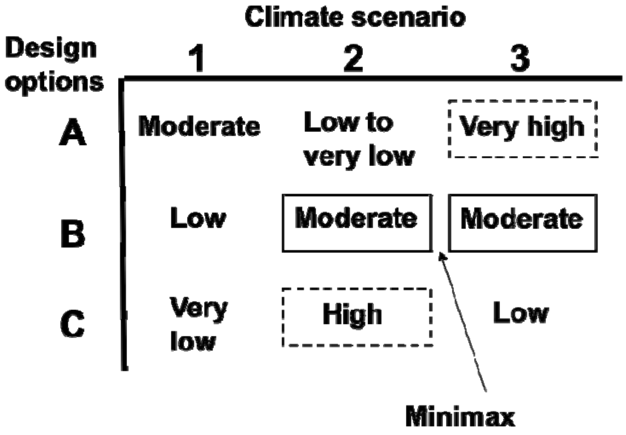
Design A: $H = \alpha\, 45 + (1 - \alpha)55 = 0.7(45) + (1 - 0.7)55 = 48.0$
Design B: $H = \alpha\, 36 + (1 - \alpha)100 = 0.7(36) + (1 - 0.7)100 = 55.2$
Design C: $H = \alpha\, 18 + (1 - \alpha)138 = 0.7(18) + (1 - 0.7)138 = 54.0$

Since Design B has the maximum Hurwicz value, it would be the preferred option.

Other types of payoffs

These criteria have been discussed in terms of an example involving quantitative impacts (e.g., dollars) for which more is preferred. They can be adapted to also apply to negative impacts, such as wildlife disruption. In such cases, the maximin criterion becomes the minimax criterion and the maximax criterion becomes the minimin criterion. The minimax regret criterion remains the same but the regret matrix is based on the lowest payoff under each scenario. These criteria can also be applied to impacts that are not quantitative as long as the impacts can be ranked in order of preference. For example, if wildlife disruption is measured on a qualitative scale of "very low" to "very high" as shown in Table 7.6, the minimax criterion would identify the maximum impacts for Designs A, B and C as "very high", "moderate" and "high", respectively. Since the minimum of these is "moderate", Design B would be chosen. The qualitative descriptors could be more complicated than shown here, perhaps constituting phrases or sentences. A regret matrix can also be constructed for qualitative measures.

Table 7.6 Wildlife disruption impacts



	Climate scenario		
Design options	1	2	3
A	Moderate	Low to very low	Very high
B	Low	Moderate	Moderate
C	Very low	High	Low

Minimax

7.2 Methods with probabilities

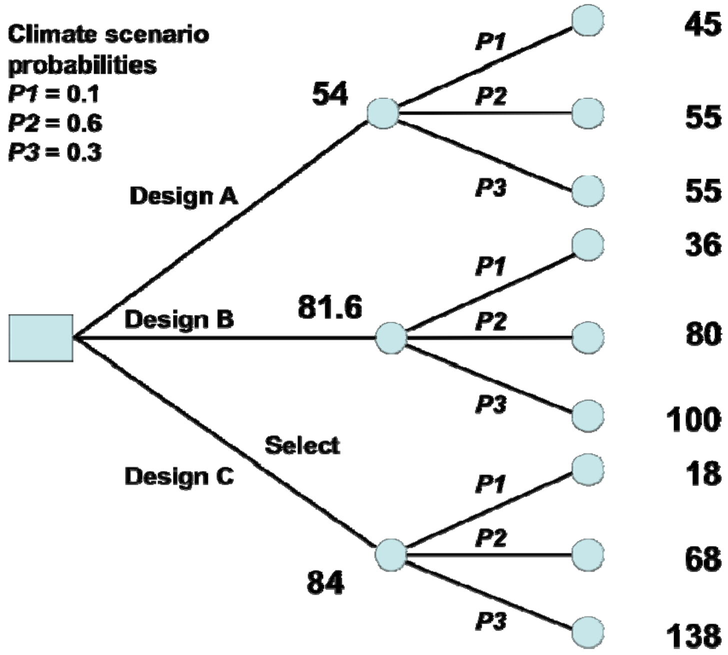
The above criteria have been applied without any estimates or assumptions regarding the likelihood, or probabilities, of the three scenarios. One of the classical decision models (the Laplace criterion) assigns equal probability to each of the unknown states (i.e., the future climate scenarios) when there is no information to suggest that any one state is more or less probable than the others. However, while there is a significant uncertainty about climate change, experts are now able to provide some information about which scenarios might be more likely than others. If the decision maker has information regarding the relative likelihood of the scenarios, or is comfortable assuming them, subjective probabilities can be assigned to each scenario and a risk-based approach may be applied. Subjective probabilities might be established through expert advice and modelling. In the example of hydroelectric power generation, one could seek estimates of the relative likelihoods of different sets of climate variables. It might result, for example, in estimates of the probabilities of Scenarios 1, 2 and 3 of 0.1, 0.6 and 0.3, respectively.

Two decision criteria based on probabilities are expected value and expected utility. Under the expected value criterion, the expected payoff of each design option is calculated as the sum of the payoffs weighted by the scenarios' likelihoods. The preferred design is the one that has the highest or lowest expected payoff depending on whether the payoff is desirable or undesirable, respectively. Risk-based decision making is often depicted in the form of a decision tree as shown in Figure 7.1 for the example. The expected payoff of Design B is this: (0.1)36 + (0.6)80 + (0.3)100 = 81.6. Likewise, the expected values for Designs A and C are 54.0 and 84.0, respectively. Because Design C has the highest expected value, it should be chosen. This is a logical choice given that there is a 90% chance of receiving relatively high returns.

The expected value criterion is appropriate for decision makers who are risk-neutral (i.e., neither risk-averse nor risk-prone). To incorporate a different (i.e., not risk-neutral) attitude toward taking risk, an expected utility criterion can be used where a utility function modifies the payoffs according to the degree of risk aversion (Hobbs 1997; Keeney and Raiffa 1976). Assessing a utility function and interpreting and presenting the results could pose significant practical difficulties in environmental assessment.

Another risk-based approach is to identify the most likely scenario and make the decision based on occurrence of this scenario. In the example, Scenario 2 is the most likely of the three scenarios. Given this scenario, Design B has the highest payoff and therefore would be chosen. This approach ignores the impacts associated with the other scenarios, which may have a reasonable likelihood of occurring. It should be used only when the likelihoods of the other scenarios are relatively low and their associated impacts are acceptable if they, in fact, occur. Since the focus of this report is not on these cases, this approach is not discussed further here.

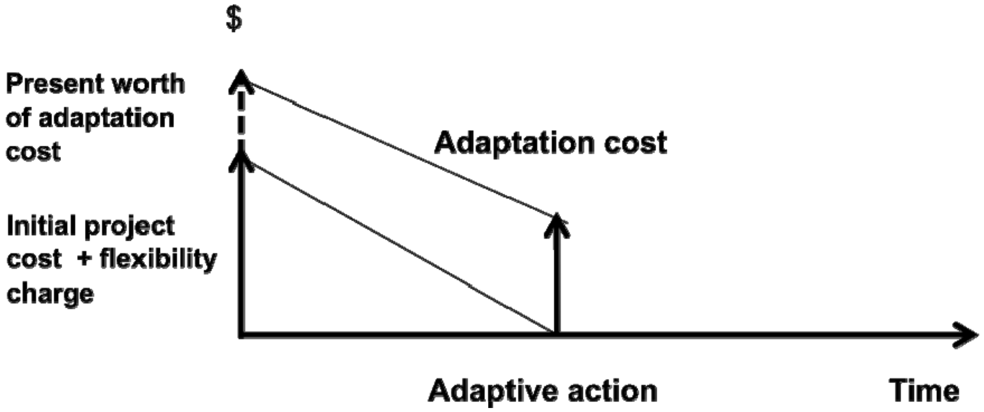
Figure 7.1 Decision tree for the expected value example.



7.3 Adaptive management and the role of flexibility

When dealing with uncertainties about the future, one appealing approach is to “wait and see”. This largely depends on waiting for further information as climate trajectory becomes more apparent. As described in Section 4.5, adaptive management can require an extra initial cost to “buy” the flexibility to permit future actions to adapt to climate change. In essence this is paying to reduce uncertainty. This is illustrated in Figure 7.2, where time is represented on the horizontal axis with an initial project followed by a potential adaptive action at some point in the future. The vertical axis represents costs; the initial project cost (with flexibility charge) is indicated, as is the future cost of adaptation.

Figure 7.2 Cash flows and present values with staged construction.



In the example, adaptive management refers to designing for a smaller capacity now (Design A for Scenario 1 – current climate) and expanding later (assumed for illustrative purposes to be 10 years in our examples[6]) to a larger capacity (Designs B or C) depending on climate change. There are three possible futures: no change in climate (Scenario 1), climate changes from Scenario 1 to 2 and remains at Scenario 2, or climate changes from Scenario 1 to 3 and remains at 3.

If the climate shifts from Scenario 1 to Scenario 2, the project can be modified to become Design B (the adaptive action) so that the project can realize larger revenues. This is possible because of the upfront flexibility charge, which reflects the incremental cost associated with a more sophisticated design permitting expansion. It could also include expenses for monitoring equipment to facilitate the wait-and-see approach; that is, to observe and record data that will allow decision makers to assess climate trajectory. The advantage is to avoid potentially unnecessary additional costs for larger upfront designs that may never be needed. A further advantage is that some of the expense of a larger project is postponed.

Adaptive management offers new design options through flexibility. For example, Design A with the capability for future expansion (flexibility) constitutes a new option (Design F) that can be evaluated against other options according to the criteria previously discussed. Table 7.7 presents this option along with Designs A and B for Scenarios 1 and 2. To simplify the discussion, Design C and Scenario 3 are temporarily omitted. The left matrix of Table 7.7 shows the upfront cost of each design. As before, costs for A and B are independent of the scenario. The upfront cost for Design F is the cost of Design A plus the flexibility (flex) charge, *X*, to allow expansion to Design B.

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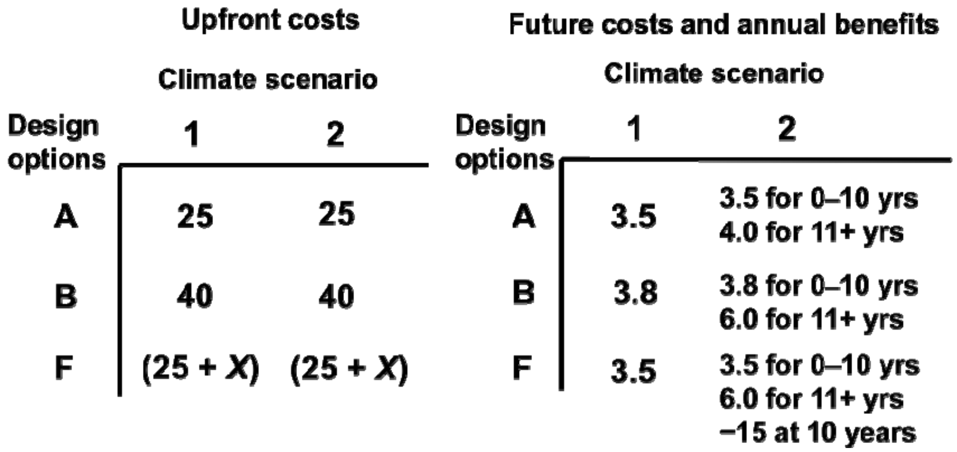
[6] Ten years is a relatively short time compared with the time that various climate scenarios might truly diverge. However, decision-makers may observe sufficient evidence of climate change well in advance of this divergence to be able to judge whether adaptive action is warranted. The use of 10 years was solely for illustrative purposes, and analysts can use sensitivity analysis to test the effect of different times.

Other costs and benefits are shown in the right matrix of Table 7.7. These comprise annual net benefits (yearly revenues from power generation minus operating costs) and, in the case of Design F, the expansion charge to modify capacity under Scenario 2. In Scenario 1, climate does not change and the equivalent annual net benefits (3.5 for Design A, 3.8 for Design B, and 3.5 for Design F because it is the same as A) remain constant into the future. For simplicity, any change in climate to Scenario 2 occurs in 10 years; therefore, the annual net benefits for Design A will be 3.5 in the first 10 years and increase to 4.0 after Scenario 2 occurs. Similarly, for Design B, the annual net benefits are 3.8 in the first 10 years and increase to 6.0 after Scenario 2 occurs. Design F has the benefits of Design A during the first 10 years and then, because of its expansion to Design B, has the benefits of Design B after Year 10. In addition Design F incurs a one-time cost of 15 for the expansion in the 10th year.[7]

Table 7.7 Costs and benefits with an adaptation strategy



Upfront costs

	Climate scenario	
Design options	1	2
A	25	25
B	40	40
F	(25 + *X*)	(25 + *X*)

Future costs and annual benefits

	Climate scenario	
Design options	1	2
A	3.5	3.5 for 0–10 yrs 4.0 for 11+ yrs
B	3.8	3.8 for 0–10 yrs 6.0 for 11+ yrs
F	3.5	3.5 for 0–10 yrs 6.0 for 11+ yrs −15 at 10 years

The net financial return (in NPV)[8] of the design options for the relevant climate scenarios are summarized in Table 7.8, with *X* being the upfront cost of flexibility for adaptive management.

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[7] The increment of 15, which is the difference in upfront costs of Designs A and B, could be even greater due to loss of economies of scale.

[8] These are obtained by using standard economic procedures that convert future amounts to present values through discounting (assumed 5%/year in these calculations). Since the annual revenues under Scenario 2 stay the same as those under Scenario 1 until the transition in year 10, the NPV for Designs A and B are lower than in previous tables (e.g., 50 instead of 55, 61 instead of 80). Appendix 2, Section 9.2, explains these calculations further.

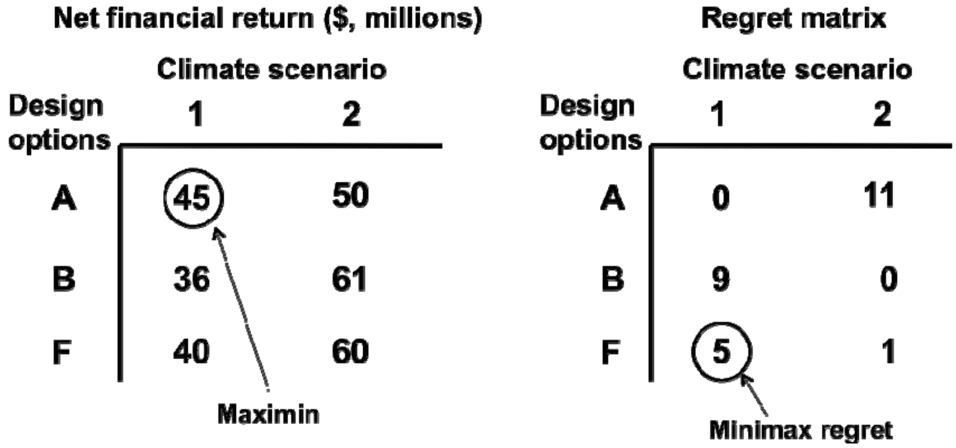
Table 7.8 Net financial return of design options and flexibility

Net financial return ($, millions)

Design options	Climate scenario 1	2
A	45	50
B	36	61
F	45 − *X*	65 − *X*

Table 7.9 shows the payoff and regret matrices for a flex charge of 5 (*X* = 5). Under the maximin criterion, Design A is the preferred option. A very risk-averse decision maker would never choose Design F over Design A because it requires a higher upfront cost and may not realize higher future benefits (because Scenario 2 may not occur). Design F is preferred, however, according to minimax regret. With Design A, the maximum potential regret is 11; with B, it is 9; and with F, it is 5, which is the flex charge *X*. Design A capacity is matched to Scenario 1, and, if Scenario 2 occurs instead, the project cannot realize the greater benefits that would result. Design B is based on Scenario 2, and, if this does not come to pass, the extra upfront expense for a larger capacity would have been wasted. Design F minimizes regret because capacity is matched to the scenario which materializes; it pays for capacity costs only when they are needed, but the flex charge would be regretted if Scenario 2 does not occur and the flexibility is not needed.

Table 7.9 Net financial return and regret matrices of the two designs and flexibility for *X* = 5



Net financial return ($, millions)

Design options	Climate scenario 1	2
A	45	50
B	36	61
F	40	60

Regret matrix

Design options	Climate scenario 1	2
A	0	11
B	9	0
F	5	1

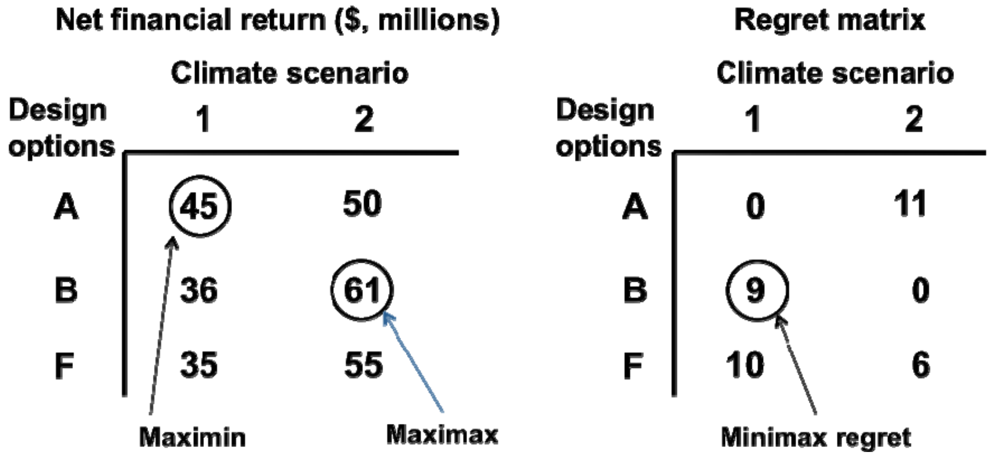
These can also be compared using the Hurwicz α criterion. If $\alpha = 0.7$, the Hurwicz values for each design can be determined:

Design A: $H = \alpha\, 45 + (1 - \alpha)50 = 0.7(45) + (1 - 0.7)50 = 46.5$
Design B: $H = \alpha\, 36 + (1 - \alpha)61 = 0.7(36) + (1 - 0.7)61 = 43.5$
Design F: $H = \alpha\, 40 + (1 - \alpha)60 = 0.7(40) + (1 - 0.7)60 = 46.0$

Because Design A has the maximum Hurwicz value, it would be the preferred option, though it is essentially tied with Design F.

These analyses can also be used to determine the most one should be willing to pay for flexibility. If the flex charge were zero, we should prefer Design F. As the flex charge increases, the preferred design will switch to a non-adaptive strategy (A or B). The point at which it switches will depend on the criterion. If the flex charge is any greater than zero, Design A is preferred with the maximin criterion. With the minimax regret criterion, if *X* = 10, for example, the preferred design is B, as shown in Table 7.10.

Table 7.10 Net financial return and regret matrices of the two designs and flexibility for *X* = 10



Net financial return ($, millions)

Design options	Climate scenario 1	Climate scenario 2
A	45	50
B	36	61
F	35	55

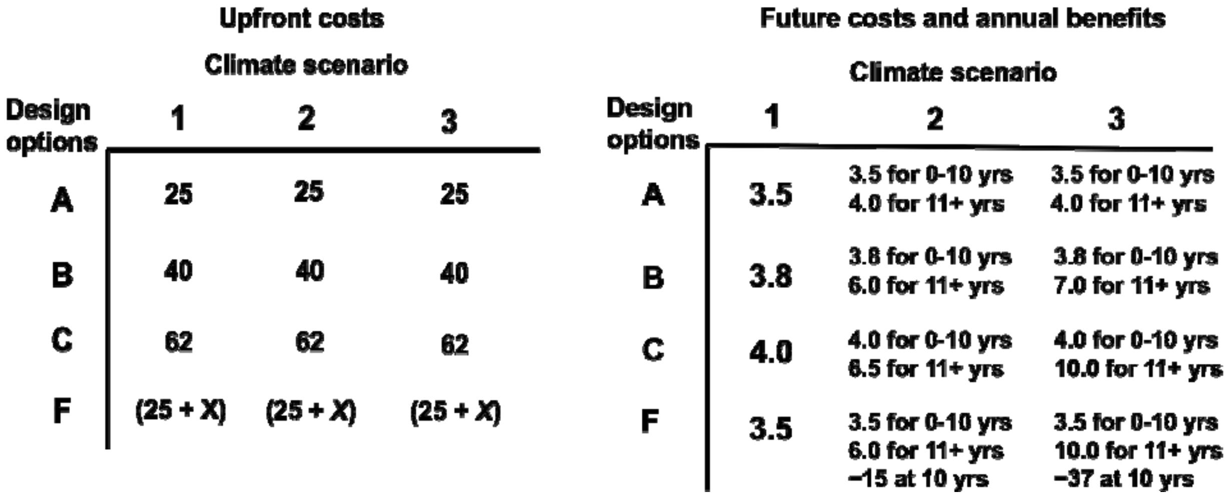
Regret matrix

Design options	Climate scenario 1	Climate scenario 2
A	0	11
B	9	0
F	10	6

The switch point with the minimax regret criterion is a flex charge *X* = 9. Any flex charge above 9 shifts preference from Design F to Design B. The maximum regret (11) associated with Design A is the forfeited revenue if Scenario 2 occurs, and this is greater than the maximum regret (9) associated with Design B, which is the cost of unused capacity if Scenario 2 does not occur. Similarly, the maximum regret with Design F is the unused flexibility if Scenario 2 does not occur, and, if this is greater than 9, Design B is preferred. A generalized version of the regret matrices in Tables 7.9 and 7.10 with *X* as a variable is presented in Appendix 3 (Section 9.3).

The discussion of adaptive management above was simplified by considering only two scenarios and three related designs. However, any decision making pertaining to future climate change should entertain at least three scenarios (as in the earlier examples): little or no change, moderate change and significant change. The previous discussion is expanded by reintroducing the initial designs/scenarios. Table 7.11, which is similar to Table 7.7, shows upfront costs and the future costs and annual benefits for the case of four designs and three scenarios. The adaptive management strategy (Design F) is Design A with flexibility. At Year 10, it is expanded to Design B (at a cost of 15) if Scenario 2 occurs, or to Design C (at a cost of 37) if Scenario 3 occurs.

Table 7.11 Costs and benefits for the three designs and flexibility

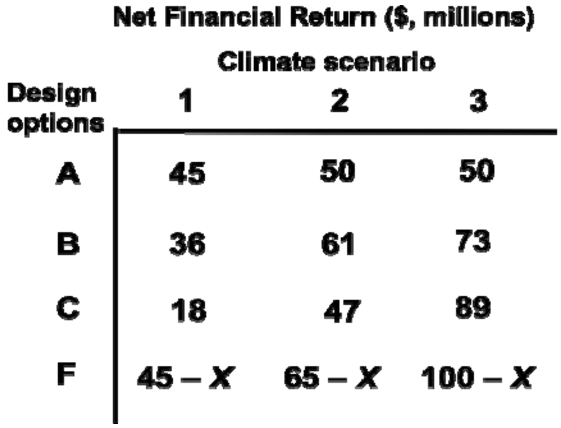


Upfront costs			
	Climate scenario		
Design options	1	2	3
A	25	25	25
B	40	40	40
C	62	62	62
F	(25 + X)	(25 + X)	(25 + X)

Future costs and annual benefits			
	Climate scenario		
Design options	1	2	3
A	3.5	3.5 for 0-10 yrs 4.0 for 11+ yrs	3.5 for 0-10 yrs 4.0 for 11+ yrs
B	3.8	3.8 for 0-10 yrs 6.0 for 11+ yrs	3.8 for 0-10 yrs 7.0 for 11+ yrs
C	4.0	4.0 for 0-10 yrs 6.5 for 11+ yrs	4.0 for 0-10 yrs 10.0 for 11+ yrs
F	3.5	3.5 for 0-10 yrs 6.0 for 11+ yrs −15 at 10 yrs	3.5 for 0-10 yrs 10.0 for 11+ yrs −37 at 10 yrs

The resulting net financial returns are shown in Table 7.12, which is similar to Table 7.8.

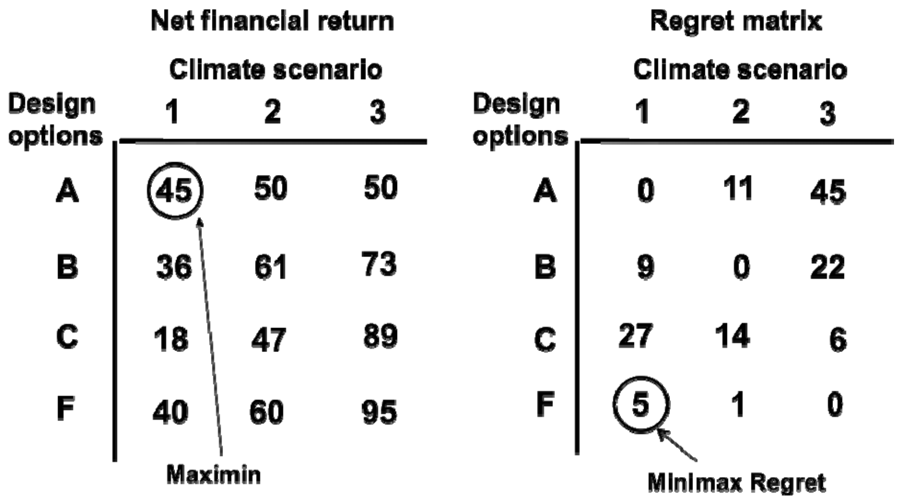
Table 7.12 Net financial returns for the three designs and flexibility with flex charge *X*



Net Financial Return ($, millions)			
	Climate scenario		
Design options	1	2	3
A	45	50	50
B	36	61	73
C	18	47	89
F	45 – *X*	65 – *X*	100 – *X*

For a flex charge of 5 (*X* = 5), the net financial return and regret matrices are shown in Table 7.13.

Table 7.13 Net financial return and regret matrices for three designs and inexpensive flexibility (*X* = 5)



Net financial return

Design options	Climate scenario 1	2	3
A	45	50	50
B	36	61	73
C	18	47	89
F	40	60	95

Maximin

Regret matrix

Design options	Climate scenario 1	2	3
A	0	11	45
B	9	0	22
C	27	14	6
F	5	1	0

Minimax Regret

The maximin criterion results in the selection of Design A and minimax regret results in Design F. These are the same results observed with the two-scenario case.

As before, if $\alpha = 0.7$, the Hurwicz values for each design can be determined:

Design A: $H = \alpha\, 45 + (1 - \alpha)50 = 0.7(45) + (1 - 0.7)50 = 46.5$
Design B: $H = \alpha\, 36 + (1 - \alpha)73 = 0.7(36) + (1 - 0.7)73 = 47.1$
Design C: $H = \alpha\, 18 + (1 - \alpha)89 = 0.7(18) + (1 - 0.7)89 = 39.3$
Design F: $H = \alpha\, 40 + (1 - \alpha)95 = 0.7(40) + (1 - 0.7)95 = 56.5$

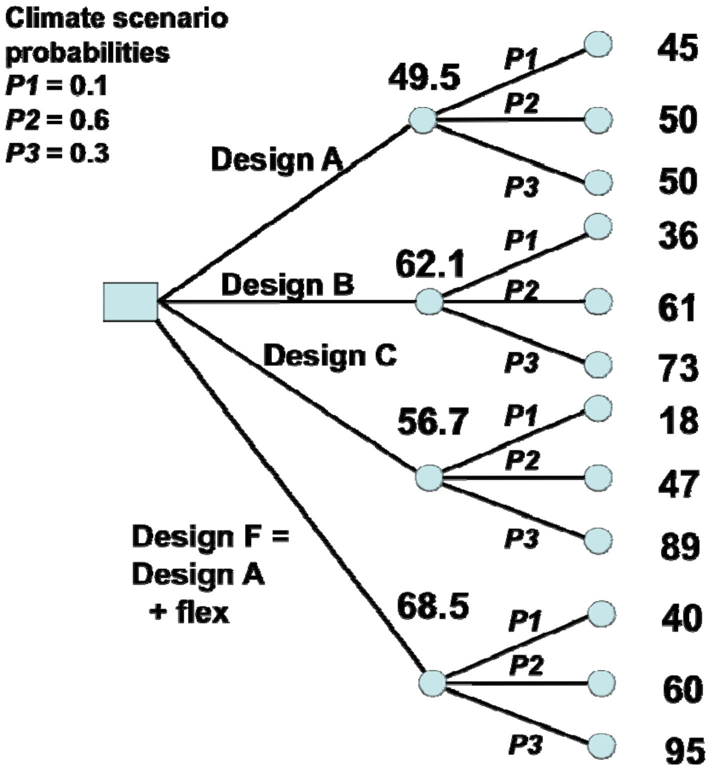
Since Design F has the maximum Hurwicz value, it would be the preferred option. In the two-scenario case, the preferred design was essentially a tie between Designs A and F. The relative improvement in Design F in the three-scenario case reflects its potential to capture significant revenues if Scenario 3 occurs.

As in the two-scenario scheme (Tables 7.9 and 7.10), an increase in the flex charge in this example will, at some point, cause a change in the preferred design.

7.4 Analysis with probabilities and adaptive management

As in Section 7.2, expected values can be calculated for the alternative designs (including the adaptive design) if probabilities can be estimated for each of the scenarios. The decision tree for this problem is shown in Figure 7.3.

Figure 7.3 Decision tree for the three designs and flexibility.



With these probabilities, the highest expected value is 68.5. Design F is therefore preferred, and Design B is in second place. The probability of Scenario 2 is significantly higher than the probabilities of the other scenarios, thus favouring Design B, which matches Scenario 2; however, Design F performs even better than Design B because it can capture the revenues of B and C at a relatively low flex charge. Given the subjective nature of probability estimates for climate change, a sensitivity analysis can be carried out to investigate how different sets of probabilities affect the preferred design.

The preceding analysis assumes: 1) that the ultimate climate scenario will manifest itself in 10 years and 2) if Design F were chosen, the project will be expanded at that time to Design B if Scenario 2 occurs or Design C if Scenario 3 occurs. A more complex approach (Bayesian analysis) assumes, more realistically, that there remains uncertainty about the final climate scenario and updates the subjective probabilities based on observations of climate trajectory (Hobbs 1997; Hobbs et al. 1997). While this would be more realistic, it involves much greater complexity and data needs that would not be practical, at least at this time, in environmental assessments.

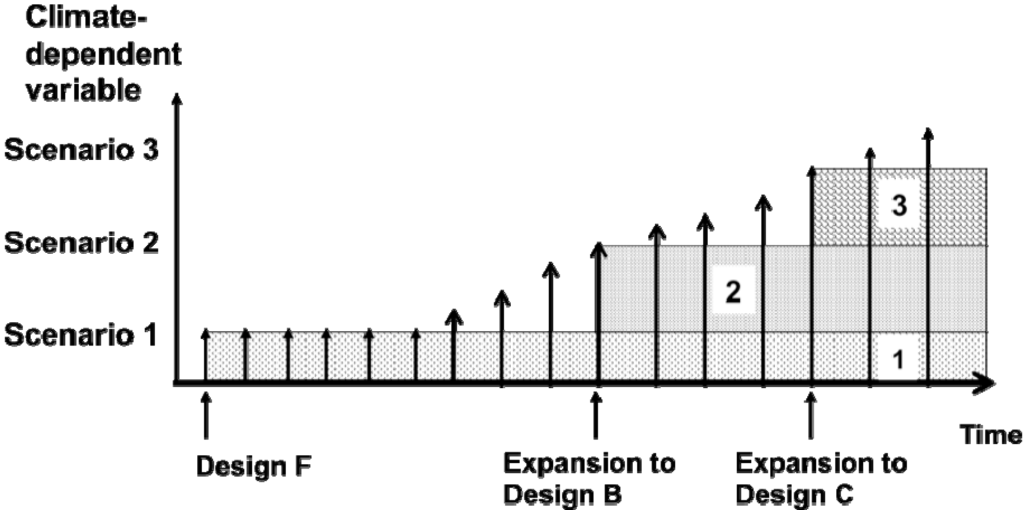
7.5 Climate transition

The examples developed thus far assume, for modelling convenience, only one possible transformation to one of three future climate scenarios (no change, moderate change and significant change: Scenarios 1, 2 and 3, respectively) in exactly 10 years, at which point the change will be sudden (i.e., a step function). In reality, climate will likely continue to change through the life of a project.

Figure 7.4 illustrates how this might occur, with time represented by the horizontal axis and the climate-dependent design variable of interest (e.g., streamflows) on the vertical axis. There is relatively smooth transition from Scenario 1 to 2 to 3. Some adaptation measures can be undertaken on an essentially continuous basis (e.g., adjustments in reservoir release policy) while others, such as expanding capacity, can be done only in limited discrete increments because of practical considerations (e.g., how frequently construction equipment can be brought to the site, disruptions, etc.) and economy-of-scale considerations. With adaptive management (Design F), the facility is initially appropriately scaled to Scenario 1, permitting it to capture the streamflow indicated in Box 1. When climate reaches Scenario 2, the design is modified to Design B, permitting it to capture the value of the increased streamflow (indicated in Box 2) and, when it reaches Scenario 3, it is modified again to capture the value indicated in Box 3.

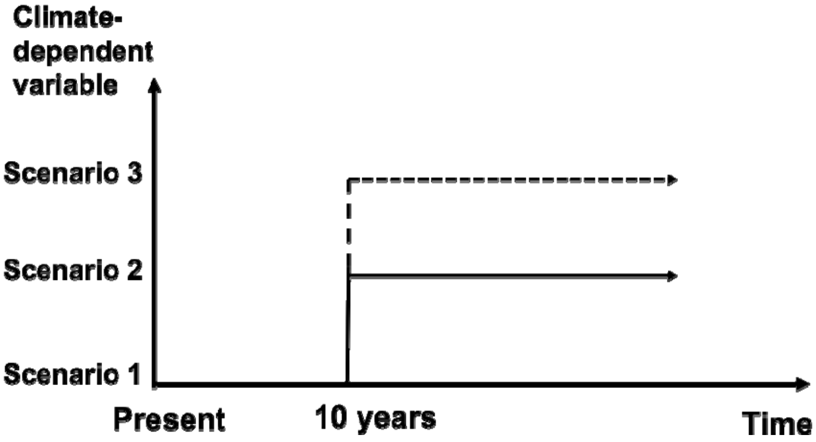
Because physical project modification must be done at discrete points in time, an analysis of adaptive management requires assumptions about the specific times in the future when these decisions would be made. Project modification would be made after there is sufficient confidence that climate is, in fact, migrating to a new scenario, which could be determined by predefined thresholds. This requires that adequate data be obtained regarding the climate-dependent variable. By waiting longer, more confidence is gained, but at the expense of having a design that does not match the changed climate.

Figure 7.4 Smooth climate transition and phased capacity expansion.



There are innumerable possible transition scenarios and the types of analyses explained above can capture their details through more complex analysis, particularly with the use of computers. The previous analyses assumed that climate under Scenario 1 would either not change or, at a particular point in time (10 years), experience a moderate change (Scenario 2) or a significant change (Scenario 3), as shown in Figure 7.5.

Figure 7.5 Single-step transition from Scenario 1 to either Scenario 2 or 3.

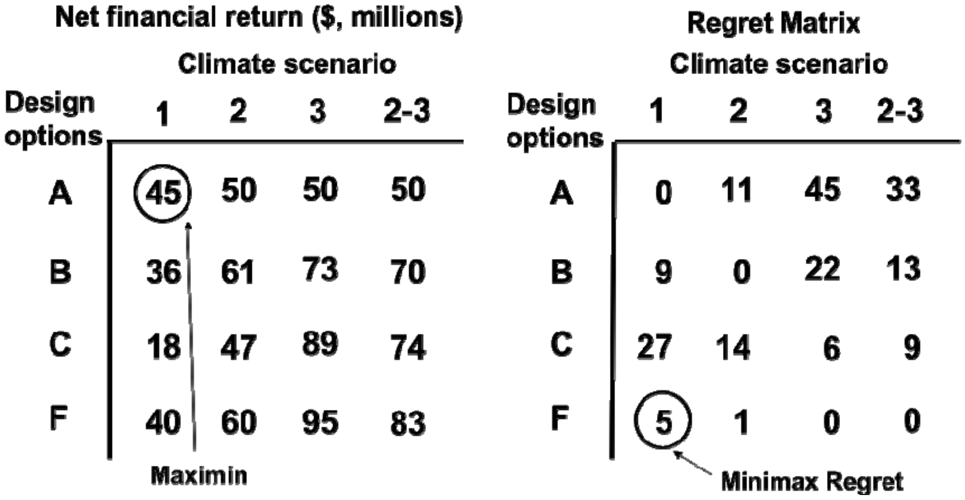


Another scenario (Scenario 2-3) that is consistent with Figure 7.4 is a transition from Scenario 1 to Scenario 2 (at 10 years) and then from Scenario 2 to Scenario 3 (at 20 years), as shown in Figure 7.6.

Figure 7.6 Dual-step transition from Scenario 1 through Scenario 2 to Scenario 3 (Scenario 2-3).

The design options can be compared given this new scenario, or given any transition scenarios. Table 7.14 shows the net financial return and regret matrices for all designs and scenarios, with a flex charge *X* = 5 for Design F. Details of the calculations are shown Appendix 2 (Section 9.2). Applying the maximin criterion, Design A is best. The minimax regret criterion results in Design F. These are the same results obtained without Scenario 2-3 (see Table 7.13). Since Scenario 2-3 unfolds more slowly than Scenario 3, the delayed effects of climate change on the streamflows results in lower benefits to Designs B, C and F. However, because of this delay, the costs of expansion are spread over a longer period in Design F (two smaller expansions at Years 10 and 20 instead of one larger expansion at Year 10).

Table 7.14 Net financial return and regret matrices including the dual-step transition (Scenario 2-3)



Net financial return ($, millions)

Design options	Climate scenario 1	2	3	2-3
A	45	50	50	50
B	36	61	73	70
C	18	47	89	74
F	40	60	95	83

Maximin

Regret Matrix

Design options	Climate scenario 1	2	3	2-3
A	0	11	45	33
B	9	0	22	13
C	27	14	6	9
F	5	1	0	0

Minimax Regret

In order to apply the expected value criterion, it is necessary to estimate the subjective probabilities with this new scenario. In this case, the probabilities of Scenarios 1 and 2 remain the same (0.1 and 0.6). The probability of significant change (either in one step at 10 years as Scenario 3, or in two steps at 10 and 20 years as Scenario 2-3) also remains the same (0.3), but is assumed for illustrative purposes to be split equally between these (i.e., 0.15 for Scenario 3 and 0.15 for Scenario 2-3). With these probabilities, the expected values of the design options are:

Design A: EV = (0.1)45 + (0.6)50 + (0.15)50 + (0.15)50 = 49.5
Design B: EV = (0.1)36 + (0.6)61 + (0.15)73 + (0.15)70 = 61.6
Design C: EV = (0.1)18 + (0.6)47 + (0.15)89 + (0.15)74 = 54.4
Design F: EV = (0.1)40 + (0.6)60 + (0.15)95 + (0.15)83 = 66.7

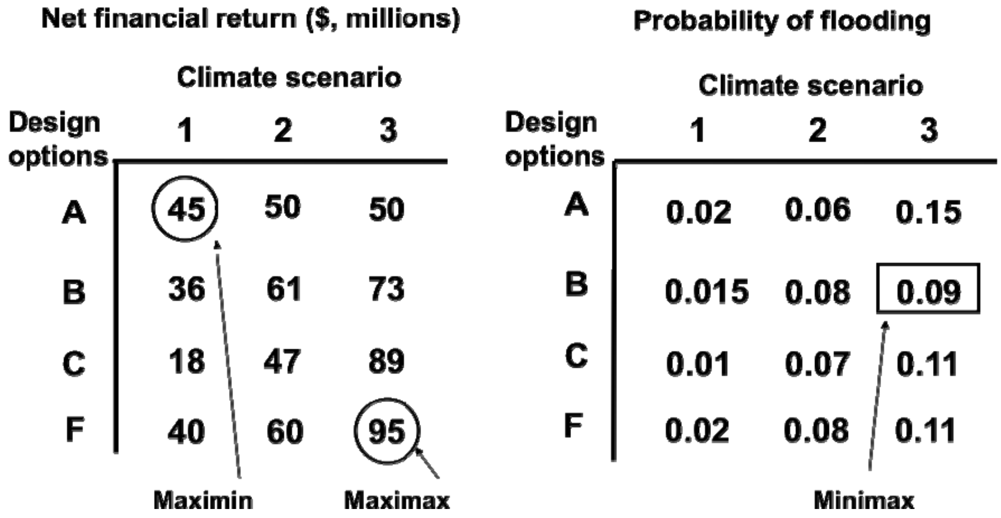
The preferred alternative is Design F.

While the incorporation of this new scenario has not changed the preferred alternatives according to these criteria, other scenarios could change the results. What is most important is for the analysis to include the range of scenarios that might materialize and affect decision making.

7.6 Greater complexity: A dual-attribute problem structure

The alternative designs will likely affect multiple valued environmental components (VECs). For example, in addition to energy production, the project could affect downstream flooding, which should be minimized. For each of the design options, there may be a different probability of flooding under each of the scenarios. Table 7.15 shows the net financial return and annual flooding probability[9] matrices for this problem without, for simplicity, the transition scenario (Scenario 2-3). The basic assumption is that expanding capacity involves a larger facility (e.g., a larger reservoir) and that this generally, though not always, leads to lower probabilities of flooding.

Table 7.15 Net financial return and annual probability of flooding matrices



Net financial return ($, millions)

Design options	Climate scenario 1	Climate scenario 2	Climate scenario 3
A	45	50	50
B	36	61	73
C	18	47	89
F	40	60	95

Probability of flooding

Design options	Climate scenario 1	Climate scenario 2	Climate scenario 3
A	0.02	0.06	0.15
B	0.015	0.08	0.09
C	0.01	0.07	0.11
F	0.02	0.08	0.11

Ideally, one wants to maximize financial return while minimizing flooding. At the outset, dominated alternatives should be identified. With multiple attributes, an alternative can be removed only if it is dominated by the same alternative across all attributes. In this example, Design C is dominated by Design F with respect to financial return but is not dominated by Design F with respect to the probability of flooding (in fact, Design F is dominated by Design C). Therefore, none of the designs can be excluded because of dominance.

The preferred design can be identified for each attribute separately based on the decision maker's attitude toward uncertainties for each attribute.[10] These attitudes may be the same or different. For example, if the minimax regret criterion is applied to each attribute (see Table 7.16), Design F is the preferred alternative (the tie between Designs B, C and F for flooding is resolved by the preference for Design F with respect to financial return). In cases such as this, where the separate analyses lead to the same preferred design, there is an obvious overall preferred alternative (i.e., F).

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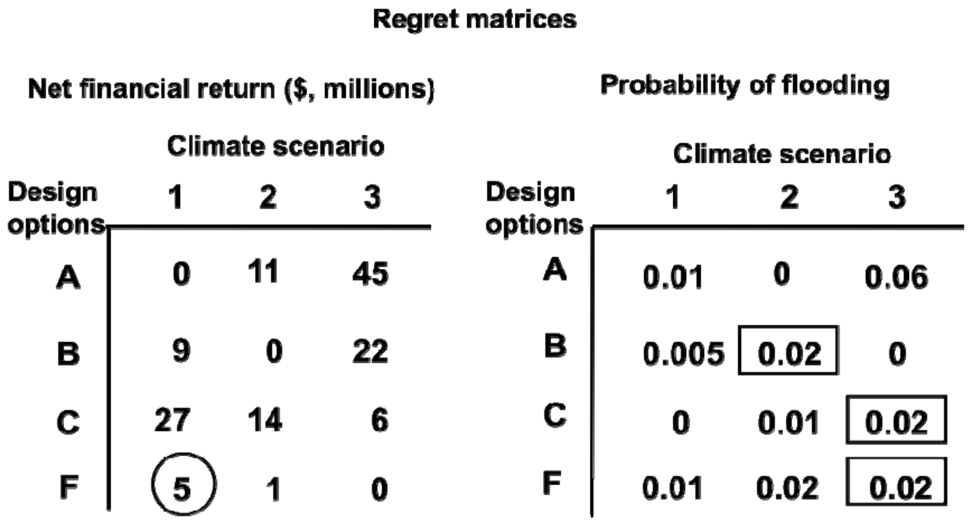
[9] These are the assumed probabilities after the scenarios materialize.

[10] In the examples below, only a few of the decision making criteria are used for illustrative purposes, but any of those discussed previously (e.g., Hurwicz alpha, expected value) could be applied.

Table 7.16 Regret matrices for both attributes, net financial return and probability of flooding



Regret matrices

Net financial return ($, millions)

Design options	Climate scenario 1	2	3
A	0	11	45
B	9	0	22
C	27	14	6
F	5	1	0

Probability of flooding

Design options	Climate scenario 1	2	3
A	0.01	0	0.06
B	0.005	0.02	0
C	0	0.01	0.02
F	0.01	0.02	0.02

Conversely, the decision maker may have different attitudes toward uncertainties for the different attributes. For example, the decision maker may be more willing to take chances with financial return but less so with respect to flooding. In an extreme case, maximax could be applied to financial return and minimax could be applied to flooding. Applying these decision criteria in Table 7.15 shows that Design F is the preferred alternative with respect to financial return and Design B is preferred with respect to flooding. This results in a conflict between the alternative designs.[11]

Visualization methods can help clarify these conflicts in the multi-attribute setting. As Bell et al. (2003, 307) explained: “Because of the large number of criteria and uncertainties in IA [impact assessment], the basic challenge is to portray highly dimensional data sets in such a way that users can grasp general trends and be stimulated to explore results further.” Data representation techniques such as bar charts, box plots, circle graphs, Cartesian plots for the pairwise comparison of attributes for different policy alternatives, etc., were suggested as ways to present impact estimates and their associated uncertainties. Effective visualization and *tradeoff displays* offer simple and transparent ways to understand and communicate conflicts.

The matrices in Tables 7.15 and 7.16 provide such a visualization method. Applying maximax to financial return and minimax to flooding led to a conflict between Designs B and F, and the matrices in Table 7.15 clearly identify the tradeoffs between these designs for the two attributes under each scenario. If Design B is chosen over Design F and:

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[11] Note that the same risk attitude applied to both attributes can also result in a conflict. For example, a decision maker who is very risk averse with respect to both financial return and flooding could apply Maximin and Minimax, respectively. This would lead to a conflict in which Design A is preferred for financial return and Design B for flooding.

If Scenario 1 occurs: \$4 million (40 − 36 = 4) is sacrificed for a reduction of 0.005 (0.02 − 0.015) in flooding probability.

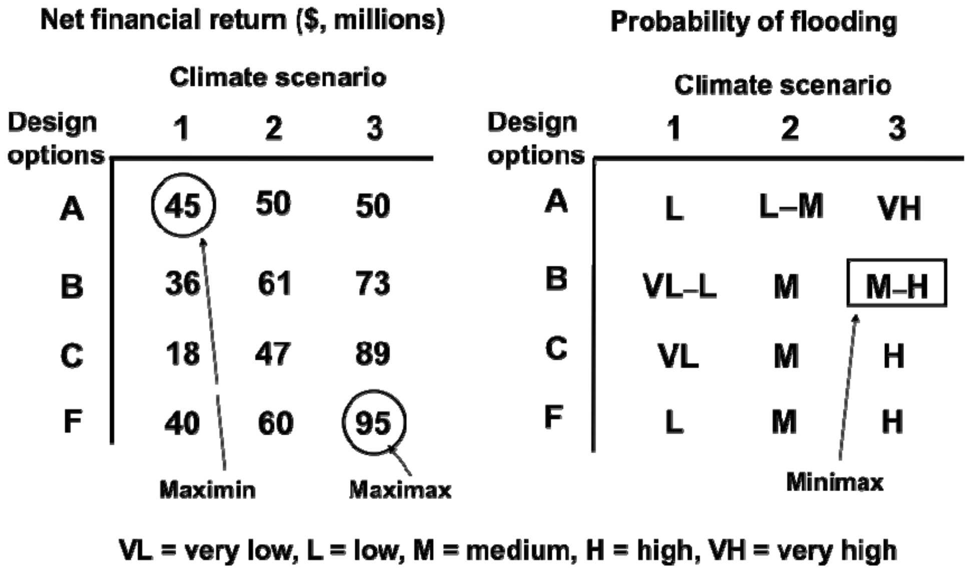
If Scenario 2 occurs: \$1 million (61 − 60 = 1) is gained for zero (0.08 − 0.08) change in flooding probability.

If Scenario 3 occurs: \$22 million (95 − 73 = 22) is sacrificed for a reduction of 0.02 (0.11 − 0.09) in flooding probability.

Understanding these tradeoffs can help the decision maker steer toward a preferred alternative, which also depends on the relative importance of the different attributes. This, in turn, depends on public consultation where a clear explanation of the tradeoffs can be presented.

As explained in Section 7.1 and shown in Table 7.6, some criteria may be measured qualitatively rather than quantitatively. For example, if the data are not sufficient to assign the flood probability estimates found in Table 7.15, they may still be sufficient to estimate the probabilities qualitatively as illustrated in Table 7.17.

Table 7.17 Dual-attribute problem with qualitatively expressed flooding probabilities



Net financial return ($, millions)

Design options	Climate scenario 1	2	3
A	45	50	50
B	36	61	73
C	18	47	89
F	40	60	95

Probability of flooding

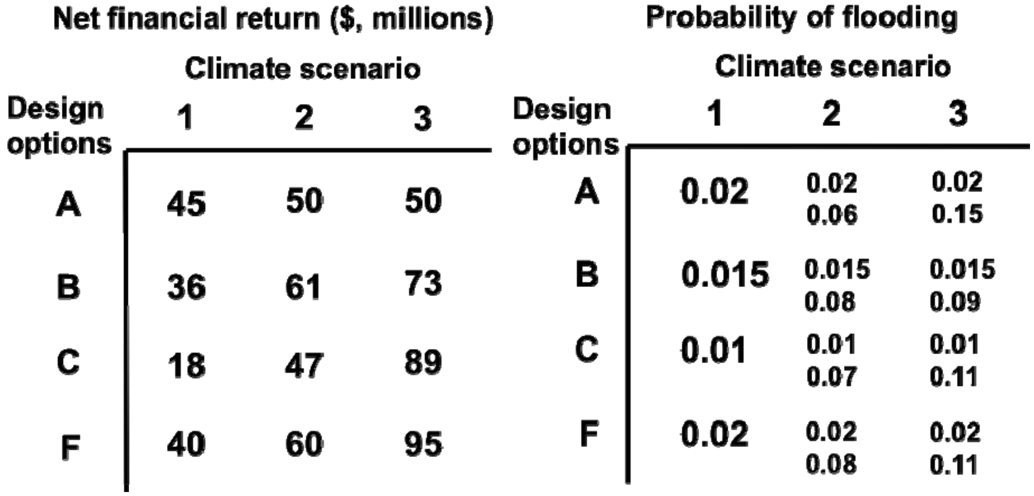
Design options	Climate scenario 1	2	3
A	L	L–M	VH
B	VL–L	M	M–H
C	VL	M	H
F	L	M	H

VL = very low, L = low, M = medium, H = high, VH = very high

Some of the decision criteria, such as maximax, minimax and maximin, can be applied to the qualitative matrix. For example, the minimax criterion leads to Design B with respect to flooding. A regret matrix can also be constructed for qualitative measures. It is also possible, though more difficult, to discuss the conflicts between the designs. However, it is not possible to use quantitative methods such as expected value or Hurwicz alpha with qualitative measures.

The examples above used flood probabilities after the scenarios materialize in 10 years. However, in the first 10 years, the probabilities of flooding are those before climate transition (i.e., Scenario 1). Therefore, there are probabilities of flooding before and after the transition for Scenarios 2 and 3, as shown in Table 7.18. (In reality, these transitions would be smoother). For example, if Design B is chosen and Scenario 3 materializes (in 10 years), the probability of flooding in the first 10 years is 0.015 (the current baseline) and 0.09 thereafter. In the case of the adaptive management strategy, Design F, the flooding probability in the first 10 years is that of Design A, and it changes to those associated with Designs B and C for Scenarios 2 and 3, respectively.

Table 7.18 Net financial return and annual probability of flooding matrices with change after 10 years



Net financial return ($, millions)

Design options	Climate scenario 1	2	3
A	45	50	50
B	36	61	73
C	18	47	89
F	40	60	95

Probability of flooding

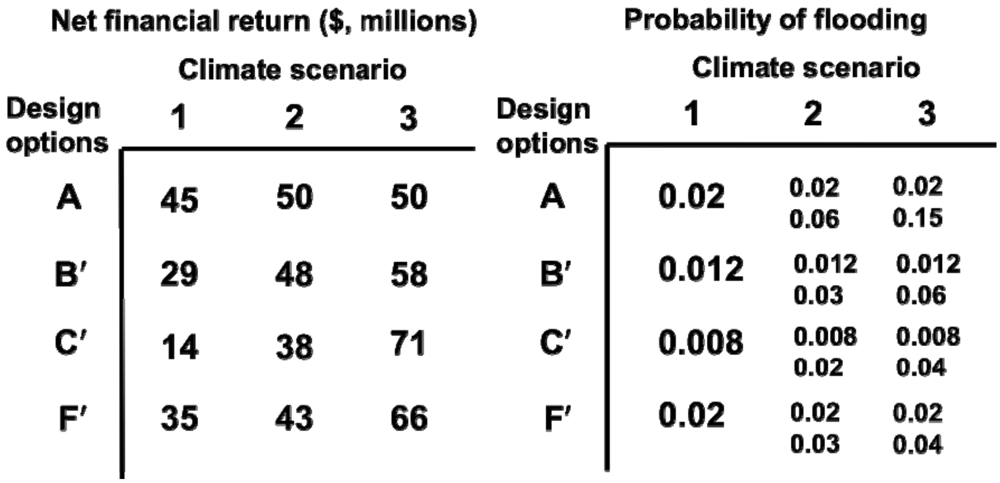
Design options	Climate scenario 1	2	3
A	0.02	0.02 0.06	0.02 0.15
B	0.015	0.015 0.08	0.015 0.09
C	0.01	0.01 0.07	0.01 0.11
F	0.02	0.02 0.08	0.02 0.11

For net financial return, the transition in costs and benefits, as shown in Table 7.11, was translated into a net present value through discounting. This is not possible with non-economic measures and the transition must be represented by different numbers at different times. Hence, there are probability pairs under Scenarios 2 and 3. Some of the decision criteria, such as minimax and minimax regret, can be applied in these cases. For example, the maximum probabilities for Designs A, B, C and F are 0.15, 0.09, 0.11 and 0.11, respectively. Because the minimum of these is 0.09, minimax would result in Design B being chosen. However, this ignores when, and for how long, these numbers apply. The decision maker could give preference to the values in the period before or the period after the transition, depending on the life of the project and how long these periods are. Alternatively, an attempt could be made to employ an averaged value over the different time periods.

7.7 A different design focus

In the above examples, the design options focused on optimizing financial return for the climate scenarios. There are also other options in which the focus is on a different attribute (e.g., flood control), as well as designs that try to address both. In Table 7.19, Designs B′, C′ and F′ are aimed primarily at flood control; Design A remains the alternative designed for the current climate. The adaptive management strategy in this case (Design F′) follows the same pattern as for its financial counterpart (Design F): it begins as Design A with flexibility to adapt depending upon observations in 10 years, at which time the design can be modified to B′ or C′ with the associated flooding probabilities. Since Designs B′, C′ and F′ give preference to flood control over power generation, the probabilities of flooding and the net financial returns are lower than for Designs B, C and F, respectively.

Table 7.19 Net financial return and flooding probability for designs focused on flood control and including flexibility



Net financial return ($, millions)

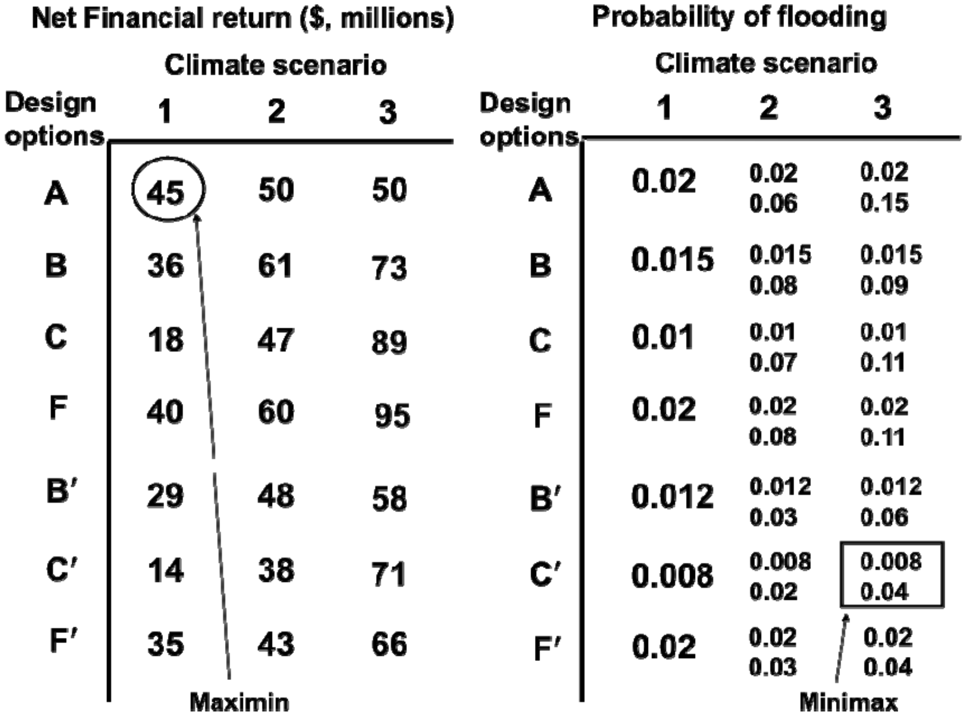
Design options	Climate scenario 1	2	3
A	45	50	50
B′	29	48	58
C′	14	38	71
F′	35	43	66

Probability of flooding

Design options	Climate scenario 1	2	3
A	0.02	0.02 0.06	0.02 0.15
B′	0.012	0.012 0.03	0.012 0.06
C′	0.008	0.008 0.02	0.008 0.04
F′	0.02	0.02 0.03	0.02 0.04

These options should be evaluated and compared against each other as well as against Designs B, C and F, as shown in Table 7.20. The same methods and concepts as applied above can be used. For example, using the maximin criterion for financial return and minimax criterion for flooding results in a conflict between Designs A and C′. Presentation of this type of information would facilitate discussion among the decision maker and other stakeholders to help identify a potential compromise from among these design options, as well as other designs that could be considered. For example, F′ in this case may emerge as one such promising compromise.

Table 7.20 Net financial return and annual probability of flooding matrices for all options



Net Financial return ($, millions)

Design options	Climate scenario 1	2	3
A	45	50	50
B	36	61	73
C	18	47	89
F	40	60	95
B′	29	48	58
C′	14	38	71
F′	35	43	66

Probability of flooding

Design options	Climate scenario 1	2	3
A	0.02	0.02 0.06	0.02 0.15
B	0.015	0.015 0.08	0.015 0.09
C	0.01	0.01 0.07	0.01 0.11
F	0.02	0.02 0.08	0.02 0.11
B′	0.012	0.012 0.03	0.012 0.06
C′	0.008	0.008 0.02	0.008 0.04
F′	0.02	0.02 0.03	0.02 0.04

7.8 Concluding remarks about decision methods

The classical methods for decision making offer potentially useful tools for comparing alternatives to adapt to climate change given the significant uncertainties. Because these methods are relatively simple and transparent, they are well suited for use in EAs. Other methods, including multi-attribute utility and Bayesian analysis, are more complex to use and are therefore not considered appropriate, at least at this time, for use in EAs because of the information they require and the difficulties in interpreting them.

The first examples dealt with only one attribute (financial return) in order to illustrate the different criteria. The examples then became more complex by adding another attribute (the probability of flooding). Analyzing for each attribute separately and comparing the results across the multiple attributes can serve to identify important tradeoffs.

The choice of method depends on attitudes toward risks and uncertainties. If the stakeholders agree on how to approach risks, such as being very risk-averse, then a corresponding criterion, such as to minimize the maximum impact, should be used. However, if the decision maker and other stakeholders have differing attitudes, then the corresponding criteria can each be used, and the resulting options preferred by each group compared. This would help identify whether and what conflicts exist and require further consideration.

A major theme of this section is the consideration of adaptive management options that adjust designs as data emerge regarding climate change. Such options can perform well as risk-averse strategies, though their appeal depends on how much is paid to permit future changes. They should therefore be considered along with the other adaptation design options.

8. Conclusions and Guidelines

A broad consensus has emerged that climate change will impact human activity in a number of spheres, though its precise effects are still highly uncertain. This research investigated alternative criteria and approaches for decision making under uncertainties in project-level EAs. In addition, adaptive management, which provides flexibility to adjust to climate change, is considered as a means of addressing the uncertainties. For background information, the research reviewed how recent Canadian project EAs addressed uncertainties associated with climate change (Section 5), and reviewed selected literature on methodologies for incorporating uncertainties into decision making (Section 6). The primary purpose of the research was to explain and discuss the use of these methods for decision making about adaptation to climate change (Section 7).

The review of 15 EAs from various sectors revealed that 13 addressed climate change to some degree, and several provided an extensive analysis that used models and predictions to evaluate their projects. However, because of the complexity of climate change and difficulties in predicting what the future climate will be, project proponents tended to favour more research, monitoring, and adaptation as the most practical strategy. Methods for choosing scenarios and adaptation strategies are needed as project developers remain significantly limited in their ability to address climate change adequately. Methods are also needed to help identify the preferred strategy given the uncertain future scenarios.

Most of the standard methods for evaluating project alternatives, such as benefit-cost analysis and multi-attribute analysis, suffer from their inability to meaningfully address uncertainties, which are a defining feature of climate change. This research has therefore focused on classical decision models for dealing with uncertainties. These methods offer potentially useful tools for comparing alternatives to adapt to climate change, including adaptive management strategies, which adjust designs as climate data emerge.

These classical decision models can provide valuable information for decision making by requiring alternative future scenarios be considered explicitly and identifying how attitudes toward risks and uncertainties affect the preferred choice. The results are transparent and can be relatively simple to interpret, thereby facilitating discussions about tradeoffs in the face of the uncertainties.

Implementation of these methods requires the choice of appropriate sets of scenarios and adaptation options, the assessment of the impacts of the combinations of options with the future climate scenarios, an understanding of the attitudes of the decision maker and other stakeholders toward risks and uncertainties, the application of corresponding decision rules, and effective communication of the results to address conflicts and tradeoffs.

Guidelines can help proponents address these issues, as well as assist reviewers in judging whether the issues were treated adequately. By providing expectations or "best practices", guidelines can elevate and bring greater uniformity to the evolving level of practice. They can be presented as basic statements of expectations such as "scoping should consider the spatial and temporal boundaries of the project", or as guides that explain methods for meeting the expectations. The Canadian Environmental Assessment Agency, for example, provides procedural guides such as the "Cumulative Effects Assessment Practitioners' Guide". The Agency also provides a guideline "Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners," which was prepared in November 2003 by the Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment (Canada FPTC 2003). As mentioned in the Introduction, this guide was an important step in clarifying the importance of climate change considerations in EAs and offering generalized advice for doing so. It recommends that proponents identify "project sensitivities to climate parameters and variability" and make public interest decision makers "aware of the climate change context within which a project is being proposed" (Canada FPTC 2003, p. 2). The FPTC guidelines offer generalized advice but do not provide information on methods for dealing with uncertainty in decision making.

Byer et al. (2004) provided a list of suggested general guidelines on how to address climate change uncertainties in project EAs. Among those were that the proponent should explicitly:

i) identify and scope whether and how future climate change may affect the project, directly and/or indirectly, and address the uncertainties in these effects; and
ii) for each of these impacts:
    - identify an appropriate method or methods for addressing uncertainties based on the level of analysis warranted for that impact;
    - justify the choice of method(s); and
    - communicate the results of the analysis of these uncertainties, such that the decision maker and stakeholders can understand the implications of the uncertainties.

The focus of this research report is to help proponents address these concerns. The following is a list of suggested general guidelines on the choice and use of methods for making decisions about adaptation to climate change given its uncertainties. The proponent should explicitly:

i) identify and scope whether and how future climate change may affect the project, directly and/or indirectly,

and, for each of these project vulnerabilities,

ii) identify the potential range of future climate change, and select climate change scenarios that adequately capture this range and the timing of effects;
iii) identify design options, including adaptive management strategies, to adapt the project to the future climate scenarios;
iv) estimate the level of the effect for each design option under each scenario;
v) identify, and justify the choice of, an appropriate decision making method or methods for comparing the design options on the basis of the estimated effects and the decision maker's attitudes toward risks and uncertainties; and
vi) communicate the results of the analysis such that the decision maker and stakeholders can understand the implications of the uncertainties and tradeoffs among the alternative design options.

Each of these general guidelines should be developed into more detailed guidelines with input from relevant proponents, agency reviewers, consultants, and non-governmental organizations interested in climate change. The discussion and explanations in this report can provide useful advice for developing more thorough guidelines.

9. Appendices

9.1 Appendix 1: Workshop schedule and participants

Workshop on
Decision Making Under Uncertainties for Adapting to Climate Change in Project Environmental Assessments

Tuesday, April 27, 2010

University of Toronto
Galbraith Building, 35 St. George Street
Room GB202

Carried out as part of a research project funded by the
Canadian Environmental Assessment Agency

SCHEDULE

8:30	Check-in and continental breakfast
9:00	Introduction to workshop - Past research project - Review of EA practices - Purpose of current project and workshop
9:45	Discussion
10:15	Break
10:30	Decision-making criteria and methods for addressing uncertainties
12:00	Break – Lunch provided
12:30	Discussion over lunch - Use of the criteria and methods - Key questions - What would help practitioners - Development of guidelines for practitioners
2:00	Next steps and workshop wrap-up
2:30	End of workshop

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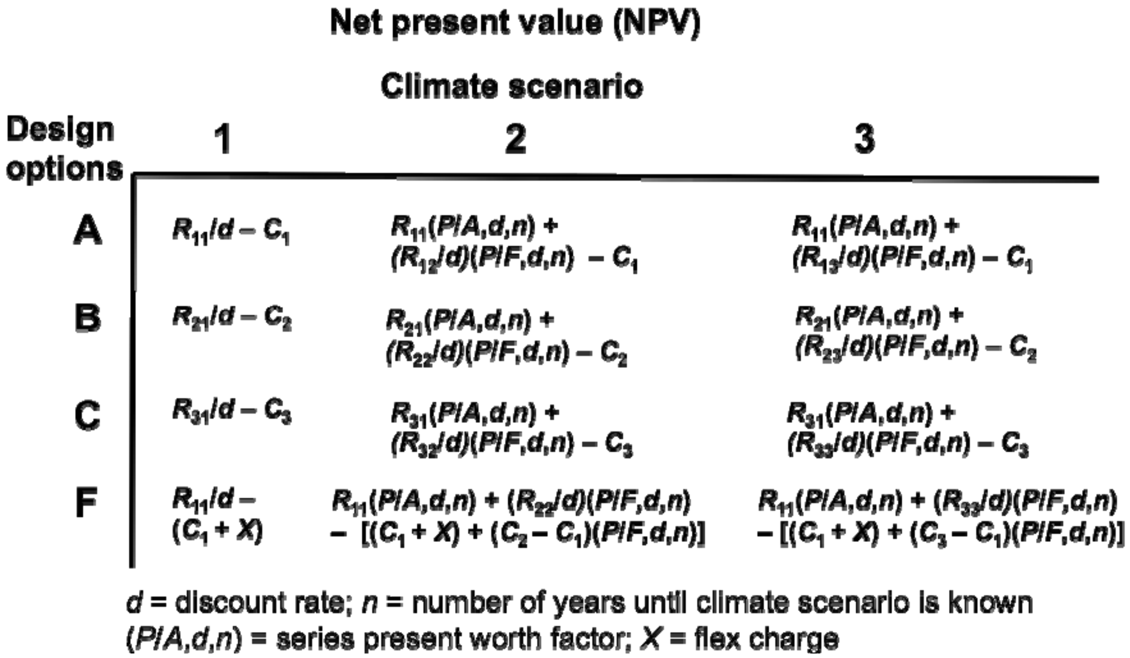
9.2 Appendix 2: Generalized calculations of net financial return

This appendix illustrates the generalized calculations for net present values calculated in many tables in Sections 7.3 through 7.7. Table 9.1 shows the formulas used to calculate net financial return (in terms of NPV) for the different pairs of scenarios and designs.

Table 9.1 Generalized determination of net present value for three designs and flexibility



Net present value (NPV)

Climate scenario

Design options	1	2	3
A	$R_{11}/d - C_1$	$R_{11}(P/A,d,n) + (R_{12}/d)(P/F,d,n) - C_1$	$R_{11}(P/A,d,n) + (R_{13}/d)(P/F,d,n) - C_1$
B	$R_{21}/d - C_2$	$R_{21}(P/A,d,n) + (R_{22}/d)(P/F,d,n) - C_2$	$R_{21}(P/A,d,n) + (R_{23}/d)(P/F,d,n) - C_2$
C	$R_{31}/d - C_3$	$R_{31}(P/A,d,n) + (R_{32}/d)(P/F,d,n) - C_3$	$R_{31}(P/A,d,n) + (R_{33}/d)(P/F,d,n) - C_3$
F	$R_{11}/d - (C_1 + X)$	$R_{11}(P/A,d,n) + (R_{22}/d)(P/F,d,n) - [(C_1 + X) + (C_2 - C_1)(P/F,d,n)]$	$R_{11}(P/A,d,n) + (R_{33}/d)(P/F,d,n) - [(C_1 + X) + (C_3 - C_1)(P/F,d,n)]$

d = discount rate; n = number of years until climate scenario is known

$(P/A,d,n)$ = series present worth factor; X = flex charge

R_{11} is the annual net financial revenue if Design A is built and Scenario 1 persists. If Scenarios 2 and 3 later occur, R_{11} is realized for the first n years of the project and then either R_{12} or R_{13} will ensue in perpetuity for Scenario 2 or 3, respectively. R_{12} is the annual net revenue if Scenario 2 materializes in n years and Design A is built now (this cash flow begins at year n and continues in perpetuity). Similar reasoning holds for the other R terms. C_1, C_2 and C_3 are costs at Year 0 except for Design F where $(C_2 - C_1)$ and $(C_3 - C_1)$ occur at year n.

The notation $(P/F,d,n)$ is typical engineering economics notation for the present worth factor: it translates as present value, P, given a future value, F, and a discount rate, d, compounded n times. The present worth factor $(P/F,d,n)$ equals $(1 + d)^{-n}$. For example, if the discount rate is 5% compounded annually and a cost of \$120 is incurred at the end of 10 years, the NPV of that cash flow is calculated as follows:

$$\$120(P/F, 5\%, 10) = \$120(1 + 0.05)^{-10} = \$73.67$$

The expression $(P/A,d,n)$ is known as the series present worth factor and is used to calculate the present value, P, of a uniform series of payments A occurring at the end of each compounding period for a given number of periods, n, and discount rate, d. For example, a series of ten \$100 payments ($A = 100$) made at the end of each year over the next 10 years is expressed thus:

$$\$100(P/A, 5\%, 10) = \$100(7.722) = \$772.20$$

If amount A continues in perpetuity, i.e., $n = \infty$, $(P/A,d,n) = A/d$. Compounding formulas, and tabulated values for common interest rates and various compounding periods, can be found in all engineering economics textbooks.

With adaptive management (Design F), the chief difference in formulaic structure is the extra cost incurred at year n for project expansion. Starting at the end of year n, the revenue cash flows are treated as a perpetuity whose capitalized value is then discounted n years to the present. If the project life is relatively short, e.g., 30 years, it would be more accurate to use a finite annuity.

The transition scenario Scenario 2-3 involves one extra step for computing the present value of the project's net financial return (shown in Table 9.2) since there are three intervals: the first 10 years, Years 10 to 20, and after Year 20. The project is assumed to continue long enough after Year 20 such that the equation for a perpetuity ($P = A/d$) can be applied.

Table 9.2 Calculation of net present value for the transition scenario, Scenario 2-3

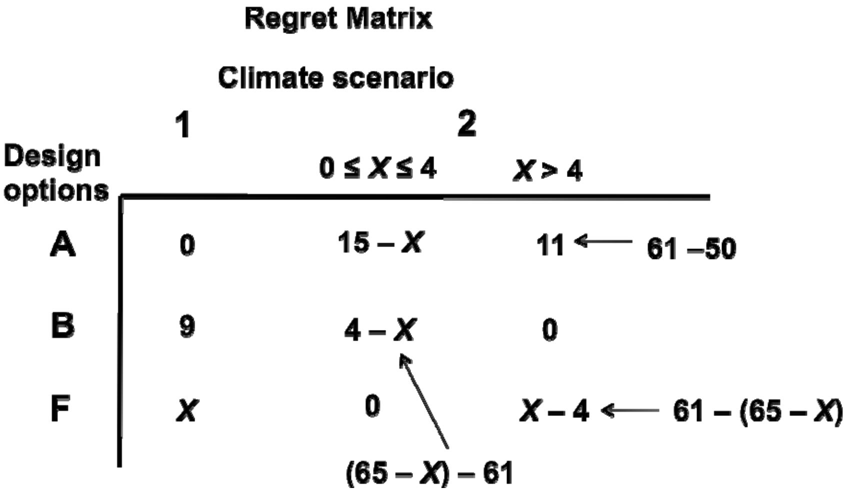
	Net Present Value (NPV)
Design options	**Transition scenario 2-3**
A	$R_{11}(P/A,d,10) + R_{12}(P/A,d,10)(P/F,d,10) + (R_{13}/d)(P/F,d,20) - C_1$
B	$R_{21}(P/A,d,10) + R_{22}(P/A,d,10)(P/F,d,10) + (R_{23}/d)(P/F,d,20) - C_2$
C	$R_{31}(P/A,d,10) + R_{32}(P/A,d,10)(P/F,d,10) + (R_{33}/d)(P/F,d,20) - C_3$
F	$R_{11}(P/A,d,10) + R_{22}(P/A,d,10)(P/F,d,10) + (R_{33}/d)(P/F,d,20) - [(C_1 + X) + (C_2 - C_1)(P/F,d,10) + (C_3 - C_2)(P/F,d,20)]$

9.3 Appendix 3: Design choice regret and flexibility charge

This appendix discusses in further detail the relationship between flexibility charge and regret explained in Section 7.3.

When *X* is left as a variable, the regret matrix for the two design-scenario scheme plus flexibility option is as shown in Table 9.3.

Table 9.3 Regret matrix for the two designs and flexibility in terms of flex charge *X*



Regret Matrix

Climate scenario

Design options	1	2 $0 \leq X \leq 4$	2 $X > 4$
A	0	$15 - X$	$11 \leftarrow 61 - 50$
B	9	$4 - X \leftarrow (65 - X) - 61$	0
F	X	0	$X - 4 \leftarrow 61 - (65 - X)$

The “switch point” with the minimax regret criterion is a flex charge $X = 9$, which is the most that should be paid for flexibility. After this point, it is better to build for the larger capacity of Design B in the first place. Any flex charge above 9 shifts preference away from Design F (designing either for Scenario 1 or 2 now, and eschewing flexibility) because, if Scenario 2 does not materialize in 10 years, building for it (Design B) now entails less cost (i.e., lower regret). Even if Scenario 1 holds after 10 years, Design F is not the preferred design because Design B has a lower cost at Year 0 and thus entails a smaller regret. Essentially, the high flex charge brings the NPV for Design F with Scenario 1 below that for Design B, and the lowest maximum regret is found for Design B.

For flex charges $X < 4$, Design F offers the largest NPV ($65 - X$) should Scenario 2 materialize, and it serves as the reference for calculating regrets in this column ($0 < X < 4$). As X increases from zero, the difference in NPV between Designs B and F diminishes ($65 - X - 61$). Once $X > 4$, the NPV of Design B with Scenario 2 is greatest and the reference for estimating regrets shifts to Design B. At this point, the regret associated with Design B becomes zero, while it increases linearly in proportion with the flex charge ($X - 4$).

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