INVESTIGATING FLOODPROOFING STRATEGIES FOR HISTORIC SETTLEMENT AREAS OF THE FRASER RIVER BASIN, BRITISH COLUMBIA, CANADA -

A COMPLEMENTARY APPLICATION OF MULTI ATTRIBUTE DECISION MAKING AND STATED PREFERENCE DISCRETE CHOICE MODELLING

by

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Abstract

Floodproofing is a non-structural flood mitigation method often used as a secondary flood protection for homes located in floodplains that are already protected by dykes. In the Fraser River Basin, since 1973, floodproofing has been required for all new residential developments in the floodplain, except those located in "urban exempt zones" of historically settled areas. Consequently, many communities in the lower Fraser River floodplain rely solely on the dyking system for flood protection.

Governments would like to encourage floodproofing in existing residential developments of historic settlement areas but are concerned about potential impacts, such as aesthetics and costs, and lack knowledge about public preferences regarding potential floodproofing programs. Academically, this resource management problem presents an interesting challenge. Traditional methods for addressing multiple objective decision problems of public concern are deficient: they either lack the ability to adequately address multi-variate decisions requiring quantitative value trade-offs, or are ill-equipped to deal with public preference elicitation on a large scale. To address these limitations, a complementary methodology was devised that combined the structured decision framework and analysis tools of multiple attribute decision analysis with the public preference survey elicitation methods of stated preference choice modelling. The results showed that this novel combination of traditionally disparate research paradigms can produce important academic insights as well as relevant management findings.

The study found that floodproofing can be an acceptable approach for achieving key flood management objectives, from the perspective of both floodplain managers and the public. Once informed about the community flood management context, homeowners preferred to make trade-offs with regards to concerns, such as aesthetics and costs, to promote floodproofing in the community, rather than maintain the status quo. In addition, homeowners would prefer to floodproof their own homes, even if floodproofing requires significant personal investment, but at the same time they would like to see an active and positive government role in funding and providing direction for such a program.

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List of Abbreviations and Acronyms

AHP	Analytical Hierarchy Process
CVM	Contingent Valuation Method
DA	Decision Analysis
DCE	Discrete Choice Experiment
DSS	Decision Support System
ELECTRE	Elimination et Choix Traduisant la Realite
FCL	Flood Construction Level
GSC	Geological Survey of Canada (geographical elevation reference datum)
HSA	Historic Settlement Area
IFM	Integrated Floodplain Management
MADM	Multiple Attribute Decision Making
MAUT	Multi Attribute Utility Theory
MAVT	Multi Attribute Value Theory
MCDM	Multiple Criteria Decision Making
MDC	Maximum Difference Conjoint
MNL	Multi Nomial Logit
MODM	Multiple Objective Decision Making
OR	Operations Research
RUT	Random Utility Theory
WTP	Willingness to Pay

Chapter 1 Introduction

1.1 The Floodplain Management Setting

The Fraser River Basin is the economic, social, and cultural heartland of the province of British Columbia, Canada (Figure 1). It is the fifth largest drainage basin in Canada and covers almost ¼ of the land area of the province (Sewell 1965). Unlike most major river systems in North America, the mainstream of the Fraser still flows freely from its headwaters to the sea unimpeded by dams (Bocking 1997). The river and its estuary support major salmon runs and provide essential habitat for wildlife including large populations of birds migrating along the Pacific Flyway (FREMP 2003).

Figure 1 The Fraser River Basin, British Columbia, Canada. (Used with the permission of the Fraser Basin Council, Vancouver, BC)

The basin contributes 80% of the total provincial economic output. Two out of every three British Columbians live in the basin, with most in the lower Fraser Valley region from Hope to the Strait of Georgia (Fraser Basin Council 2003, Bocking 1997). Over 2 million people live in the Greater Vancouver Regional District at the mouth of the Fraser, making it the basin's most densely populated and urbanized region. The population is growing rapidly; in the next twenty years, it is estimated that the population will increase by nearly 800,000 residents (FREMP 2003). Furthermore, a considerable proportion of the population and economic activity of the lower Fraser Valley is located in the floodplain (Bocking 1997, Sewell 1965). For example, in 1994 it was estimated that development in the floodplain was valued at over $13 billion dollars (Fraser Basin Council 2004).

Government standard dikes have been erected along the river banks to protect major population centres from flooding, but if a dike break were to occur, or if flood waters were to overtop the dykes during a major flood on the Fraser, the damage and disruption to people and infrastructure in the floodplain would be severe; estimates of 2 billion dollars in damages have recently been established (Fraser Basin Council 2004).

In addition to dikes, a secondary flood defence strategy used in the floodplain is floodproofing. In general, floodproofing is an attempt to reduce flood damages by modifying an individual structure, or the land on which the structure sits, in a way that either prevents flood waters from entering the main living areas (e.g. elevation) or enhances the structure's ability to withstand flood waters (e.g. utilizes flood resistant building materials). Floodproofing is often undertaken during construction, but can also be applied to existing buildings. Between 1973 and 2004, the provincial government required all new developments in the floodplain, excluding those in special planning zones, be floodproofed to the 1:200 year flood standard (Smith 1991). Certain areas in the floodplain were exempted from floodproofing requirements due in large part to local government concerns over the potential impacts on development (Smith 1991). The exempt areas in the floodplain generally correspond with what are called historic settlement areas, which are regions within the floodplain that were originally developed by early settlers and that will continue to be developed through infill or redevelopment (Fraser Basin Council 2002a). The historic city cores of many communities are located in historic settlement areas (e.g. downtown Chilliwack and downtown Port Coquitlam). As a result, many densely populated urban areas in the Fraser River floodplain rely solely on the existing dyking system for flood protection. For the most part, the dyking system is more than 50 years old, since many dykes were built with government infrastructure funding in the 1950s in response to the 1948 Fraser River flood (Smith 1991, Shrubsole 2000).[1] The aging dyking system is a concern because without continual funding for maintenance and repair, the structural ability of the dykes to withstand a major flood will decline (Shrubsole 2000). To make matters worse, as mentioned previously, the Fraser Basin is experiencing a period of high population growth. As a result, the urban population density of many historic settlement areas will increase as communities work to control population growth and urban sprawl with redevelopment and densification strategies in existing historic developments. The influx of new residents to the floodplain who may have little knowledge of, or past experience with flooding will be a major issue for governments concerned with managing future flood risks.

The current lack of floodproofing requirements in historic settlement areas of the Fraser River floodplain is an interesting flood management problem, because it is an issue of concern to multiple interest groups (e.g. governments, developers and homeowners) and involves various conflicting objectives (e.g. aesthetic impact of floodproofing designs vs. flood damage prevention). Within the realm of floodplain management, there are two distinct research approaches that have traditionally informed management thought and activities. The first is associated with water resources or river basin planning, which is a field dominated by technical and engineering tools and techniques. The second active area of research is led by social scientists and in particular applied geographers interested in the perceptions and responses of floodplain residents to flood hazards.

[1] The Fraser River Flood Control Program was created following the 1948 flood on the Fraser by the Government of Canada and the Province of British Columbia in order to repair, strengthen, construct and rebuild dykes in the Fraser Valley. Although funding was provided through the federal and provincial governments, agreements stipulated that local authorities (e.g. municipalities) are responsible for dyke operation and maintenance and for encouraging floodproofing behind the dykes (Smith 1991).

1.2 The Methodological Context

Prior to 1960 in the field of water resources planning, the focus in floodplain management was on large-scale structural projects for flood control, which resulted in a field dominated by civil engineers concerned with the design, construction and operation of control works. Over time the popularity of structural engineering works for water management and flood control has declined in recognition that other non-structural methods could potentially be used to achieve a reduction in flood damages with lower costs and with less environmental and social impacts (Laituri 2000, Grigg 1996). Today, integrated flood hazard management, which promotes the use of a complement of structural and non-structural flood management methods at various stages in the planning process, is a firmly established principle in floodplain management. Another trend has been the adoption of collaborative planning for making floodplain management decisions, which emphasizes the role of participatory public involvement in developing broadly acceptable and effective management plans (Grigg 1996).

The techniques of multiple objective mathematical programming (also referred to as multiple objective decision making) had a large early influence in water resource management because the techniques were well suited for assisting engineers with the design and operation of structural control works (Grigg 1996). With the increasing use of integrated flood hazard management and participatory models of decision making, tools appropriate for broader strategic level planning in a multiple stakeholder environment were developed or adopted. Attempts have been made to expand or modify traditional mathematical optimization methods to address complexities such as multiple conflicting objectives and multiple stakeholder participation (Goicoechea *et al.* 1982). In addition, multiple attribute decision making has enjoyed a wider applicability due to its stronger focus on problem structuring, well-defined value theories and preference elicitation methods, suitability for evaluating discrete policy alternatives, and often simpler and more accessible quantitative structure (Keeney 1992).

Social science research has also made significant contributions to floodplain management and its role seems likely to increase in the future given recent trends towards more holistic approaches to flood management and the increasing demand for participatory decision making processes. Geographers have analysed the human-environment relationship by focusing on human perceptions of flood hazards and by exploring the reasons for observed responses and adjustments to such threats (Burton, Kates, and White 1993). In addition to hazard perception and responses, social science methods in the form of public values surveys have been used to obtain information on floodplain residents' values and preferences for aspects of flood management techniques and strategic plans (e.g. Rasid 2000). Although many surveys have used simple tools for preference assessment, few have addressed the trade-offs and values associated with multi objective management problems.

As stated previously, both multiple objective and multiple attribute decision analysis methods have been used as planning and decision-making tools for addressing floodplain management problems and can be used in planning environments involving multiple stakeholders. Unfortunately, most decision analysis techniques demand a level of participation in the planning process that is infeasible when it comes to large-scale public values elicitation and a level of technical comprehension of the decision problem that is beyond the abilities of the average citizen. While multiple stakeholder planning is a crucial component of the collaborative planning process, there is no guarantee that the interest groups involved can effectively represent the views of the general public (Loomis 2000). Although there are other tools that can be used to analyse and document public views (e.g. open houses, invitation for public comment, and focus groups), these methods have two important drawbacks. First, since they generally rely on the initiative of individual citizens to get involved, adequate representation of the public interest is questionable. Secondly, while the outcomes or products of many public preference techniques are informative, they are not usually of a type suitable for direct use or comparison with the quantitative decision making methods that are becoming more popular for planning processes. As a result, there is a need for alternative public preference elicitation techniques that are complementary to the techniques used in multiple objective, multiple stakeholder planning. Such techniques should be capable of addressing the multi objective nature of natural resource problems and of providing information on public values and trade-offs in a way that is compatible with a decision analysis framework. The use of such a tool would improve the likelihood that the views of the public are effectively represented in natural resource planning and management processes along with the views of key stakeholders and decision makers.

In an attempt to address the limitations identified above regarding the abilities of both traditional decision analysis methods and public preference research tools to facilitate the quantitative analysis and inclusion of public values into multiple objective planning processes, the research undertaken in this project explored the complementary application of survey-based public values research tools (discrete choice experiments and maximum difference conjoint methods) with multi attribute decision analysis. This integrated methodology was used to analyse a multi objective decision problem concerned with identifying appropriate flood proofing strategies for historic settlement areas of the Fraser River Basin in British Columbia, Canada.

1.3 Purpose and Objectives

The purpose of the project was twofold. First, the research investigated the complementarity of multi attribute decision analysis and stated-preference choice modelling. Second, the project was concerned with the applied problem of identifying and evaluating strategies to encourage floodproofing of existing homes in historic settlement areas of the Fraser River Basin in British Columbia, Canada. The detailed research objectives below reflect the dual purpose of the study.

General Objective 1 - To develop innovative and multi-disciplinary quantitative tools for including public values in planning and decision making processes by demonstrating the compatibility of decision analysis techniques and stated preference (discrete choice) methods in an applied setting.

Specific Sub-objectives:

- Use the methods and theories of decision analysis to help guide the development of a public preference survey.
- Obtain public preference information from a large-scale survey for a set of decision objectives that is suitable for direct use in a multi attribute decision analysis.
- Elicit preference information from managers/experts for the same set of objectives.
- Use multiple attribute decision analysis to derive rankings for alternatives from the perspective of both managers and the public.
- Compare decision analysis-derived rankings of alternatives to rankings derived using the results of a stated preference discrete choice model.
- Provide a DSS that allows the interactive evaluation of alternatives based on homeowner preferences.

General Objective 2 - To provide scientifically sound information that promotes publicly acceptable decisions regarding strategies for encouraging floodproofing in historic settlement areas of the Fraser River Basin.

Specific Sub-objectives:

- Thoroughly structure the problem by developing a concise problem statement, a list of fundamental management objectives and attributes, and a number of alternative floodproofing strategies.
- Use multi-objective modelling techniques to identify the potential impacts or community outcomes that could be associated with different alternatives.
- Document preferences and values for management objectives and attributes.
- Explore and compare how various floodproofing strategies are perceived by the general public and by floodplain managers.

Given these project objectives, the report will be organized as follows. Chapter 2 describes the floodplain management context for the floodproofing problem including an overview of the history and the specific flood management issues associated with the case study area. Chapter 2 also contains a review of the research approaches typically used in the flood management field. Chapter 3 reviews the two primary methods applied in this project, and concludes with a comparison of the two methods. Chapter 4 describes in detail how the two methods were implemented in a complementary manner to analyse the floodproofing management problem in the case study area. Chapter 5 summarizes the research results and concludes with an evaluation of the suitability of combining stated preference surveys and multiple attribute decision analysis. Finally, Chapter 6 provides a discussion focusing on the implications of the research for floodplain management.

Chapter 2 The Flood Management Context

Human societies have a long history of attempting to manage water resources and reduce flood threats to human settlements. Archaeological discoveries of ancient canal systems, aqueducts and earthen dams built as early as 2900 BC show that humans have been engaged in water works for millennia (Wohl 2000).

The floodplain management literature classifies modern human attempts to deal with flood hazards into two main categories: structural and non-structural. Structural approaches are generally associated with flood control projects in which technical and engineering solutions are used to prevent floodwaters from entering human settlements (Watson and Biedenharn 2000). In contrast, non-structural measures involve adjustment of human activities to accommodate the flood threat and are often associated with soft engineering approaches (Gruntfest 2000, Wohl 2000). Figure 2 categorises some common flood mitigation measures in terms of the structural/non-structural classification.

Flood Hazard Adjustments

Structural

Engineering Works
Levees and dikes
Floodways
Storage dams
Channel improvement

Abatement Methods
Topographic modification
Vegetation modification

Non-structural

Preparedness
Floodplain mapping
Flood forecasting and warning

Loss Sharing
Disaster Aid
Flood Insurance

Threat Reduction
Land use planning and ordinances
Acquisition and relocation

Floodproofing

Figure 2 Categorization of flood hazard adjustment methods (adapted from Smith and Ward 1998 with information from Gruntfest 2000).

Throughout the 20th century flood prevention methods focused on structural methods for a number of reasons: 1) the benefits of engineering projects were obvious and easy to measure economically, 2) a negative attitude towards land use restrictions persisted, 3) government cost sharing agreements tended to favour large-scale projects, and 4) decisions were often made without due consideration for secondary environmental and social impacts (Gruntfest 2000, Merritts 2000).

Unfortunately despite massive investments in structural flood prevention measures, flood damage costs worldwide have continued to rise each year (Wohl 2000, Shrubsole 2000). Increasing flood damage costs are likely caused by a number of factors. First, land use changes resulting from rapid urbanization in river basins have resulted in increased volume and rate of water flow during high water. Secondly, human population density has increased in floodplain areas over time (Wohl 2000). The tendency of humans to increase settlement in floodplains protected by structural flood works is referred to as the "flood protection-development spiral" (Merritts 2000). In fact, studies have shown a disturbing link between investments in flood defence and subsequent increases in floodplain populations (see Parker 1995, White *et al.* 1958, and Ramachandran and Thakur 1974 for examples from England, the United States and India respectively).

2.1 Integrated Floodplain Management

In recent years, there has been a move away from relying solely on structural measures for flood protection to a more integrated approach in which a variety of flood management measures are considered as part of a comprehensive flood management strategy (Grigg 1996, Arlington Group 2001, Laituri 2000). This process may be referred to simply as integrated floodplain management (IFM), although a variety of terms have been used in the literature.[2] As shown in Figure 3, IFM can be categorized into three phases according to the timing of management activities with respect to a flood event (Simonovic 1999).

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[2] For example, integrated flood hazard management, flood hazard mitigation, flood mitigation planning (Fraser Basin Management Board 1996, Yin 2001, Fordham 1999, Wetmore and Jamieson 1999).

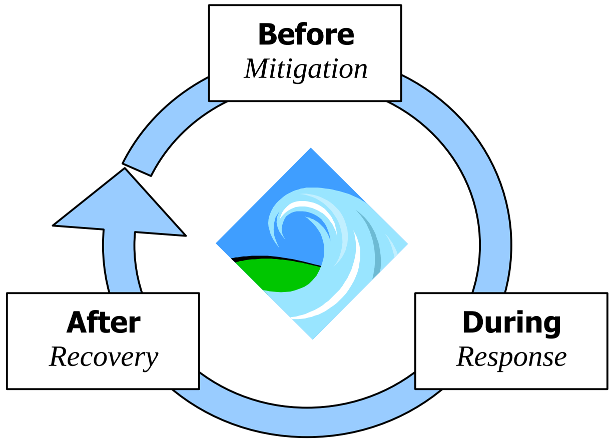

Figure 3 Categorization of the IFM process by planning and activities that occur before, during and after a flood event.

The emphasis on management tools that may be used before, during, and after a flood event highlights the iterative nature of the ideal IFM planning process. The grouping of IFM methods provides a simple yet effective organization for the purposes of this paper.[3]

An integrated flood management strategy utilizes a variety of tools and techniques that may be employed at all stages of the planning process. A combination of structural and non–structural methods is promoted. For instance, investments in floodplain mapping (mitigation), dykes (mitigation), floodproofing (mitigation), flood warning systems (response) and flood disaster assistance programs (recovery) could all be components in an integrated floodplain management program.

2.2 Floodproofing

As illustrated in Figure 2 and Figure 3, floodproofing is generally considered a non-structural flood hazard mitigation method. Although the focus of this research report is on floodproofing, it should be clear that floodproofing is only one component of an integrated floodplain management strategy. The USACE (1993, pg. 1) defines

[3] Other categorizations are also used. For instance, the Fraser Basin Council classes what it calls Integrated Flood Hazard Management into three components: flood protection works, land use planning and management, and emergency response and recovery (Fraser Basin Management Board 1996).

floodproofing as "any combination of structural or non-structural changes or adjustments incorporated in the design, construction, or alternation of individual buildings or properties that will reduce flood damages." This broad definition allows many different methods to qualify as floodproofing. In the United States and in other parts of Canada, at least five different methods of floodproofing are recognised: relocation, elevation, berms/floodwalls, dry floodproofing, and wet floodproofing (USACE 1993, FEMA 1998).

In British Columbia, the definition of flood proofing tends to be more specific. For example in a 2001 report for the Fraser Basin Council, the Arlington Group defined floodproofing as "the elevation of habitable space to the specified Flood Construction Level[4] and may include the use of flood damage resistant building materials" (Arlington Group 2001, pg. 1). From this definition, it appears that only elevation or wet floodproofing qualify as floodproofing methods.

2.3 History of Flood Management in BC and the Lower Fraser Basin

The Fraser River Basin drains approximately ¼ of the land area of British Columbia and supports around two thirds of the province's total population (Sewell 1965, Day 1999, Dorcey 1991). Historic settlement of the region was directed predominantly by the location of prime agricultural lands, the proximity to transportation corridors, and the location of sites of high fisheries values (Arlington Group 2001). Unfortunately, these areas also tended to coincide with regions of high flood risk, especially in the Lower Fraser Valley region. Figure 4 shows the extent of the Fraser River floodplain as it existed in 1894.

The major floods of 1894 and 1948 caused significant damage in the area (Sewell 1965); the 1948 flood damages were estimated at $142 million in 1994 dollars (Fraser Basin Council 2002b).

[4] Flood construction level – the minimum allowable elevation for habitable space, above mean sea level, based on a flood with an annual probability of occurrence of one in 200 years, which typically includes a safety factor of 2 feet (Fraser Basin Council 2002a, Arlington Group 2001).

Figure 4 The Fraser River floodplain in 1894.
(Used with permission of the Fraser Basin Council, Vancouver, BC)

In response, dikes were built to protect flood-prone settlements and now comprise the primary protection against future flooding (Sewell 1965). The heavy reliance on structural flood protection measures in the Fraser River floodplain is regrettable for a number of reasons. First, residents and homeowners are given a false sense of security, which provides a disincentive to manage their own flood risk (Day 1999). Second, the existence of the publicly funding dyking system acts as a perverse incentive to encourage more development in flood prone areas, and thus contributes to the flood protection-development spiral mentioned previously. Third, most of the dykes have been built to withstand the flood of record, which occurred in 1894, but in the event of a flood equal to or greater than the construction level of the dykes, unprecedented damage could occur if the dikes were breached (Sewell 1965).[5] Finally, the recent experiences of other jurisdictions during major flood events (e.g. Red River in 1997, Mississippi in 1993) has shown that relying solely on structural means for flood protection can have devastating consequences when these measures fail. For example, numerous levee failures during the 1993 floods on the Mississippi River caused damages in excess of $12 billion US dollars (NOAA 1994).

In recognition that a comprehensive floodplain management strategy would likely be more successful in minimizing future flood damages, floodplain managers in British Columbia are also interested in other non-structural methods for flood mitigation. For instance, after 1972, flood proofing was mandatory for all new developments in the Fraser River floodplain but excluded those areas located in special planning zones, which generally corresponded with "historic settlement areas" (Smith 1991).[6]

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[5] As discussed in Chapter 1, the Fraser Basin Council has recently estimated damages of approximately $2 billion.

[6] An amendment to the Land Title Act (Section 82) was made following significant flood damages to some communities in the 1972 flood on the Fraser (e.g. Oak Hills). The amendment required that approvals for all new subdivisions on floodplain land be submitted by the local approving officer for consent to the Ministry of the Environment. Covenants against the land title of the subdivision were required including floodproofing conditions and "no liability" provisions. Historic Settlement Areas were exempt under section 187 of the Municipalities Enabling and Validating Act (Smith 1991).

2.4 Historic Settlement Areas and the Fraser River floodplain

The Fraser Basin Council (2002a) defines Historic Settlement Areas (HSA) as regions within the floodplain that have been developed through early settlement patterns and that are committed to further development, either through infill or redevelopment.[7] Provincial policy has exempted numerous planning regions in historic settlement areas from floodproofing standards, leaving many populated areas situated in the Fraser River floodplain with little or no floodproofing requirements.[8] The current exemptions account for 1/3 of the floodplain area of the Greater Vancouver Regional District (Smith 1991). As a result, a significant proportion of existing homes and businesses located in historic settlement areas are unprotected in the event of a dike failure or if flood waters overtop the dikes. Furthermore, the population densities within many historic settlement areas have been increasing with the growing population of the region. The current lack of floodproofing regulations for existing developments in most historic settlement areas is likely due to a complex interaction of a number of factors such as concern over costs, fear of public opposition in established neighbourhoods, potential aesthetic impact, and a lack of public knowledge regarding the seriousness of the flood threat in the Fraser floodplain (Sewell 1965, Arlington Group 2001).

[7] The definition of historic settlement areas (HSAs) was a topic of debate at meetings with floodplain managers during the two working group meetings held for the purposes of problem structuring. It was suggested that the term might have limited usefulness for this study since municipalities do not recognize a standard definition. The definition given in the text does not preclude historic settlements that have already been floodproofed. In general, this study was interested in HSAs because they tend to represent areas located behind standard dykes that have not been floodproofed to the FCL.

[8] As of January 1, 2004, Section 16 of the Flood Hazard Statutes Amendment Act (2003) repealed Section 82 of the Land Title Act (1996). As a result, approval for new developments in the floodplain is no longer required by the province but is under the authority of the local approving officer. The Flood Hazards Statutes Amendment also allows the local approving officer to modify or discharge covenants previously required under Section 82 of the Land Title Act. Furthermore, Section 910 of the Local Government Act was also changed by removing the authority of the Province to designate floodplain areas and set flood construction levels. Although local authorities are reviewing the effects of these legislative changes, it appears that the intent is to give local governments primary authority for determining the appropriate building restrictions for structures located in floodplains. As a result, 'historic settlement areas' may no longer be a meaningful term for describing areas that are exempt from floodproofing requirements since the new legislation appears to 'exempt' all areas in the floodplain from provincial floodproofing regulations. Setting flood construction levels inside and outside of historic settlement areas will likely now be under the jurisdiction of each municipality.

The following section will introduce the case study area, the City of Richmond, which is an example of a growing urban community that contains a large designated historic settlement area.[9] The review will focus on flood hazard management issues of particular importance for the City of Richmond.

2.5 Case Study Area – the City of Richmond

The City of Richmond is a young community located just south of Vancouver on the southwest coast of British Columbia, Canada. The first European settlers arrived in the area around 1860 and by 1879 Richmond was incorporated as a municipality. Designation as a city did not occur until 1990. Historically, Richmond was primarily an agricultural and fishing community due its location at the mouth of the Fraser River and its abundance of fertile delta soil (City of Richmond 2003a). In the past few decades, Richmond has experienced significant population growth driven by factors such as its proximity to the major urban centre of Vancouver and the location of the Vancouver International Airport on Sea Island. Much of the population growth has occurred since the early 1990's and has been driven by Asian immigrants, particularly from China and Hong Kong, who now compose around 1/3 of the population. Today over 168,000 people live in the City of Richmond in an area of approximately 50 square miles (City of Richmond 2003b).

In general, housing in the City of Richmond is dominated by single-family detached homes located in traditional suburban neighbourhoods, although towards its urban core, higher density apartments and complexes begin to contribute the majority of residential units. In 2003, single-family dwellings accounted for 47.2% of the existing housing stock, while apartments, townhouses and semi-detached homes accounted for 29.6%, 21.1%, and 2.2% respectively (City of Richmond 2003c). Single-family dwellings are gradually contributing a smaller proportion to the new housing stock built in Richmond each year. In 1981, 61% of the new housing units constructed were single-family homes, a number that declined to 47% by 2002 (City of Richmond 2003c).

[9] More accurately, Richmond did contain a large HSA, see footnote 8.

The entire community is located on a series of low-lying islands at the mouth of the Fraser River (at an elevation of approximately 1 meter above sea level). The islands are composed primarily of river born sediment deposits (e.g. silt, sand and peat) accumulated over the last 11,000 years since the retreat of the glaciers (Cassidy and Rogers 1998, Christian 1998). In addition, Richmond is located in one of Canada's most seismically active regions (Rogers 1998).

Due to its geography, the flood threat to Richmond arises from two main sources: the Fraser River and the Pacific Ocean. Richmond's largest island, Lulu Island, is nestled between the two main arms of the Fraser River. As a result, flooding caused by the annual spring freshet on the Fraser is a major threat primarily in the southeast and northeast regions of the island. In addition, the Pacific Ocean lying to the west of Richmond, poses a flood threat during high tides (Hay and Company 1989).[10] To combat the dual nature of the flood threat, Richmond's main island, Lulu, has been completely ringed with dykes. The dykes were constructed to withstand the design flood plus a safety factor of 2 ft. For the dykes on the east side of Richmond, the design flood is designated as the flood of record for the Fraser, which occurred in 1894 and was associated with a return frequency of approximately 1 in 200 years (Hay and Company 1989). For west Richmond, the design flood corresponds with the estimated 200-year tide.

The dyking system and all associated components (e.g. pump houses) comprise Richmond's primary defence against flooding. In addition, some new developments in the community have been floodproofed but these represent only a small proportion of the housing stock, which was largely constructed at grade (ground level) prior to the Provincial government's 1973 floodproofing policy (Hay and Company 1989). The historically settled areas of Richmond comprise a large proportion of the total residential area in the city. In fact, most of the populated regions are located inside a special planning area called an "Urban Exempt Zone" (Figure 5).

[10] Much of Richmond lies below the elevation of the mean high tide (1.4 m, GSC), thus even during normal tidal events Richmond's west dykes prevent inundation. The highest recorded tide in Richmond occurred at approximately 2.6 m (GSC) and the 200-year tide is estimated at 2.8 m (GSC) (Hay and Company 1989).

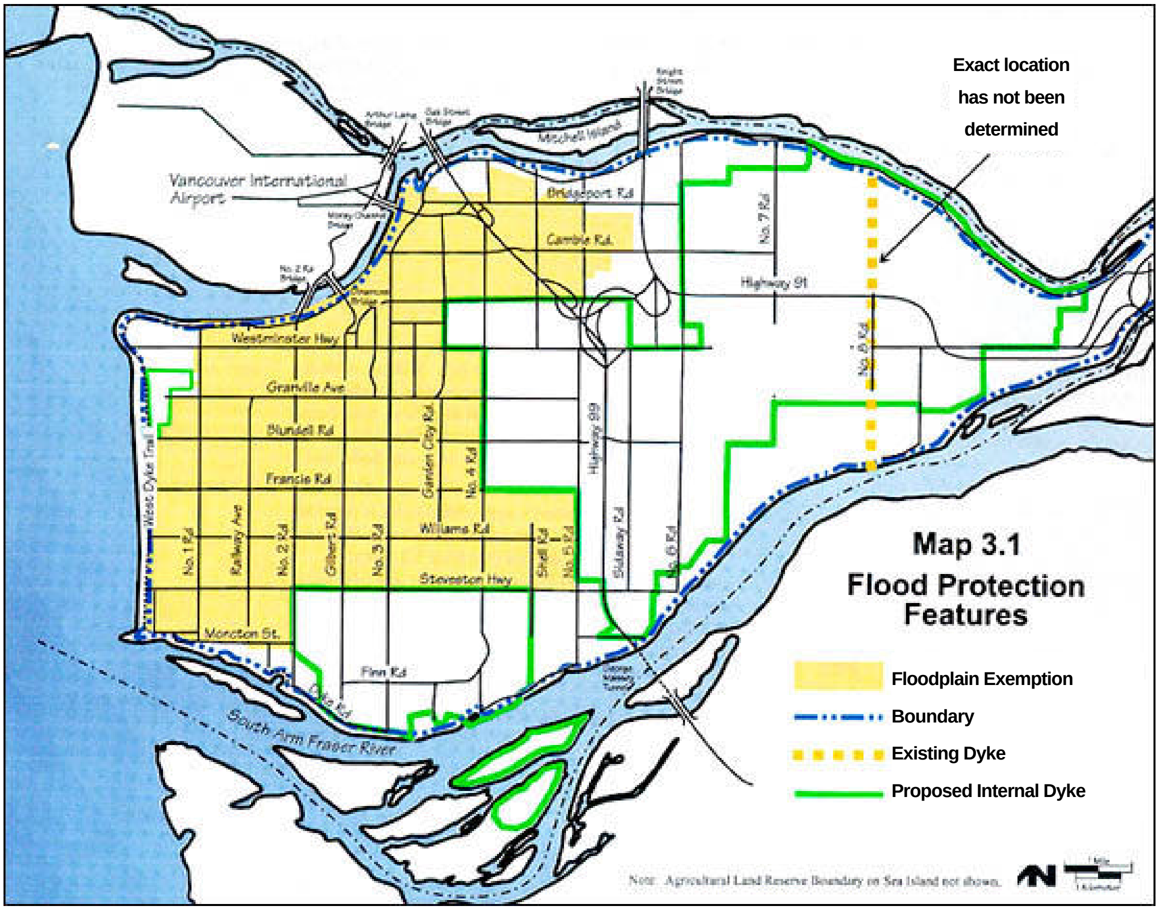

Figure 5 **Floodplain features in the City of Richmond including the location of the urban exempt zone (yellow shaded area).[11]**
(Used with permission of the City of Richmond)

The shaded area in Figure 5 shows the extent of the urban exempt zone. Note that the areas outside of the exempt zone are primarily located in the existing agricultural land reserve (A.L.R.). Residential developments located inside the urban exempt zone are exempt from provincial floodproofing requirements and are only obligated to have the first floor level of the home elevated to the minimum city standard of 0.9 m (GSC), which is approximately at grade. Outside of the exempt zone, residential developments

[11] As noted previously (footnote 6), recent legislative changes have eliminated the need to designate exempt areas. The map shows the location of the exempt zone as it existed prior to January 2004.

must be floodproofed to the appropriate FCL[12], which is based on the sea and river floods of record.[13]

Despite the protection of the dyking system, the threat of flooding is still a concern in Richmond under two scenarios: 1) dyke failure at flood levels less than the design flood, and 2) the occurrence of a flood of greater magnitude than the design flood level of the dykes. The threat of a dyke failure is a serious yet unquantified risk. As noted previously, dyke failure was a major cause of damage during the recent flood events on the Red and Mississippi rivers (1997 and 1993). Furthermore, in British Columbia a section of the dyke collapsed near the community of Oak Hills during the 1972 spring freshet causing serious damage to 125 single family homes and 65 mobile homes (Smith 1991). The probability of a dyke failure depends on a number of factors such as the severity of the flood event, the prior maintenance of the dykes, and the existence of structural faults caused by earthquakes, roots, animal burrows, etc. (Fraser Basin Council 2002b). The probability of exceedance for the design level of the dykes is easier to quantify, since flood return frequencies are based on historical occurrences. For example, there is a 1 in 200 chance (0.5% probability) that a flood equal or greater to the flood of record will occur in any given year. This annual probability translates into a 22% chance that a flood of this magnitude will be equalled or exceeded sometime in the next 50 years (Smith 1991). It should also be noted that these probabilities are based on historical occurrence patterns of high water events, which may not accurately reflect future trends in a world experiencing the effects of global warming and rising sea levels.[14] Under either dyke failure scenario, the severity of flooding in Richmond would

[12] Flood Construction Level, see footnote 4 for a definition.

[13] The FCLs for Richmond vary depending on the location of the home on the floodplain. The FCL for homes located west of No.8 Road (and outside of the Urban Exempt Zone) is either 2.6 or 3.0m, while the FCL for homes east of No. 8 Road is 3.5m. These FCLs were established in 1989 upon the assumption that a number of flood protection improvements would occur in the near future (e.g. installing a mid island dyke at No. 8 Rd) (City of Richmond 1989) and were based on the findings of the Hay and Company (1989) report. These additional dykes have still not been completed. If the exempt zone did not exist and no additional flood works were completed, the desirable FCL for all areas in Richmond would be 3.5 m (Stuart Jones, personal communication, March 2003).

[14] Some climate models have predicted that southwestern BC may experience even more precipitation under global warming (Slaymaker 1990). Sea level rise and increased precipitation patterns are two effects of global warming likely to have significant impacts on the flood protection capabilities of current dykes. Shaw *et al.* (2001) showed that two areas of the British Columbia coast are particularly sensitive to global

depend on the nature of the flood event and the location of the dyke breach; a dyke breach due to a river flood event in east Richmond would likely be far more severe than a dyke breach in west Richmond due to a tidal event (Hay and Company 1989). In the worst-case event of a river flood, water levels in Richmond could reach levels of 3.35 m within a few days but the majority of Richmond would feel the effects of lesser water levels within 24 hours (Hay and Company 1989).[15,16] Under a tidal flood situation, flood levels would likely be lower; the duration of the flood event would be shorter and phased to the tidal cycle (Hay and Company 1989).

In conclusion, Richmond's large urban population, its extensive floodplain exempt zone, and its significant flood risk make it an ideal candidate site for floodproofing research.

2.6 The Applied Research Problem

The past decisions to exclude many HSAs, such as Richmond's urban exempt zone, from provincial floodproofing regulations provide current floodplain managers with an interesting planning problem and some difficult questions. For instance, should any attempt be made to encourage or regulate floodproofing in historic settlement areas? If so, what sort of strategies should be used, and what would be the likely impacts of those strategies on the community? In addition, what would be the reaction of the public or stakeholders to such strategies? The focus of this research project is on evaluating alternative strategies for encouraging floodproofing of existing homes in historic settlement areas using the City of Richmond as a case study area. As a result, this project did not address the larger problem of identifying what flood management tools should be part of an integrated floodplain management strategy for HSAs. Other

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sea level rise of the magnitude predicted by the Intergovernmental Panel on Climate Change (1995): 1) the northeast tip of the Queen Charlotte Islands (vulnerable to erosion) and 2) the Fraser River Delta (vulnerable to flooding of dyked areas).

[15] Given that a substantial portion of homes are built at grade (~0.9m), this level of flood water (~2.45m) would cause significant damage to buildings without floodproofing.

[16] The sea dykes, which protect Richmond from tidal inundation on a regular basis, would actually worsen the effects of a river flood in the event of a dyke breach. Without the sea dykes, water levels in Richmond would peak just above the natural ground level as river water flowed over the island and into the ocean (Hay and Company 1989). The ring of sea dykes provides a barrier to this water flow and could cause water to accumulate inside the dykes.

management options, such as building additional or higher dikes, introducing flood insurance, or redirecting development out of HSAs might be more effective than trying to floodproof previously developed areas. This project starts from the assumption that floodproofing should be encouraged and attempts to evaluate various strategies designed to promote floodproofing.[17] Despite the fact that the larger IFM strategic level planning issue for HSAs is not addressed, the results of this project are essential for such planning efforts. For example, it would be very difficult to decide if floodproofing should or should not be part of an IFM strategy for HSAs without first having some reliable information about issues such as the likely impacts of floodproofing strategies or the perceptions of the public with regards to such impacts.

The challenge of trying to develop a flood proofing strategy for historic settlement areas is associated with complex trade-offs among several issues including potential damages to property, implementation costs, aesthetics, and public safety (Arlington Group 2001). In addition to multiple objectives, this problem is of concern to multiple stakeholder groups including developers, taxpayers, and governments. Finally, floodproofing policies would likely have significant implications for those individuals in the general public not represented by any organized interest group. Specifically, homeowners would likely have strong opinions on floodproofing strategies since floodproofing involves modification to individual residential dwellings.

2.7 Review of Flood Management Research – Traditional Approaches in Water Resources Management and the Social Sciences

The previous section established the issue of floodproofing in HSAs as a multi-objective, multi-interest decision problem. In this section, the approaches used to analyse such flood management problems will be reviewed, with a special emphasis on the planning and decision-making methods traditionally applied in water resources planning and

[17] The assumption that floodproofing should be encouraged is supported, at least in the study area for this project (Richmond, BC), by a floodplain policy document drafted in 1989 and updated in February 2003 (City of Richmond 1989).

management, followed by a summary of social science contributions to floodplain management.

2.7.1 Water Resources Planning and Management – Decision Making

Prior to 1960, water resource management was perceived primarily as an engineering challenge, which for flood management meant a predominant focus on structural flood control projects. As a result, practitioners were chiefly civil engineers concerned with the design, operation, and management of capital intensive projects such as dams, floodways, cannels and reservoirs (Grigg 1996).

Project planning was firmly rooted in the rational model of planning, which has strong links to operations research and systems analysis.[18,19] As early as the 1930's, water resource managers were using cost-benefit analysis for the purposes of project evaluation, a method traditionally focused on economic and technical criteria, but eventually recognition of the need to address a wider range of criteria led to the development of multi objective project evaluation methods (Grigg 1996, Ahmad and Simonovic 2001).

With the onset of computer technology in the 1950's and driven by the desire to develop techniques that were capable of efficiently evaluating a wide selection of alternatives in a reasonable time, the systems analysis approach to water resource management was developed. In general, water resources systems analysis utilizes quantitative methods such as mathematical models and computerized tools (e.g. databases, geographic

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[18] Many modern theories of decision analysis and rational decision making have roots in operations research or systems analysis, which can be described as the "application of scientific rationality to the organization and management of human activity" (Watson and Buede 1987, pg. 13). Operations research (OR) got its start during World War II, when it was realized that the application of engineering methods to logistics might result in considerable improvements in performance. After the success of OR during the war, the methods were applied widely and enthusiastically to the operation of businesses such as manufacturing, oil refineries and railways (Watson and Buede 1987).

[19] The rational planning model advocates a logical series of sub-steps in the planning process including problem identification, development of goals and objectives, identification of alternative solutions, analysis of alternatives, decision or recommendation for action, and implementation (Dzurik 2003, Grigg 1996).

information systems, computer programs)[20] to analyse the interactions between system components and their environment. The systems approach is a structured way of conceptualizing water resources "systems" using the tools of systems analysis to define and evaluate water resources management alternatives (Grigg 1996).

Owing to the early focus in water resource management on engineering works, traditionally systems approaches were developed for designing and screening large numbers of alternatives with mathematical programming techniques that used optimization methods and relied on continuous mathematical functions to describe the problem (e.g. Haimes *et al.* 1975, see Rajabi *et al.* 2001 and Solyody 1997 for recent examples).[21] These techniques were very suitable for specific operational type problems, which are generally well structured, rational and mechanistic (e.g. managing a storage reservoir) (Eschenback *et al.* 2001, Ahmad and Simonovic 2000). The tools and techniques developed for this purpose are often referred to as multiple criteria or multiple objective decision making (MODM) (Hwang and Yoon 1981, Stewart and Scott 1995) and are often associated with problems that are well-defined, involve large (or infinite) numbers of alternative options, and can be reduced to sets of mathematical functions and constraints (Grigg 1996). However, optimization tools developed for operational problems may be less suitable for decision-making at the broader, water policy level of management (Stewart and Scott 1995) where issues tend to be unstructured, political, and systematic (e.g. developing a watershed management plan) (Grigg 1996). As a result, water resources managers have increasingly utilized alternative systems analysis approaches, which are generally less focused on mathematical algorithms and intended for the evaluation of a discrete number of alternatives. These alternative approaches are often referred to as multiple attribute decision making (MADM) (Hwang and Yoon 1981). Some examples of multi attribute techniques used recently in water resource management include the Analytical Hierarchy Process (Karamouz *et al.* 2003, Pavlikakis and Tsihrintzis 2003, Srinivasa Raju and Pillai 1999, Al-Kloub *et al.* 1997), Simple Additive Weighting (based on Multi

[20] See for example Rajasekarem, Simonovic, and Nandalal (2003).

[21] Mathematical programming is not limited to continuous functions. Integer programming methods are also used.

Attribute Utility/Value Theory) (Karamouz *et al.* 2003, Pavlikakis and Tsihrintzis 2003, McDaniels *et al.* 1999, Stewart and Scott 1995, Hobbs *et al.* 1992), and outranking techniques (e.g. ELECTRE and PROMETHEE) (Anand 2001, Srinivasa and Pillai 1999, Al-Kloub *et al.* 1997, Hobbs *et al.* 1992). The two types of decision analysis approaches used in water resources management (e.g. multi objective decision making and multi attribute decision making) will be compared in more detail in Chapter 3.

According the Grigg (1996) there have been two significant changes in water resources planning since the early 1970's. First, planning has increasingly been directed towards non-structural approaches in recognition of the importance of environmental and social considerations, which has resulted in less emphasis on capital-intensive projects. Secondly, public involvement has become much more important, especially the use of 'direct democracy' approaches where citizens are active participants in the decision making process (see Fearon 2003, Pavlikakis and Tsihrintzis 2003, and Smolko *et al.* 2002 for examples from Australia, Greece and the United States). The direct democracy approach may be contrasted to the traditional 'representative government' model, which assumed that elected officials effectively represent citizens. Collaborative planning processes have increasingly been used in water resources planning (see for example de Garis *et al.* 2003, Smolko *et al.* 2002, Fearon 2003, Moorhouse and Elliff 2002) to provide avenues for public participation through the use of stakeholder representatives who are normally citizens belonging to organized interest groups.[22] The two changes identified above have encouraged the application of the theories and methods of other non-engineering disciplines, and in particular the social sciences, to the realm of water resource management (Grigg 1996).

[22] The use of stakeholder planning has presented managers with a new series of questions and challenges such as who should be involved and when (de Garis *et al.* 2003).

2.7.2 Social Science Contributions to Floodplain Management

In the early era of flood alleviation schemes dominated by structural engineering works, the physical and economic aspects of flood management were the primary concerns, while the social and environmental dimensions were often secondary or not considered at all (Smith and Tobin 1979). However, since the 1970's there has been an increased recognition of the need for social and environmental project assessment and for information derived from social science research (Grigg 1996). The recent move towards more participatory decision making processes has encouraged social science research aimed at understanding the opinions, perceptions, and preferences of the general public (Rasid and Haider 2002).

Beginning with the pioneering work of Gilbert White in the 1950's, social scientists and in particular geographers, have made important contributions to floodplain management (White 1945, White 1974, Kates and Burton 1986, Burton *et al.* 1993). Gilbert White (1964) brought widespread recognition to the failure of structural methods of flood control for reducing flood damages in the United States and conducted extensive research to identify and explain alternative flood hazard adjustment measures.

According to Smith and Tobin (1979) social science research in floodplain management has focused on two main areas: 1) human adjustment to flood hazards including research into the perceptions of floodplain residents towards the flood hazard and 2) decision making processes and public participation in planning. The area of flood hazard research has primarily relied on a behavioural approach focused on the individual within a human ecology theme (Burton *et al.* 1993). In responding to extreme flood events, individuals are assumed to be influenced in their response to hazards by their incomplete knowledge of the situation and their past flood experiences (Kates 1962). Other researchers have placed more stress on the social circumstances and situational context (e.g. poverty) as crucial factors that influence the impact of hazards and the individual's response to the hazard (Hewitt 1983, Mitchell *et al.* 1989, and Penning-Rowsell 1996).

Social science efforts have also been directed towards exploring public perceptions and preferences for floodplain management alternatives and policies (e.g. Rasid 2000; Shrubsole, Green, and Scherer 1997; Blanchard-Boehm, Berry, and Showalter 2001). Traditionally these approaches have relied on simple preference questions. While preference information in this form is undoubtedly useful to floodplain managers, this type of survey output is not necessarily immediately suitable for use in decision-making processes, which often require quantitative information on values and trade-offs (e.g. the weights for various management objectives). As a result, quantitative social science methods that can provide information on public value structures and trade-off behaviour are starting to become more widely utilized. For example multivariate stated preference tools, such as discrete choice experiments and maximum difference conjoint procedures, have been used in water management, for such purposes as eliciting public preferences for municipal water supply options (Haider and Rasid 2002) and assessing preferences for water level management (Haider and Rasid 1998). In the specific area of floodplain management, discrete choice experiments have also been used to analyse public preferences for flood control projects in Bangladesh (Rasid and Haider 2003), assess emergency evacuation policies in the Red River Basin, Canada (Rasid *et al.* 2000), and investigate preferences for non-structural flood control measures (Rasid and Haider 2002).

2.7.3 Identification of Research Need – The Methodological Gap

In summary, up to this point, Chapter 2 has accomplished three important tasks.

- The floodplain management context of the Fraser River Basin was reviewed and the City of Richmond was identified as a suitable case study area for research.
- Encouraging floodproofing of existing homes in historic settlement areas was identified as a multiple objective management problem of public concern.
- The approaches traditionally used in water resources management and the social sciences for addressing water and floodplain management issues were summarized.

⇒ Although the methods of traditional water resources management and the social sciences have been effective, both are associated with a number of important limitations when used to analyse decision problems that are of a multi objective nature AND associated with important public values (e.g. the interests of individual citizens in the general public). These key limitations are outlined in the next section.

2.7.3.1 Limitations of Traditional Approaches

Water Resources Management ***(including MODM and MADM).***

- Highly structured mathematical modelling approaches characteristic of systems analysis are not normally designed to accommodate public participation but are usually limited to the participation of a few key decision makers. Even the more general decision analysis processes used in many participatory planning processes are best suited to situations involving a limited number of well-informed participants.
- While multiple stakeholder participation in structured planning processes (e.g. those based on the concepts of MODM and/or MADM), allows increased public access to decision making processes, the views of stakeholder representatives cannot be assumed to be indicative of the true public interest, since stakeholder groups are usually organized around a specific interest (e.g. developers, environmental protection) (Loomis 2000).

- Avenues for general public involvement (e.g. for participation of the average citizen) are routinely limited to options such as focus groups, town hall meetings, and invitations for written comments. Although these techniques all provide valuable feedback to decision makers about public sentiments, they are still limited; there is no guarantee that the sample of individuals who participate is representative of the public at large. In addition, the information derived may not be in a format that is directly useful in a multi attribute decision analysis process.

Social Science Methods

- The focus has traditionally been on analysing public perceptions, behaviours, motivations, and desires. While these issues are important, they are not necessarily relevant or directly informative for the purposes of structured decision making.
- The type of information derived from traditional public surveys is not in a form that is directly compatible with the needs of decision makers. For example, planners may be interested in obtaining quantitative information regarding how the public views trade-offs over various management objectives.

2.7.3.2 The Methodological Gap and the way forward.

The limitations or deficiencies outlined above identify a methodological void in the current approaches. Specifically, methods are not available for effectively eliciting preferences from the general public in a way that is compatible with the requirements of structured decision-making processes. As a result, public preference elicitation methods are required that are capable of addressing the multi-variate nature of natural resource management problems. Specifically, methods are needed that provide quantitative information on public values and trade-offs for components of multi-objective alternatives (e.g. floodplain management strategies). Such methods would further democratize decision-making (McDaniels *et al.* 1999) by allowing public preference information to be used alongside the preference information of stakeholders and decision makers in structured decision-making processes.

It must be stressed that the limitations listed in the previous section are not specific to the context of floodplain management, but are relevant in many areas of resource management, and reflect a general discrepancy between scientific and social scientific research and analysis approaches. As holistic approaches and interdisciplinary cooperation are increasingly necessary to ensure long-term effective solutions to management problems, research that attempts to overcome traditional academic boundaries by pursuing approaches that meld the theories and methods of multiple disciplines is essential.

To address the methodological void identified above, this research project explored a complementary application of two different approaches. The first was a quantitative trade-off modelling tool used in the social sciences for analysing aggregate public preferences, while the second was a structured decision analysis method. Chapter 3 will describe these two methods in detail.

Chapter 3 Review of Methods

Chapter 2 reviewed issues associated with flooding and floodplain management with particular emphasis on the Fraser River Basin in British Columbia, Canada. The lack of floodproofing regulations in the historic settlement areas (HSA) of most communities was acknowledged as an issue of concern. Furthermore, encouraging floodproofing in the existing residential developments of HSAs was identified as a multiple objective, multiple interest research problem and the City of Richmond was recognized as a good candidate community for study in this regard. The chapter closed with a review of research approaches typically utilized in floodplain management including a discussion of social science contributions to the field and a review of decision-making and planning methods in water resources management. A gap was identified regarding the inclusion of public values in the current decision making techniques and it was concluded that floodplain management, and natural resources management in general, would benefit from research into public preference techniques that are compatible with decision analysis methods.

The research project described in this document addresses this need by exploring the compatibility of a class of multi-variate social science survey methods called stated preference choice models with a simple multi attribute decision analysis process. With specific reference to the flood management issue of interest for this research project, the multi-objective, multi-interest nature of the problem, make it a good candidate for analysis using such techniques. In addition, the potential for significant public interest in the problem justifies the use of a public values survey instrument. Chapter 3 will now review the methods of decision analysis and stated preference modelling.

3.1 Decision Analysis and Multi Attribute Decision Making

Decision analysis is an attempt to formalize and structure the decision making process in order to make effective, defensible decisions in an efficient, consistent and systematic manner. The fundamental axioms of decision analysis purport that the attractiveness of alternative solutions depends on two key factors: 1) the likelihoods of the possible consequences of alternatives and 2) the preferences of decision makers for those consequences (Keeney 1982, Savage 1954). The predicted consequences or impacts of an alternative (e.g. costs) are based on factual information derived primarily through technical knowledge or analysis. Conversely, preferences for outcomes or impacts are value judgements arising from a decision maker's assessment of the importance of fundamental aspects of the decision-making problem (e.g. objectives). As a result, separating facts and values is a key concept in the field of decision analysis.[23] Decision analysis assumes that optimal decisions will result if certain rational axioms and guiding principles are observed (Yoon and Hwang 1995) such as order, transitivity, dominance, and substitutability (for a review of these axioms refer to Clemen 1996 (pgs. 504-505), Keeney and Raiffa 1976 (Chapter 3), von Winterfeldt and Edwards 1986 (Chapter 9), and Bunn 1984 (pgs. 53-56).

Although decision analysis is primarily normative[24] (e.g. describes how decisions should be made) (Bunn 1984), it should not be seen as a replacement for more informal or intuitive decision making processes. According to Bunn (1984, pg. 13) "the purpose of decision analysis is not to replace judgement but to help organize it and to provide a model of the problem which through experimentation can develop a greater understanding of the situation." The strength of decision analysis is in the provision of tools that promote clear and logical thinking in decision situations characterized by complications such as multiple conflicting objectives, multiple interests, uncertainty, and lack of information (Gregory and Keeney 2002). The broad purpose of decision analysis has led to the development of many sub-disciplines focused on one or two key aspects of the practice. For example, whole books and university courses are dedicated to the analysis of risk and uncertainty in decision problems (e.g. see Morgan and Henrion 1990); other practitioners may focus on the development of tools and techniques for

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[23] In reality, there is never a clean separation between facts and values (or objective and subjective information) in any analysis. Often the determination of facts may require subjective judgments. For example, what a researcher decides to measure or how the analysis is performed often requires subjective judgments that may influence the 'facts' (Gregory and Keeney 2002).

[24] Normative or prescriptive methods may be contrasted with descriptive methods, which describe how decisions are actually made (Watson and Buede 1987, pg. 82; Yoon and Hwang 1995).

analysing multiple criteria decision problems (for example refer to von Winterfeldt and Edwards 1986 or Goicoechea *et al.* 1982). Decision analysis is such a large field of study that novices can find the array of decision analysis approaches overwhelming. What is called decision analysis in one field may be so different in its tools and conception from the type of decision analysis practiced by another that is hard to recognise the commonalities. Since this document is intended for an interdisciplinary audience, whose members may have been exposed to vastly different decision analysis techniques in their own fields, a brief review of the scope of decision analysis practice follows.

3.1.1 A Review of Multi Criteria Decision Making (MCDM)

Due to the multiple objective nature of the flood management problem considered for this research project, the review will focus on multi criteria decision analysis methods in which decisions must be made under the influence of multiple conflicting objectives.[25]

Multi criteria decision making (MCDM) is a general term that can be used to describe all decision analysis techniques that are concerned with making decisions in the presence of multiple conflicting objectives (Hwang and Yoon 1981). MCDM techniques can be generally divided into two classes (Hwang and Yoon 1981, but refer to Goicoechea *et al.* 1982 for another classification): 1) Multiple objective decision making (MODM) and 2) Multi attribute decision making (MADM).[26]

[25] It should be noted that there are many decision analysts who are concerned primarily with single objective decision problems and, as a result, concentrate on the first fundamental factor of decision analysis: the likelihoods of possible consequences of alternatives. Their focus is on the way that data is interpreted and utilized to derive the estimated impact of potential alternative solutions or decisions. As a result, decisions are often approached as single objective optimization problems (e.g. how to minimize the expected value of costs). Decision makers' preferences may only play a minor role and may be used primarily to describe attitudes towards risk through a utility function.

[26] Hwang and Yoon's classification is both sensible and useful for the purposes of this report but readers should be aware that unfortunately there is no universally accepted classification in the literature. For example, Watson and Buede (1987, pg. 71) refer to what this report calls MODM as multi-criteria decision making (MCDM).

3.1.1.1 Multiple Objective Decision Making (MODM)

In general, MODM is concerned with selecting a preferred alternative from among a very large of infinite number of possible alternatives that could be considered (e.g. there is a continuum of options), and tends to be better suited for designing the best alternative (e.g. determining the optimal design for a bridge).

MODM methods have a long tradition in engineering and related disciplines (e.g. see Goicoechea *et al.* 1982) and tend to rely heavily on mathematical programming and optimization routines. The roots of MODM are in linear programming (e.g. single objective optimization) but the discipline has expanded to include many advanced techniques designed for the multiple objective case such as goal programming, compromise programming, and the surrogate worth trade-off method (Watson and Buede 1987, Haimes *et al.* 1975). The use of mathematical functions (usually continuous) to describe the set of objectives and constraints that define the decision problem is a key aspect of the techniques (Watson and Buede 1987, Goicoechea *et al.* 1982).

3.1.1.2 Multiple Attribute Decision Making (MADM)

In contrast to MODM, MADM is concerned with selecting from a finite number of predetermined alternatives and is best suited for selecting between or evaluating alternatives (e.g. choosing what car to buy) (Hwang and Yoon 1981, Watson and Buede 1987). MADM has a more varied academic heritage than does MODM. Many of the techniques that may be grouped under the MADM heading have arisen from different schools of thought and in different parts of the world. MADM methods may be classified by how the available information on attributes and alternatives is processed in order to arrive at a conclusion. A useful distinction is between methods that allow trade-offs between attributes (compensatory) and those that do not (non-compensatory) (Hwang and Yoon 1981). Most non-compensatory methods involve simple decision rules; examples include dominance, maximin, maximax, conjunctive and disjunctive constraint methods, the lexicographic method, and elimination by aspects. With non-compensatory models, an unfavourable value in one attribute cannot be offset by a favourable value in another attribute (Hwang and Yoon 1981). In general, compensatory methods utilize more complicated algorithms for evaluating alternatives. According to Hwang and Yoon (1981), these algorithms can be classified into three groups: 1) scoring methods, 2) compromising methods, and 3) concordance methods. The scoring method assumes that the decision maker wants to maximize total value or utility and, as a result, the alternative with the best overall score should be selected. The compromising model has more in common with mathematical programming methods of MODM in that the preferred alternative is assumed to be the one with the shortest mathematical distance from the perfect or ideal alternative. Finally, concordance models identify alternatives that best satisfy a set of concordance or discordance measures.

Perhaps the best know MADM techniques are Multi Attribute Utility Theory (MAUT)/Multi attribute value theory (MAVT) (Keeney and Raiffa 1976, von Winterfeldt and Edwards 1986), the Analytical Hierarchy Process (AHP) (Saaty 1992), and outranking methods such as ELECTRE (Elimination et Choix Traduisant la Realite) (Roy 1968, or for a review in English see Roy 1973). MAUT/MAVT and AHP are examples of scoring methods, while ELECTRE is an example of a concordance method.

MAUT and MAVT

MAUT and MAVT are based on the precepts of classical decision theory, which provides a quantitative framework for dealing with complex decision problems (Watson and Buede 1987). Problems are approached analytically by decomposing them into key component parts (e.g. objective weights, and impacts or consequences), analysing each part separately and then recombining the parts to provide an overall evaluation of competing alternatives (Bunn 1984). MAUT is concerned with decisions under risk while MAVT deals with the simple case in which risk and uncertainty are not considered. MAUT and MAVT will be discussed in more detail in section 3.1.3.

AHP

The AHP is similar in structure to the basic form of MAUT/MAVT. For example, the method derives relative weights for objectives and uses additive scores to combine information on objective weights and attribute impacts into an overall evaluation for each alternative. What makes the AHP distinctive is its strong focus on a hierarchical structuring of the decision problem, and the characteristic preference elicitation tools and techniques (e.g. verbal evaluation on a nine point scale, eigenvector analysis). Pairwise comparisons of impacts (including consistency checks) are used to derive weights for objectives, although this method is not specific to the AHP. The analytical hierarchy process has found wide application in many fields (e.g. refer to Zahedi 1986, Duke and Aull-Hyde 2002, and Ulegin *et al.* 2001), but it has also been subject to some considerable criticisms (see French 1988, pg 359-361). For example, the 9 point scale is arbitrary and may be associated with internal inconsistencies in the elicitation process; the weights are derived before the ranges of attribute impacts have been established; and the method has been shown to exhibit the rank reversal phenomenon when new alternatives are added to an existing evaluation (Watson and Buede 1987, Dodgson *et al.* 2000).

ELECTRE

ELECTRE has its roots in continental Europe. As with AHP, ELECTRE also assumes that a decision situation can be described by a set of alternative options, attributes, and attribute weights, but instead of assessing some overall score for each alternative, ELECTRE calculates concordance and discordance measures for each pair of alternatives. The decision maker selects threshold values for concordance and discordance, which are used to evaluate whether one alternative in a pair can be said to outrank the second. For example if concordance within a pair (A vs. B) is greater than some value C and discordance less than some value D then alternative A is said to outrank B. The concordance and discordance comparisons are continued until a subset of the alternatives is identified in which no alternative outranks any other within the subset and all the alternatives outside the subset are outranked by at least one alternative inside the subset. As a result, ELECTRE does not identify the best alternative but produces a set of very good alternatives and leaves the final deliberations to the decision maker. The benefit of ELECTRE is that it does not give the illusion of an incontrovertible best alternative. As with the AHP, one of the primary criticisms is related to the arbitrary nature of some of the measures used in the analysis (e.g. the concordance and discordance equations) (Watson and Buede 1987). In addition, the results may be highly sensitive to the threshold values, which are subjectively selected by the decision maker (Yoon and Hwang 1995).

In review, this section provided a brief overview of multiple criteria decision making including MODM and MADM methods. AHP, ELECTRE, and MAUT/MAVT were identified as well known techniques in MADM. In general, ELECTRE is a method concerned primarily with the evaluation of alternatives, while the Analytical Hierarchy Process is a technique that is focused primarily on the problem structuring and preference elicitation aspects of MADM, since the final evaluation of alternatives is left simple additive weighting. MAUT and MAVT, methods that will be discussed in more detail in section 3.1.3, are equally concerned with all aspects of the MADM process.

Conclusion

Since this research project was exploratory in nature with regards to how stated preference survey tools could be integrated into a decision analysis process with multiple objectives, the straightforward and widely accessible techniques of MADM were used instead of the more technical optimization approach involving mathematical programming as offered by MODM.[27] Of the available MADM techniques, this research project utilized the methods associated with multi attribute value theory (MAVT). In the next two sections, the general MADM process will be reviewed with a focus on the tools and techniques of MAVT.

[27] Although MODA was not used, an integration of stated preference tools with a MODA approach could be insightful given that both methodologies are able to analyze large sets of alternatives whereas MADA assumes a discrete, finite predetermined alternative set which may or may not contain the optimal solution (Hwang and Yoon 1981).

3.1.2 The Multiple Attribute Decision Making Process

In general, the practice of multi attribute decision-making can be reduced into a number of steps which emphasize the decomposition of the decision making process into a structured set of sub-components. The clear organization and structure offered by the MADM approach make it a useful and appealing tool for solving complex natural resource management problems in which non-technical individuals may be involved in the decision making process (Gregory and Keeney 2002). Figure 6 provides an overview of the four main steps.

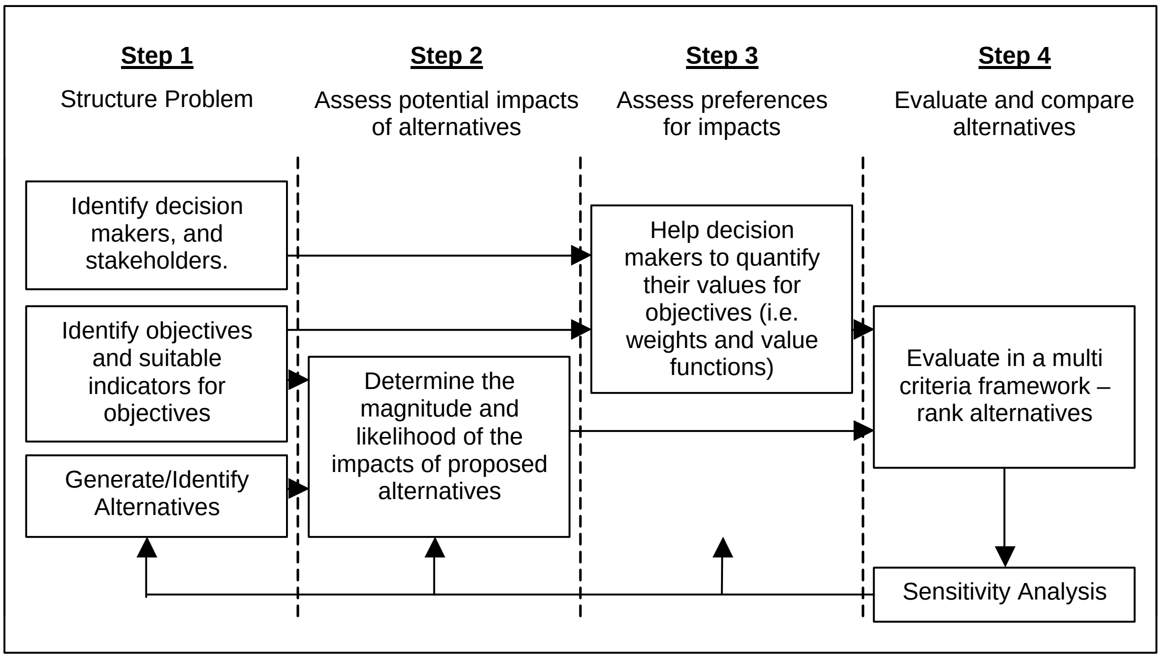

Figure 6 Summary of multi attribute decision making as a four-step process. (based on Keeney 1982).

Although there is a separation of facts and values in the process (e.g. Step 2 is concerned with measurement while Step 3 is concerned with preferences), these two elements are eventually combined in a multi attribute framework to arrive at a ranking of alternatives. Note the iterative nature of the process. For each step in the framework, a multitude of specific tools and techniques exist and are used in decision analysis practice.

3.1.3 Multi Attribute Decision Making – Tools and Techniques

To exemplify the types of tools and techniques used in MADM, and specifically MAVT, the following sections will explain the four steps in more detail.

Step 1 - Structuring the Decision Problem

Many decision analysts consider the structuring phase to be the most important part of the decision analysis process. Without an adequate understanding of one's goals and objectives or a full documentation of the available alternatives, the decision making process can be misleading or even fail to address the appropriate question. Structuring involves defining a complete problem statement, determining constraints, recognizing and documenting goals and objectives, defining appropriate variables to measure the achievement of objectives (attributes), and developing a representative set of alternatives. The attributes are used to indicate the various positive and negative consequences of each alternative. For example, purchase price, trunk size, and gas mileage are three different attributes that could be used to describe different cars available for purchase. Many different tools are utilized during this step such as objectives hierarchies, means/ends diagrams, and influence diagrams (Keeney 1992).

Step 2 - Impacts of Alternatives

To determine the impacts of proposed alternatives, quantitative analysis must be completed for each attribute defined in Step 1 (e.g. constructing physical models and undertaking data analysis). The effort required to complete the impact assessment depends on the attributes selected and the complexity of the decision problem. For example, in a car purchase decision, an attribute such as price could be determined from an automobile magazine. On the other hand, deciding on an appropriate climate change policy might require an estimation of expected sea level rise. Such an attribute would undoubtedly require the use of an expert derived mathematical model involving many complex equations, assumptions, and substantial research. The tools and techniques of step 2 include spreadsheet models, simulation modelling, Monte Carlo simulation, probability and decision trees, expected value calculations, and Bayesian statistics.

Step 3 – Preferences for Impacts

As summarized in Figure 6, there are two distinct aspects to preference elicitation in MADM: 1) obtaining preferences for objectives or attributes (culminating in the derivation of relative importance weights) and 2) obtaining preferences for changes in attribute levels for each objective over its range (culminating in the derivation of value or utility functions for each attribute). In general, a decision analysis weight is an estimate of the relative importance that the decision maker feels that an objective should have in comparison to the other objectives in the analysis, for that particular decision problem and given the range of impacts.

Value and utility functions define preferences for changes in attribute levels within an objective. The value or utility function converts different levels of the attribute into a measure of worth using an interval scale[28] and reflects the decision maker's judgement about the relative desirability of the attribute's natural scale (von Winterfeldt and Edwards 1986, Clemen 1996). For example, imagine that 'number of bedrooms' was used as an attribute to evaluate the benefits of potential homes. A decision maker (e.g. a home buyer) may have strong preferences towards the levels of a particular attribute and they may be of a non-linear functional form. For instance, to the decision maker the value or worth of a two bedroom house may not be that much different than that of a one bedroom house but the value of a three or four bedroom house may be significantly greater (as described by the non-linear value function in Figure 7).

[28] There a number of terms commonly used to describe different measurement scales (for a succinct review, refer to Malczewski 1999). One taxonomy uses four different levels of measurement: nominal (unordered discrete classes), ordinal (rank orders of discrete classes), interval (continuous measurement on a scale with equal intervals), and ratio (continuous measurement on a scale with equal intervals and an absolute zero). Ratio and intervals scales are also commonly referred to as cardinal, while nominal and ordinal scales are also referred to as categorical.

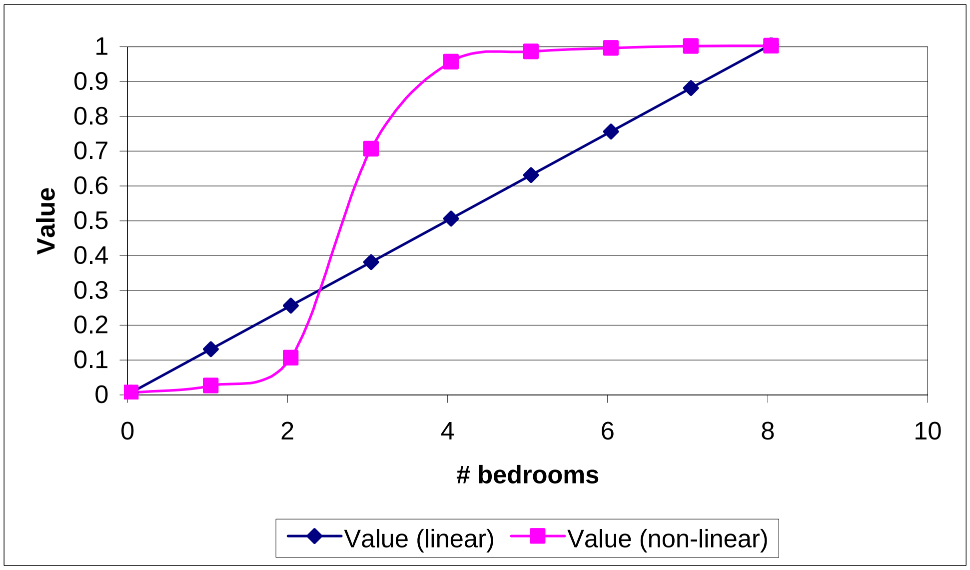

Figure 7 Examples of linear and non-linear value functions for a housing attribute.

In evaluating worth, decision analysts distinguish between utility and value functions. The decision analysts' utility function, in addition to measuring the worth of a criterion, also captures an individual's attitude towards risk (Hobbs *et al.* 1992, Keeney and Raiffa 1976).[29] Multi Attribute Utility Theory (MAUT) governs the type of multi attribute decision analysis that incorporates risk attitudes through utility functions while Multi Attribute Value Theory (MAVT) is used when risk and uncertainty can be ignored.

Determining weights and value functions requires eliciting preferences from the primary decision makers involved in a problem. A number of tools and techniques are available for assisting in preference elicitation, including swing weighting, standard gambles, direct rating, and pairwise comparison (von Winterfeldt and Edwards 1986, Keeney and Raiffa 1976, Clemen 1996).

[29] The type of utility used by decision analysts is called Neumann-Morgenstern utility. This type of utility uses a cardinal measurement scale and reflects relative preferences for lotteries (uncertain outcomes) over different levels of an attribute in addition to an individual's preferences for different levels an attribute. In this way, the Neumann-Morgenstern utility function encodes information about the risk attitude of an individual because the evaluation of the utility function requires trade-offs over uncertain or probabilistic outcomes. The concept of the risk-based utility is fundamentally different from the utility commonly associated with traditional economic theory (e.g. marginal utility), which relates no information about risk attitudes (Keeney and Raiffa 1976). Economist's utility functions are primarily based on ordinal scales although Luce and Tukey's theory of conjoint measurement introduced the concept of a riskless cardinal utility, which is applicable in the absence of uncertainty (Watson and Buede 1987).

Once the value functions and weights have been assessed, the overall performance of each alternative can be determined as described in Step 4.

Step 4 - Evaluating and comparing alternatives

An amalgamation rule is usually selected to combine the individual value functions into an overall worth function. Various forms may be used such as additive, multilinear, or multiplicative, but the additive form is the most popular due to its simplicity and the robustness of its results (von Winterfeldt and Edwards 1986). The additive value function assumes that the overall worth, V_i, is equal to the weighted sum of the individual value functions (von Winterfeldt and Edwards 1986):

Equation 1 $$Vi = \sum_{m=1}^{M} w_m v_m (x_{im}),$$

where Vi is the value of alternative i; w_m is the vector of weights for the attributes; v_m is the value function for attribute m; and x_{im} is the level of attribute m for alternative i, and M is the number of attributes.

The additive value function above assumes that the decision maker is risk neutral. In situations where risk and uncertainty are important components of the decision problem, MAUT applies and a similar functional form is used in which the value functions are replaced by utility functions (Keeney and Raiffa 1976). The evaluation of alternatives can be achieved using a simple spreadsheet calculation or through sophisticated decision analysis software.

The preceding discussion briefly illustrated the four main steps in the decision analysis process with a particular focus on the methods of multi attribute value theory (MAVT). As discussed previously, this research project relied on the methods of MAVT. Since MAVT is a simple decision analysis technique that is widely used and accepted for many applications in resource management (Weber and Borcherding 1993), research based on its concepts will be widely relevant. Furthermore, the methods of the basic expression MAVT are simple and general in nature, which assists the comparative nature of the study. The following section will review some specific issues associated with preference elicitation in MADM.

3.1.4 Preference Elicitation in MADM - Some Important Issues

Although the field of MADM is vast, there are a few key preference elicitation issues of specific relevance for this floodproofing research project. These issues will be reviewed in the following order: 1) weighting methods and validity, 2) the theory of the constructed nature of preferences, and 3) MADM preference methods for situations involving multiple stakeholders and public preferences.

3.1.4.1 Weighting Methods and Validity (Range Sensitivity)

An abundance of weighting methods are documented and described in the decision analysis literature. Comprehensive reviews of these weighting methods are available, which describe the theoretical validity of competing methods and often provide comparative studies that describe the results of using different methods to evaluate the same set of objectives. Many reviews have revealed that different weighting methods can lead to widely different results and subsequently lead to variable conclusions on the overall attractiveness of competing alternatives (Hobbs 1980, Hobbs *et al.* 1992, Fischer 1995, Poyhonen and Hamalainen 2001, Schoemaker and Waid 1982, Weber and Borcherding 1993). Arguably the most important issue raised by these reviews, for the purposes of this research, is the principle of range sensitivity (Fischer 1995).

Most decision analysts are careful to state that they utilize relative weights, as opposed to absolute importance weights.[30] The term 'relative weight' implies that the weight should be sensitive to the range (or scale) of outcomes associated with a given attribute in the particular decision context. In other words, the weight should be proportional to the change in value associated with moving a given attribute from its worst to its best

[30] In theory, decision analysis weights should be range sensitive but this is not always true in practice. Studies have found that many of the weighting methods used by decision analysts provide weights that are not range sensitive (Weber and Borcherding 1993).

level (Fischer 1995, Keeney and Raiffa 1976). Since decision analysis problems are usually described in local terms (e.g. a specific decision context as opposed to a broad or global decision context), it is standard practice to normalize utility or value functions "relative to the range of outcomes in the local decision context" (Fischer 1995). Normalization to the local decision context, as opposed to a global decision context, implies relative weights.[31] In a different local decision context associated with different attribute ranges, the relative weights should be different. As an example of the difference between relative and absolute importance weights, consider the following scenario. When questioned many people would probably say that safety should be a more important consideration than aesthetics, but in a local decision problem where a safety indicator only varies by 1% and an indicator for aesthetics varies dramatically, aesthetics would likely be more important in choosing a preferred alternative.

The concern over the potential for confusion between relative weights and the idea of overall importance weights led Keeney and Raiffa (1976) to call the relative weights used in their equations "scaling constants." The principle of range sensitivity has frequently been used to help identify which decision analysis weighting methods provide valid results (Weber and Borcherding 1993, Hobbs *et al.* 1992, Fischer 1995). Among the available weighting methods, the swing weighting method is a simple method that seems to encourage respondents to provide answers that are range sensitive (Fischer 1995, Weber and Borcherding 1993, von Winterfeldt and Edwards 1986).

[31] See Fischer (1995) for an excellent review of the implications for decision analysis of global vs. local specification of decision problems. Specifically, if normalization is undertaken in the local context then weighs should be "range sensitive." In contrast, if the global context is used for normalization, then attribute weights should not be sensitive to local changes in attribute ranges (Fischer 1995). Furthermore, Fischer (1995) showed that the local attribute weights are a known function of the global weighting factors (e.g. the absolute importance weights) and the value differences between the best and worst outcomes on the global scale.

3.1.4.2 The Theory of the Constructed Nature of Preferences

In brief, the theory of the construction nature of preferences holds that individuals (especially laypersons) do not have a pre-existing set of detailed preference or value information waiting to be uncovered and reported by the analyst, but that preferences are constructed in the course of value elicitation (Slovic 1995, Gregory *et al.* 1993, Payne, Bettman and Schkade 1999). Researchers have made several suggestions for accommodating the constructed nature of preference formation in preference elicitation tasks (Payne, Bettman and Schkade 1999). For example, respondents should be encouraged to consider multiple options and objectives by using an expanded set of alternative options, and by differentiating between fundamental and proxy attributes. The survey instrument should be designed clearly and efficiently and in a way that makes information processing easier. In addition, extensive pre-testing and manipulation tests should be used while developing the instrument. Researchers also recommend including explicit information on the ranges of attribute values, using consistency checks, and using multiple value elicitation tasks that encourage participants to think meaningfully about their values in different ways. Including some or all of these recommendations during the design of value elicitation tasks will help to ensure that the information provided by respondents is realistic and stable (Gregory 2000). Clearly, how much assistance the analyst provides to help a respondent learn about their preferences is a contentious issue (Payne, Bettman and Schkade 1999). The analyst must carefully balance the need to help the respondent provide meaningful responses with the risk of unconsciously biasing the results by asking leading or suggestive questions that promote a certain view or by providing information in a way that favours one response pattern over another (Payne, Bettman and Schkade 1999).

3.1.4.3 MADM Methods for Multiple Stakeholder and Public Decision Making

Traditionally it was considered sufficient that public officials, as representatives of the public, would consider multiple views when deciding on a management action. The assumption was that social concerns and public values were implicitly incorporated into the decision making process through the participation of a benevolent decision maker (Keeney and Raiffa 1976). Recently, however, the representative government model has become less acceptable for public decision making in favour of direct democracy approaches in which the public participates more actively in the decision making process. The desire to promote public participation has led to the development of a variety of techniques in many different disciplines for the purpose of understanding public values and incorporating them into the decision-making process (McDaniels *et al.* 1999); one popular approach has been to utilize the multiple stakeholder methods, in which representatives of various interest groups participate in a roundtable type planning process designed to promote consensus decisions. For example, in British Columbia the public utility BC Hydro has successfully and repeatedly applied multi attribute decision analysis in a number of multi stakeholder decision making processes including water use planning for hydro dam operation and developing integrated electricity plans (McDaniels *et al.* 1999, BC Hydro 1995).

Since decision analysis was originally aimed at aiding the decision process of one or a few primary decision makers (Keeney and Raiffa 1976)[32], the value elicitation techniques of decision analysis were designed for situations in which extensive interaction between the decision maker and the analyst is possible, which is not the sort of environment conducive to large scale public involvement. In addition, the techniques assumed that the decision maker had a very good technical knowledge of the decision problem (Russell *et al.* 2001). As the use of stakeholder groups to inform (or even to share responsibility for) decisions increased, the techniques of traditional decision analysis were modified and generally simplified for application to larger group settings (for

[32] Decision analysis techniques were traditionally developed as decision aids for organizations with hierarchical decision-making structures (e.g. corporations and the military), where the values of stakeholders or the broader public were often of limited concern. Refer to footnote 18.

example, a variety of simple techniques are described in von Winterfeldt and Edwards 1986, Clemen 1996, and Keeney 1992). The approach has often been to retrofit or adapt the traditional techniques designed for the single decision maker to the case where multiple decision makers are involved. Analysts have not had too much difficulty applying decision analysis techniques to group decision-making settings involving a limited number of multiple stakeholders. In this environment, the opportunity for significant interaction with the participants was still possible and individuals could devote considerable time to obtaining a reasonable understanding of technical or scientific issues.

Although multiple stakeholder methods have improved the access of the public to decision making processes, as discussed in Chapter 2, stakeholder groups are not necessarily representative of the general public interest. Unfortunately, further extending the capabilities of decision analysis techniques, beyond the multiple stakeholder environment, to elicit the preferences of the general public is much more complicated. Gregory (2000) identified four primary disadvantages of multi attribute value elicitation techniques in the context of making decisions requiring the input of large numbers of people.

1. **Requires well-informed individuals** – Experts or representatives of interest groups who do not necessarily represent the views of the wider public interest.
2. **Requires substantial interaction between analyst and respondent** – As the amount of interaction required increases, the cost and the time required to complete the analysis also increases. At the same time, the number of individuals who can be expected to provide values is reduced (see 4 below).
3. **Contains the potential for bias** – With extensive interaction between analysts and respondents, questions arise regarding the potential influence of the analyst on the elicitation process. For instance, would a respondent's answers change if a different analyst were used?
4. **Limited to small numbers of individuals** – Precludes large-scale public involvement, and prevents tests of statistical significance. Would a different group composed of similar individuals come to the same conclusions?

These four limitations may explain why the decision analysis literature contains so few examples of attempts at large-scale public preference elicitation. Furthermore, the existing attempts to extend the techniques to obtain preference information from the general public have revealed some limitations (see attempt by Russell *et al.* 2001).[33]

Given the potential limitations of decision analysis tools for the purposes of large-scale public value elicitation, it is appropriate to consider alternative public preference elicitation methods that may be more suitable for surveying the preferences of large numbers of individuals. Ideally, such a method would be compatible with decision analysis so that any public preference information obtained could be used alongside the preference information of key decision makers and stakeholders in a participatory planning process. One such alternative public preference elicitation tool is the stated preference survey, which can be used to evaluate competing alternatives and to elicit weights and value functions for multiple objectives. Stated preference survey tools will be reviewed in the next section.

3.2 Stated Preference Survey Tools

Many econometric methods have been designed for the purposes of analysing preferences. In general, these techniques may be divided into two categories: revealed and stated preference approaches.[34]

Revealed preference approaches rely on statistical analysis of data describing actual behaviour to determine the factors influencing a decision problem. Readers with an economics background should note that the 'travel cost method' is a type of revealed preference technique. Conversely, stated preference approaches rely on hypothetical

[33] Examples of public surveys inspired by decision analysis include efforts by Gregory *et al.* (1997), Gregory (2000), McDaniels (1996), Gregory and Wellman (2001), and Duke *et al.* (2002).

[34] Readers should be warned that the term 'revealed preferences' has often been misleadingly used in the literature. A number of authors have used the term to refer to stated preference methods of elicitation, based on the conclusion that these methods attempt to 'reveal' the preferences of the respondent to the analyst. In this way, econometric methods have been contrasted with other methods (often decision analysis methods) that attempt to account for the 'constructive' nature of preference formation (e.g. see Payne *et al.* (1999), Hajkowicz and Prato (1998), and Dennis (1998)).

behaviour derived from evaluations of alternatives using a survey instruments for the same purpose (Timmermans 1984, Louviere *et al.* 2000; for an application to flood management see Rasid *et al.* 2000). The most common stated preference technique is the Contingent Valuation Method (CVM) (Mitchell and Carson 1989). In a CVM study, the respondent is provided with a very detailed description of the management problem and then asked for some type of evaluation such as a statement of willingness to pay (Morrison *et al.* 1996). A large body of literature has accumulated with respect to the application of this technique to environmental valuation (e.g. see Loomis 2000, and Boxall *et al.* 1996). Although the CVM has a strong theoretical basis, it has been shown to be prone to numerous serious biases. As a result, many researchers urge caution in analysing preferences using CVM (Morrison *et al.* 1996). A classical CVM is not a multiattribute technique, because the price or WTP is the only attribute that changes.

Multi-variate (e.g. multi attribute) forms of stated preference techniques have become increasingly popular over the last two decades as value elicitation tools for three primary reasons (Louviere *et al.* 2000):

1. Their ability to provide statistically significant estimates of parameters.
2. Their ability to model the preferences of large numbers of individuals.
3. Their ability to model or evaluate hypothetical situations (e.g. a proposed alternative).

Multi-variate stated preference models may be divided into compositional and decompositional approaches depending on whether respondents evaluate single components (single attributes) of alternatives or full profiles (e.g. simultaneously consider multiple attributes) (Timmermans 1984). Decompositional models require respondents to give an evaluation of a set of attributes (a profile). The overall evaluations are then decomposed using statistical analysis to derive a part-worth utility function for each attribute (Timmermans 1984). A method in which respondents use rating or ranking to separately evaluate single profiles (or alternatives) is usually referred to as conjoint analysis[35] (Louviere 2000). An alternative method of combining two or more hypothetical attribute profiles into choice sets (from which respondents would choose the most preferred alternative) was suggested by Louviere and Woodworth (1983) and is commonly referred to as the discrete choice experiment.[36] This advancement allowed researchers to develop choice models based on Random Utility Theory (McFadden 1974) and use the multinomial logit model (MNL) as the statistical method of analysis (Ben-Akiva and Lerman 1985).

Although discrete choice experiments are not free from potential bias, the problems associated with this technique are minimized in relation to other alternative methods (Morrison *et al.* 1996).[37] In addition, DCEs offer the sound theoretical basis in random utility theory that may be lacking in other approaches (e.g. conjoint analysis) and provide a multi-attribute framework that is very applicable to decision problems involving multiple objectives.

3.2.1 Discrete Choice Experiments

Discrete choice experiments (DCEs) belong to the group of multi attribute stated preference research techniques. Like MADM, the term attribute in the discrete choice literature generally refers to a variable that is used to measure an aspect of an alternative

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[35] Some decision analysts may be familiar with the techniques of conjoint analysis as described in Keeney and Raiffa (1976) and von Winterfeldt and Edwards (1986). According to Louviere (2000, pg. 1) conjoint analysis is a method for eliciting preferences that is based on a mathematical representation of the "behavior of rank orders in response to systematic, factorial manipulation of independent variables." Conjoint analysis, as originally specified, did not utilize a behavioural theory about human preferences but relied mathematical theories that attempted to represent individuals' rankings of multiattribute alternatives as simple algebraic processes. Rankings are normally analysed using ordinary least squares regression on the assumption that the underlying latent variable is measurable on an interval scale, which has repeatedly been shown to not hold in practice (Adamowicz *et al.*1998). Violations of the theoretical axioms of conjoint analysis led to the development of statistical error theories, such as Functional Measurement (an implementation of Information Integration Theory) (Louviere 2000).

[36] While the terms "discrete choice experiment" and "discrete choice model" can technically be used to distinguish between stated preference and revealed preference research, in practice the terms "choice model" and "discrete choice model" are commonly used to describe both types of preference analysis.

[37] In addition to a strong basis in behavioural theory, which has found to be lacking in other stated preference techniques such as conjoint analysis, the discrete choice experiment is generally considered less prone to potential biases, such as strategic bias. Strategic bias occurs when individuals deliberately under- or overstate values in an attempt to influence the outcome (Morrison *et al.* 1996).

that is important to the decision. The term discrete refers to the fact that respondents are asked to choose between two or more distinct alternatives.[38]

Practitioners of discrete choice experiments assume that individuals faced with a decision problem choose between various alternatives by considering and trading-off among the important attributes of each alternative according to some internal decision rule (Louviere *et al.* 2000, Adamowicz *et al.* 1998). Generally, this decision rule is deemed to be utility maximization (Louviere *et al.* 2000, Train 2003).

The discrete choice method elicits preferences for the attributes of alternative options from a large sample of respondents who are asked to evaluate, and typically choose, among hypothetical profiles of attributes (alternatives). Hypothetical alternatives are usually derived from a statistical design plan; the most common plans are orthogonal (independent) main effects plans.[39,40] Two or more attribute profiles are combined into a choice set (Louviere *et al.* 2000).[41] To view an example of a choice set, as it would appear in a survey, please refer to Figure 14 in Chapter 4.

In the process of choosing, individuals are expected to make trade-offs over both attributes and attribute levels simultaneously (Adamowicz *et al.* 1998). The specification of the decision problem as a choice task makes the DCE compatible with Random Utility Theory (RUT), which has been used to successfully model behaviour based on revealed preferences (Louviere *et al.* 2000).

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[38] A defining characteristic of discrete choice modeling is that the number of attributes in finite, which distinguishes the method from regression models. If the alternative space is infinite, DCEs cannot be applied (Train 2003).

[39] Orthogonal Design – An experimental design in which attribute levels across alternatives are uncorrelated thereby providing unconfounded measures of part-worth utility or attribute parameters (Adamowicz *et al.* 1998).

[40] Main effects plans allow the analyst to estimate the influence of each attribute separately on an individual's choices, but ignore potential interactions among attributes. As a result, any interactions are confounded with the main effects. However, DCEs can also be designed to include selected interactions.

[41] Note that there is often the option to choose none of the alternatives as well (Adamowicz *et al.* 1998).

RUT assumes that utility (non - risky)[42] consists of two components: a systematic component and a random component (Equation 2). Alternatively, these components can be referred to as deterministic (V_{iq}) and stochastic (e_{iq}) (Louviere *et al.* 2000).

Equation 2 $$U(NR)_{iq} = V_{iq} + e_{iq}$$

The systematic (deterministic) component (V_{iq}) for alternative 'i' and individual 'q' is assumed to be that part of the utility that can be modelled by attributes "observed" by the analyst (Louviere *et al.* 2000). In a discrete choice experiment, "observed," means those attributes that have been selected for inclusion and measurement in the experiment. The selection of attributes is usually based on a combination of the results of focus groups with relevant individuals (decision makers and stakeholders), expert interviews, and literature review (Louviere *et al.* 2000). In general, the deterministic component, V_{iq}, may be expanded as follows (Equation 3):

Equation 3 $$V_{iq} = \sum_{k=1}^{K} b_{ik} S_{ikq}$$ (Louviere *et al.* 2000),

where b_{ik} is a vector of utility parameters (often referred to as part-worths), which indicates the relative contribution of each attribute level to the total worth $U(NR)_{iq}$. The taste parameter vector, b, contains the marginal utilities of the measured attributes (Adamowicz *et al.* 1998).[43] S_{ikq} is the vector of attributes and attributes levels, k, faced by individual q, for alternative i (Louviere *et al.* 2000).[44]

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[42] Given the potential for confusion due to the different implied meanings of the word "utility" in the decision analysis and discrete choice literature (see footnote 29), this document will distinguish between the two types of utility, when reviewing the concepts of RUT, through the following notation. U(R) and U(NR) will denote the decision analyst's Risky utility (Neumann-Morgenstern) and the choice modeller's Non – Risky utility (part-worth) respectively.

[43] Similar to a derivative, the marginal value indicates the incremental change in the amount of utility obtained from a unit increase in a given variable (akin to an estimate of the slope of the value curve).

[44] S_{ikq} can also be expanded to include other terms such as socio-demographic variables, which adds another layer of complexity to the model.

The stochastic component of total utility (e_{iq}) represents the contribution to the total utility of immeasurable or variable factors that the analyst does not observe (Louviere *et al.* 2000). Thus, the error term could account for factors such as the value contributed by attributes omitted from the study and measurement error. The term random does not imply that individuals maximize utility in a random matter; its use is an attempt to define the distribution of the error in the analyst's measurement of an individual's utility function (Louviere *et al.* 2000). The error term is necessary, as it would be impossible with a general model to accurately define precisely what influences each individual's decision in the typically large sample. Since e_{iq} is unknown, a deterministic model of choice cannot be derived. Instead, probabilistic models are used from which the probabilities of choice may be derived (Train 2003). Assumptions regarding the distribution of the error term define the type of probabilistic choice model that may be estimated by the analyst (Train 2003, Adamowicz *et al.* 1998). The most common statistical distribution for the error term is the Gumbel or Extreme Value Distribution 1 (EV1) since it easy to compute and ensures fairly robust results (Louviere *et al.* 2000). The model derived from this specification is the multinomial logit (MNL)[45], which provides the probability that individual q will choose alternative i (Equation 4).[46]

Equation 4 $$P_{iq} = \frac{e^{Viq}}{\sum e^{Vjq}}$$ for alternatives j ≠ i (Louviere *et al.* 2000)

The results of discrete choice tasks are normally analysed using maximum likelihood estimation (MLE) in order to derive estimates of the ß values (part-worth utilities) for each attribute level used in the survey. There are a few limitations on the interpretation

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[45] The MNL model allows the choice probabilities to be calculated exactly from a closed form expression. For other model specifications, it is not possible to analytically solve for the choice probabilities; the solution must be approximated through simulation (Train 2003).

[46] If the assumptions of the MNL model are violated, there are numerous other specifications available such as the multinomial probit. The multinomial probit model assumes the error terms are normally distributed (Ben-Akiva and Lerman 1985). The most important assumption made by the MNL model is that of Independence of Irrelevant Alternatives, which "states that the ratio of the probabilities of choosing one alternative over another is unaffected by the presence or absence of any additional alternative in the choice set" (Louviere *et al.* 2000).

of the ß values. First, inter-dimensional (e.g. inter-attribute) comparisons of part-worth utility associated with individual attribute levels is prohibited, because for each attribute the part-worth utility values are measured on separate scales with different origins (Louviere *et al.* 2000).[47,48] In other words, the scale used to measure each attribute is unique; there is no common or global scale (Cohen 2003). For instance, suppose the utility values derived for different levels of a safety attribute were on average three times greater than the values for an aesthetic impact attribute. In this case, it would be incorrect to state that safety provides three times more utility than aesthetics. Despite the fact that individual part-worth utilities for attribute levels cannot be compared between attributes, differences in utility are relevant and may be compared (Train 2003, Cohen 2003). Since relative differences in utility are comparable between attributes, estimates of relative attribute importance can be calculated by comparing, across attributes, the relative difference in utility between the best and the worst attribute levels. The second limitation associated with the DCE may be relevant when such models are used for decision-making and policy development, as opposed to forecasting market choices. In particular, the overall influence of an attribute on choice (e.g. overall importance weight) is confounded with the measurement scale used to define the attribute for that particular problem (Louviere *et al.* 1993).[49] As a result, it is impossible to separate the fundamental importance of an attribute in a decision problem from the value associated with the scale used to define the attribute.

The potential limitations outlined above arise from the nature of the discrete choice task, which prompts respondents to provide an overall evaluation of the profiles by choosing the preferred alternative. A variation on the stated preference choice task, called maximum difference conjoint analysis, has been developed that is not subject to these limitations but retains the behavioural basis of the discrete choice experiment.

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[47] However, intra-attribute comparisons are valid (e.g. comparisons of utilities within an attribute).

[48] This limitation is shared with additive conjoint analysis (Lynch 1985).

[49] This is only a limitation if one is interested in determining absolute importance weights and investigating the relative influence of global vs. local concerns on the analysis. As mentioned previously, decision analysis is primarily concerned with relative importance weights, which may be derived from the results of a DCE.

3.2.2 Maximum Difference Conjoint

Maximum difference conjoint (MDC) analysis is another multi-attribute stated preference technique. As in a DCE, alternative profiles are designed using attribute levels but instead of choosing between two profiles, respondents are asked to choose between attribute levels within one profile. The dependent variable for a MDC model is the choice frequencies of attribute values within profiles instead of the frequencies of choice for the overall profiles, as in the DCE. Please refer to Figure 12 for an example of an MDC in a survey format.

Upon viewing the full profile, respondents are expected to identify the two attribute values that are the most and least preferred respectively (or some other preference measure). In this case the choice set now becomes the profile of attribute values. An MDC task shares some similarity to the paired comparison approach often utilized in decision analysis to derive attribute weights, but instead of comparing pairs of attribute values, participants compare all the values in an attribute profile simultaneously. The act of choosing the most and least preferred values identifies which two attribute values have the largest utility difference in the set (Louviere *et al.* 1993).[50] Since the task is consistent with the decision models underlying discrete choice experiments, the random utility model described in the previous section can also be applied to MDC data as shown below (Louviere *et al.* 1993):

Equation 5 $$D_{ij} = d_{ij} + e_{ij},$$

where D_{ij} is the true but unobservable difference between attribute levels i and j, d_{ij} represents the scale difference between attribute levels i and j, and e_{ij} is a random error component associated with that difference.

[50] Respondents are assumed to behave as if they are examining every possible pair in each profile and then identifying the pair that is associated with the maximum difference in utility. As a result, MDC questioning may be considered an efficient alternative to traditional paired comparison evaluation tasks (Cohen 2003).

The advantage of the MDC task over the discrete choice task is that all the attributes and attribute levels are evaluated using the same measurement scale. Therefore, the utility values for each attribute level, which are estimated from such data, can be located on a general interval utility scale with a common origin. Due to the commensurate scales shared by all attributes, it is possible to make inter-attribute comparisons of utility values and to determine an estimate of overall attribute importance in addition to relative attribute importance (Louviere *et al.* 1993).

The ability to separate scale values for each attribute level from the overall importance weight for each attribute can add some very interesting information to an analysis. For example, one might imagine a situation in which an attribute expected to be important was found to be not important at all. Separating overall importance weights from scale values would allow the analyst to determine if an attribute had little impact in a decision problem because it was inherently unimportant, or because the range used in the analysis was too small to detect a significance difference in value between attribute levels. Conversely, an attribute found to have a large impact might be unimportant overall.

3.2.3 The Stated Preference Modelling Process

Louviere *et al.* (2000) summarizes the steps in the choice modelling process as follows (Table 1).

Table 1 Steps in a choice modelling process. (adapted from Louviere *et al.* 2000, pg. 255).

Steps		Specific Tasks Required
1	Define study objectives	Scope research problem and develop specific study questions
2	Conduct supporting qualitative study	Use focus groups, personal interviews or other means to - Define attributes and attribute levels; - Identify population sub-groups of interest; and - Help structure choice sets.
3	Develop and pilot the data collection instrument	- Ensure that preference tasks are understandable/meaningful to participants - Ensure participants respond as intended by the analyst.
4	Define sample characteristics	Determine the appropriate target population to sample and the number of responses required for statistical significance
5	Perform data collection	Self explanatory
6	Conduct model estimation	Fit an appropriate preference model to the data
7	Conduct policy analysis	Varies depending on the project but can include - calculating expected support for specific options - evaluating alternatives - 'pricing out' various attributes - determining elasticities for various attributes - evaluating the relative importance of attributes

Choice experiments are carefully constructed to allow the analyst to produce a statistically efficient design across the entire array of attribute level combinations, which can effectively model the determinants of choice. The need to produce realistic choices for respondents must be balanced with the cognitive burden on respondents and the computational skills and resources of the analyst (Louviere *et al.* 2000, Hanley *et al.* 1998, Adamowicz *et al.* 1998).

3.3 A Comparison of MADM and Stated Preference Modelling

In spite of their diverse applications and histories, the choice modelling and decision analysis processes include many similar tasks. To facilitate further comparison between the methods of decision analysis and discrete choice modelling, the process of discrete choice modelling can be re-categorized into a number of steps akin to those of decision analysis (Figure 8).

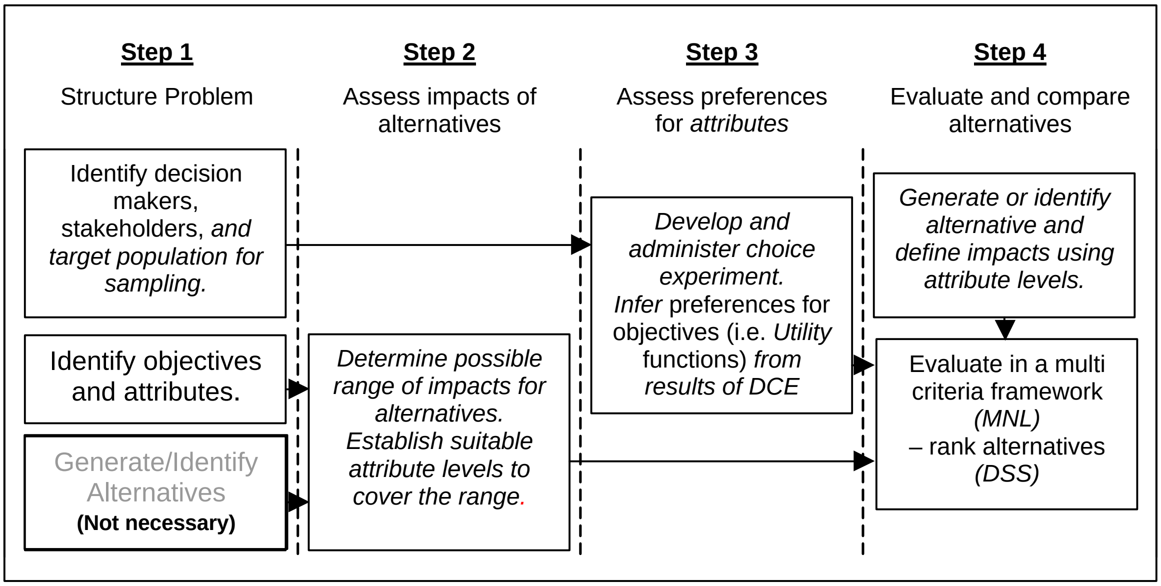

Figure 8 **The choice modelling process structured in a four step decision analysis framework. Compare to the decision analysis process outlined in Figure 6. Words in italics show changes or additional information about the discrete choice process.**

Choice modelling contains many of the same components and many of the same steps as decision analysis (the four steps of the MADM process were outlined in Figure 6). Unlike decision analysis, the focus is not on generating alternatives early in the process but on eliciting preferences over the entire range of potential attribute levels,[51] which allows analysts the flexibility to later evaluate any alternative could be constructed within the range of attribute values used in the survey. As a result, the power of the choice experiment depends on the ability to make predictions over a realistic range of attribute values. Clearly, the accuracy of the model will be improved by selecting attributes that are important to decision-makers and the public.

Given the preceding comparison of the discrete choice and decision analysis processes, it should be apparent that the processes are quite compatible. In addition, many similarities can be identified from a theoretical perspective. Although space does not permit a full discussion here, the following table highlights the major similarities and differences (Table 2).

[51] The ability to evaluate very large sets of alternatives or even to 'design' alternatives that maximize utility is similar to many MODM optimization techniques. As a result, another interesting exploration of the compatibility of decision analysis and stated preference modelling would involve a complementary application of MODM and discrete choice modelling.

Table 2 A comparison of MADM and stated preference modelling (DCE and MDC) – theoretical similarities and differences. Part I: Objectives

	Issue	MADM	DCE/MDC	Comments
Objectives	Alternatives can be specified by a predefined set of measurable objectives (attributes)	**YES**	**YES**	The means used to identify objectives are similar but the specific techniques used to identify and structure objectives are more developed in decision analysis.
	Objectives are assumed to completely define all important aspects of alternatives for decision makers	**YES**	**NO**, random component of utility, e, is used to model inability to exactly specify each alternative in terms of all important objectives. The enumeration of error is inherent to the stochastic nature of Random Utility Theory.	Difference is due to the history of DCEs as preference tools for large samples. With large numbers of respondents, the analyst is not likely to know (or be able to include) each individual's determinants of choice.
	Measuring preferences for objective/attributes	**Relative weights (w_i) and value functions (V_i)**	**Part-worths,** b The β values encode information about both the relative attribute weight and the shape of the value function. Weights can be derived by comparing, among different attributes, the relative difference in utility between the best and the worst levels of an attribute. Similarly to a value function, the β values contain information on the marginal change in preference over the range of the attribute.	The β values and the characteristics of the error term used to define the choice model are intimately related (Adamowicz *et al.* 1998). As in decision analysis (at least in theory), the β values are sensitive to the scale used in the analysis (the specific range of attribute values). Maximum difference conjoint tasks can provide information on both the relative value associated with attribute scale (relative weight) and provide estimates of the overall or global importance of attributes (Louviere, Anderson, and Edwards 1993).
	Preference Elicitation Tasks	**Variable, decomposed**. May consist of ratings, rankings, pairwise comparison, standard gambles, etc.	**Full profiles** of attribute values are considered. Profiles are derived from statistical design plans. Respondents make trade-offs within profiles (MDC) or between profiles (DCE).	Decision analysis techniques do not make use of statistical design plans to develop preference tasks. Often questioning is purposefully redundant to check for consistency in responses.
	Treatment of error in preference elicitation	**Assumes errorless preference and judgements** Decision analysis methods do not deal formally with random response error (Fischer 1979).	**Explicit incorporation of error into probabilistic models of choice.**	In decision analysis, error is acknowledged but treated as inconsistency and is dealt with 'by forcing consistency or fitting consistent models to judgement data' (von Winterfeldt and Edwards 1986, pg 219).

Table 2…Cont. Methodological comparison between MADM and stated preference modelling (DCE and MDC). Part II: Evaluation of Alternatives.

Alternative Evaluation

Issue	MADM	DCE/MDC	Comments
Model Type	**Usually compensatory**	**Compensatory**	High values of one attribute can compensate for low values of another.
Overall evaluation equation used to estimate the total value of each alternative over all attributes	$V_i = \sum_{m=1}^{M} w_m v_m (x_{im})$ For MADM, simple additive summation (shown), multilinear, or multiplicative forms are possible.	$U(NR) = \sum_{k=1}^{K} b_{ik} S_{ik} + \varepsilon$ The form is very general and basically consists of discrete point estimates for value (utility) at each attribute level used in the model. Continuous functions (e.g. linear, quadratic) can be fit to interval scaled attributes.	The implications of these two different model forms are significant. Decision analysis evaluation models are defined for the individual and are deterministic or algebraic.* Conversely, stated choice tools are used to define aggregate models over many individuals and are stochastic or probabilistic. *Decision analysts often model uncertainty in attribute impacts (e.g. measure expected value of costs) or derive preferences over uncertain outcomes but they do not include error in the specification of utility or value models.
Functional forms used to describe alternatives	**Usually selected by analyst** prior to preference elicitation.	**Derived by analyst** using results of preference survey.	Common practice in decision analysis is to settle on the additive model form, then work to ensure that the objectives are mutually preference independent.
Linear attribute value functions	**NOT necessary** Linear value functions are often assumed as a simplification.	**NOT necessary** Analysts derive the appropriate functional forms for value functions from the preference data.	
Decision Rule = Maximize Net Benefit	**YES**, select alternative with largest total value or utility.	**YES**, select alternative with largest estimated total utility.	Selection based on utility maximization is the general rule.
Models are usually estimated for each decision maker (could be an individual or stakeholder group)	**YES**, ranking of alternatives usually done for each decision maker.	**NOT USUALLY**, alternatives evaluated from the perspective of groups of respondents.	If Bayesian statistical techniques are used, choice models for each decision maker can be produced (e.g. Bragge 2001, Huber and Train 2000) but are limited to one survey version.
Evaluation of new alternatives after most of the data analysis has occurred	**DIFFICULT**, may require analysts to redo some tasks (e.g. preference elicitation).	**EASY**, for any new alternative that has impacts are within the range of attribute levels used in the survey.	DCEs are designed to allow the continued evaluation of any alternative within the experimental design space.

In general the ultimate goal of both MADM (and DA in general) and stated preference modelling is to aid in the decision making process and to compare and evaluate alternatives. Despite differences in their respective academic backgrounds and traditional areas of application, the two approaches have much in common from a theoretical perspective. Both assume that the overall value or benefit of an option or alternative can be described by decomposing the option into a subset of attributes, all of which contribute to the overall assessment of value.[52] Furthermore, the models used to calculate overall values for each alternative are usually compensatory and can be calculated by deriving suitable mathematical functions to describe the value of each attribute. Using preference information and a description of the attribute values for each alternative, scores that reflect the overall value or utility of an option can be calculated. Scores determine the relative desirability of an alternative in relation to another alternative.

The main differences between the methods are generally related to the applied purpose for which each approach was developed. The methods of MADM were designed for situations in which decisions are made from the perspective of one or more key decision

[52] The word "decompose" must be used with caution as it can mean different things to a decision analyst and to a choice modeler - another example of how linguistic distinctions can make interdisciplinary work very challenging. For example, choice modelers call the DCE a decompositional approach because overall evaluations of profiles or outcomes (as indicated through choice) are 'decomposed' into part-worths for each individual attribute. In contrast, decision analysts used the term decomposed to refer to evaluation approaches in which overall utility is first defined as a function of simpler subcomponents (e.g. attribute weights and value functions for each objective). Preference assessment follows at this lowest (or decomposed) level of complexity. In the jargon of a decision analyst, full profile methods like DCEs would probably be considered 'holistic' as opposed to 'decompositional' because evaluation is performed on overall profiles instead of being 'decomposed' simpler sub-tasks. A decision analyst might also contrast the two methods by saying that decision analysis methods involved 'explicit decomposition' while stated preference methods rely on 'statistical inference' (Fischer 1979). 'Holistic' type evaluation methods have not been widely used or highly regarded in decision analysis (e.g. see Hobbs 1980) because the early incarnations of these methods required respondents to make extremely challenging unaided utility assessments (e.g. rank ordering all the possible outcomes of every decision alternative under consideration). For decision problems involving large numbers of attributes and alternatives, these types of evaluations would have been too difficult and time consuming to be practical. According to Fischer (1979), the 'principle virtue of decomposed scaling methods is that when the number of outcomes and/or attributes is large, such methods greatly reduce the subjective judgements required. Fortunately, owing to advancements in methodological approach and in experimental design, many modern methods, such as DCEs and MDC analysis, that might be branded as 'holistic' are no longer subject to the limitations of their predecessors.

makers. The preference elicitation tasks assume that ample time is available for deriving precise preference structures (e.g. weights and value functions) using extensive and potentially challenging elicitation procedures (e.g. standard gambles, certainty equivalents, pairwise comparisons) (Keeney and Raiffa 1976). Since the decision analyst can work iteratively with the decision maker, any inconsistencies that defy the precepts of rational behaviour can be cleared up through repeated questioning, consistency checks and reassessment. In addition, the problem-structuring phase of the decision analysis process is viewed as extremely important. Helping the decision maker to explore and document ideas and values is considered by many decision analysts to be a key responsibility. Using the theory of the constructed nature of preference, it is assumed that decision makers do not necessarily have predefined value sets for complex decision situations and that the analyst should assist the decision maker in exploring and defining his or her preferences.

In contrast to the heritage of decision analysis, stated preference modelling was developed out of a desire to understand consumer preferences and to model consumer behaviour (specifically in marketing and transportation research, see Ben-Akiva and Lerman 1985). Market research focuses on situations were hundreds or thousands of 'decision makers' are involved. Consequently, eliciting preferences in a survey environment is necessary. In a public survey, the questions are normally relatively short and simple enough that lay persons are willing and able to complete the tasks in a reasonable time. Furthermore, a viable error theory is essential for aggregate modelling since it is assumed that the analyst will not be able to clarify any responses that are inconsistent or irrational and that it is impossible to include all the attributes that are important to every respondent. Furthermore, stated preference modellers have historically not spent an equivalent amount of time on the problem-structuring phase or in helping respondents to explore and construct their preference sets. It is usually assumed that the respondent has a defined preference structure and that these preferences can be communicated to the researcher though analysis of the responses, which is a very defensible position when preferences are elicited over well-known consumer products. In general, stated preference modellers are more concerned about the potential for introducing bias into the results by asking leading questions or through the provision of information that unduly influences the respondent.

Recently, both decision analysts and stated preference modellers have begun to expand the application of their methods into non-traditional realms. Decision analysis has been increasingly used in public planning processes where decisions concern multiple stakeholders and the general public, while stated preference discrete choice methods have found uses in public policy and natural resources decision-making where public values are a large concern. For both approaches, the crossover to non-traditional territory presents some challenges. The techniques of decision analysis - designed primarily for experts - are not necessarily suitable for lay people and cannot easily be modified for use in public preference surveys to analyse the preferences of the general public. Traditional stated preference techniques, while ideal for analysing preferences for consumer goods, such as televisions, may have limitations when it comes to evaluating more complex situations, such as forest management alternatives or floodplain management strategies, that are difficult to describe using simple attributes and about which respondents may have no prior experience or knowledge.

Due to the basic theoretical similarities between the methods of decision analysis and stated preference modelling and the potential limitations of each method when applied to the realm of public policy making and natural resource management, it is useful to explore the potential for a compatible application of both methods to one management problem. In particular the organized analysis framework, the extensive problem structuring techniques and the quantitative analysis methods found in decision analysis practice can be complemented by the quantitative, multi-variate, public-preference elicitation techniques offered by stated choice modelling.

The following section will briefly review the few attempts documented in the literature at combining some form of multi-variate stated preference modelling (e.g. DCE or CA) with a multiple criteria decision analysis process.

3.4 Complementary Applications of Decision Analysis Techniques and Stated Preference Survey Tools – A Review

Bragge (2001)

Bragge (2001), in an analysis of the energy taxation dispute in Finland, demonstrated the compatibility of the analytical hierarchy process (AHP) and conjoint analysis. The techniques were used to elicit preferences for objectives associated with evaluating hypothetical negotiated solutions in an energy taxation dispute. The taxation problem was structured as a decision analysis with four mock decision makers: two environmentalists and two industrialists. The first stage involved in-depth interviews with decision makers to help identify and structure fundamental objectives. Several decision analysis techniques were used including objectives hierarchies and the concept of fundamental objectives. The objectives hierarchy included seven fundamental objectives that were measured by independent criteria. Preference elicitation followed the structuring phase and consisted of two steps: 1) warm-up and 2) main task. The warm–up component consisted of a paired comparison task based on the AHP and was used to derive weights for each of the seven objectives. The main task consisted of a full profile conjoint analysis over the levels of the attributes used to measure the objectives.

Individual value models were estimated for each interviewee using a Bayesian statistical analysis technique; the AHP data from the warm-up task were used as "priors" to update the information obtained from the primary conjoint task.

Using the estimates of the part-worth utilities (b_k) for each attribute level (k) from the conjoint task, Bragge calculated the relative importance weights for each of the seven attributes (i) with the following formula.

Equation 6

$$w_i = \frac{\{\max(b_{ik}) - \min(b_{ik})\}}{\{\sum_{i=1}^{n} \max(b_{ik}) - \min(b_{ik})\}}$$

Equation 6 implies a number of key assumptions, which are not clearly specified in Bragge's paper. First, the use of the max and min in the formula linearizes the value function for each attribute. In other words, the marginal change in utility with increasing attribute level is assumed to be constant. Assuming a linear value function is a simplification that allows the calculation of a single weight for each attribute from point estimates of part-worth utility for each attribute level.

The 'weights' thus derived from the conjoint model were compared to the weights derived from the AHP exercise. Using the preference information and the attribute values, the scores for all hypothetical alternatives from the perspective of each individual were calculated using a simple additive model. Bragge used these results to determine the efficient set of alternatives for the interviewees. An alternative (A) was defined as part of the efficient set if there were no other alternatives that were at least as good as A for all four disputants and better than A for at least one disputant. The efficient set or non-dominated set is a concept often used in multiple objective decision analysis. The application of this technique to the results of the conjoint evaluation survey is an interesting complementary use of techniques from stated preference modelling and decision analysis.

Hajkowicz and Prato (1998)

Hajkowicz and Prato (1998)[53] used multiple objective decision analysis to rank farming systems using a set of five key objectives. Four different methods were applied to derive the weights for each of the objectives: fixed point scoring, paired comparison, ordinal ranking, and judgement analysis. The overall evaluation of the alternatives was achieved using a simple additive summation rule. The weight sets resulting from each of the methods were compared, as were the rankings for the 36 farming systems.

Of the preference methods used, judgement analysis is an example of a stated preference valuation technique. In fact, from the authors' description, judgement analysis, described by Cooksey (1996), appears to be very similar to conjoint analysis. For

[53] Also see Prato and Hajkowicz (2001).

example, the judgement analysis task required farmers to score 15 hypothetical attribute profiles on a scale of 1 to 100 and estimated the relative beta (β) values for attributes using multiple regression. The attribute weights were derived using a simple transformation of the beta (β) values, similar to the approach of Bragge (2001).

Opaluch, Swallow, Weaver, Wessells and Wilchelns (1993)

In a study designed to include public preferences in noxious facility siting, Opaluch *et al.* (1993) developed a discrete choice model for the multi-attribute decision problem of siting noxious facilities. Using the part-worth parameter estimates from the model, the authors developed what they called site scores for alternative landfill locations.

Using the standard Multinomial Logit Model (Equation 4), the authors derived the following model for the probability of choice:

Equation 7
$$P_A = \frac{e^{ScoreA}}{\sum_{I}^{N} e^{ScoreI}},$$

where P_A is the probability of choice for alternative A, as described by its attributes, N is the entire set of alternatives, and ScoreI is the representative utility for alternative I. The 'Score' for alternative i is simply the sum of its attribute values multiplied by the Beta parameters estimated from the DCE.

Equation 8
$$ScoreA = b_1 * X_1 + b_2 * X_2 + \ldots + b_n X_n \quad \text{for all n attributes.}$$

The use of the "site scores" concept is an attempt to make the methods of stated choice modelling relevant to the field of hazardous waste management, which utilizes these types of simple performance indices on a regular basis. The site scores are similar to the most basic linear additive summation technique for evaluating alternatives that is used in decision analysis. Although it was a simple application, the authors successfully demonstrated the similarities between simple decision analysis techniques and discrete choice modelling, specifically in the representative portion of the utility function.

Ulegin, Ulegin, and Guvenc (2001)

Ulegin *et al.* (2001) attempted to measure the importance of quality of life indicator attributes for the residents of Istanbul. The authors developed an objectives hierarchy and a value tree that linked fundamental objectives to lower level measurable attributes. The construction of the values hierarchy tree was aided by expert opinion, focus groups, and background research.

Preferences were elicited over the higher order constructs using the Analytical Hierarchy Process, while preferences among lower level attributes were analysed using conjoint analysis. Although the methodology was not explained in detail, weights at the lowest level of the objectives hierarchy were apparently derived using the results of the conjoint analysis. Once the preferences at each level of the hierarchy were determined, the overall value of an attribute could be calculated as the multiplication of its individual construct weight and the weight of the higher-level construct to which it belonged, an action which effectively 'rolled back' the value tree.

Duke, Ilvento, and Aull-Hyde (2002)

Duke *et al.* (2002) elicited preferences for non-market services of preserved land in Delaware using two difference techniques: the AHP, and conjoint analysis. In an expansion of the traditional applications of the AHP, the method was implemented in a survey that sampled 129 members of the public. The survey identified the relative importance that the public associated with a number of attributes related to land preservation. The results were then compared with the results of a conjoint analysis survey on a separate sample of 199 individuals in which respondents were asked to rank and then rate 5 farms described by seven attributes.

The preceding review highlighted the few published attempts to combine stated preference modelling and decision analysis techniques.[54] The sources cited primarily used conjoint analysis; only one paper applied a discrete choice experiment. To be compatible with the relative weights used in decision analysis, part-worth values for attributes and attribute levels, as supplied by conjoint analysis, were usually transformed into relative weights using a simple calculation. This research project will also attempt to combine the techniques of stated preference modelling and decision analysis in a management problem of public concern, but instead of using conjoint analysis, this research project will utilize two stated preference tools with a theoretical basis in random utility theory: discrete choice experiments and maximum difference conjoint analysis.

3.5 Chapter Conclusion

- Multiple attribute decision analysis provides a strong structural framework for analysing complex multiple objective decision problems but is deficient in techniques for eliciting preferences from the general public.
- Stated preference choice models provide an alternative multi-variate approach for eliciting public preferences that is suitable for administration in a large-scale survey environment.
- A comparison of the underlying behavioural and theoretical assumptions of multiple attribute decision analysis and stated preference choice modelling revealed that the two approaches are very compatible.
- The challenge is to develop a methodological approach that combines the strengths of multiple attribute decision analysis and stated preference choice modelling.
- Chapter 4 will outline the complementary approach developed for the purposes of this research project and describe how this methodology was implemented for the multiple objective management problem of evaluating strategies for encouraging floodproofing of existing homes in HSAs of the Fraser River floodplain.

[54] Although this review focused on applications of econometric stated preference modelling approaches, it should be noted that the literature also documents a number of attempts by decision analysts to develop public preference elicitation survey tools that are based on the fundamental concepts of decision analysis (McDaniels 1996, Gregory and Wellman 2001, Russell *et al.* 2001, and Gregory 2000).

Chapter 4 Implementation of Methods

The decision analysis process outlined in Figure 6 of Chapter 3 represents a suitable methodological framework for the floodproofing study for several reasons. First, the four steps of the decision analysis process provide a convenient conceptualization of the research problem by separating it into workable subcomponents. Second, the stated preference modelling literature does not provide an equivalent rigorously structured approach to problem analysis. Third, the differentiation of the steps provides a convenient guide for explaining the complementarities between the stated preference modelling and decision analysis approaches.

4.1 Overview of Project Methodology

The following steps were used to analyse the management problem associated with evaluating strategies for encouraging floodproofing in historic settlement areas of the Fraser River Basin.

Step 1 - Structure the decision problem

- Develop a complete problem statement
- Define fundamental objectives and attributes for those objectives (e.g. indicators).
- Identify the set of management alternatives (required for decision analysis only).

Step 2 - Determine the potential impacts or consequences of alternatives

For this problem, the impacts are the estimated outcomes of hypothetical floodproofing strategies as specified by selected attributes, which measure the achievement of the multiple fundamental objectives (e.g. costs, safety). The impacts were calculated using simple simulation models. This step was important for two reasons.

1. Decision analysis – to allow a multiple objective comparison of the selected alternatives. For instance, alternatives can be compared using multiple criteria such as costs, aesthetic impact, or safety.

2. Stated preference modelling – Stated preference surveys require respondents to evaluate hypothetical scenarios. If the survey results are to be relevant for decision-making purposes, these scenarios must contain realistic attribute values. As a result, analysts must determine appropriate attribute ranges and levels to use in the survey beforehand. The impact model was used to provide this information.

Step 3 - Preference Elicitation (Establish preferences for each objective)

This step was used to establish preferences for each objective. For this project, preference information was derived from two sources.

- The general public (homeowners in the City of Richmond).
- Floodplain managers (experts knowledgeable about flooding, floodplain management and floodproofing)

Step 4 - Calculate an overall evaluation or score for each alternative.

In this step, the information from step 3 (preferences for objectives) and step 2 (the impacts assessment for each alternative) was combined to derive an evaluation of each alternative. Due to the comparative nature of this research project, the final evaluation step was completed in two ways:

1. Using traditional decision analysis methods. In this case a simple additive summation evaluation rule was used but other decision analysis techniques could have been used (e.g. compromise programming, ELECTRE)
2. Using a decision support system (DSS) developed from results of a discrete choice experiment.

The four-step methodology summarized above will be used to structure the remainder of Chapter 4, which describes how the methodology was implemented. The four-step organization will be also used to structure Chapter 5, which reviews the results and analysis of the research project.

4.2 Step 1 - Structuring the Decision Problem

According to the maxims of decision analysis, a comprehensive problem-structuring phase should be the first step in any attempt to address a decision problem. There are three key activities in the problem structuring phase: 1) defining a precise problem statement, 2) identifying and structuring fundamental objectives and appropriate attributes for objectives, and 3) defining a complete list of alternatives to be evaluated as potential solutions to the decision problem (Keeney 1982, Keeney 1992). In order to characterize the three key components of the problem structuring phase, research was undertaken in two phases: 1) background research/literature review, and 2) floodproofing workshops.

Background research

A number of documents were used to investigate floodproofing in British Columbia with specific regard to the problem of designing strategies to encourage floodproofing of homes in historic settlement areas of the Fraser River Basin (Arlington 2001, USACE 1993). In addition, ongoing conversations with Steve Litke, the project coordinator for integrated flood hazard management with the Fraser Basin Council in Vancouver, BC provided further guidance and insight into the problem. The background information was compiled into a preliminary scoping document that outlined ideas for a specific problem focus, objectives, attributes and potential alternatives.

Workshops

A floodproofing workshop (5 hours) was conducted in early September of 2002 with participants drawn from two levels of government (municipal and provincial) and from a non-governmental organization (Fraser Basin Council). Appendix C contains a complete list of workshop participants. The purpose of the workshop was twofold: (1) to introduce local decision makers to decision analysis and stated preference survey techniques as tools for decision making processes, and (2) to obtain assistance with appropriately structuring the floodproofing question.

Based on the information generated at the floodproofing workshop, a detailed problem-scoping document was developed that attempted to incorporate the ideas generated at the workshop. The scoping document included the following key components: a problem statement, a list of fundamental objectives and associated attributes, and a description of some alternatives for encouraging floodproofing of homes in historic settlement areas. The scoping document was circulated to workshop participants for comment.

A second 2-hour meeting was organized with the original workshop participants in early December of 2002 to provide a forum for detailed comment on and analysis of the scoping document. In general, participants were supportive of the problem structure that had been developed but had a number of suggestions for adding/improving objectives, attributes and alternatives. Following the second workshop, a revised version of the scoping document was produced and circulated to participants for final comments. The following sections provide an overview of the key outcomes of the problem structuring phase: 1) Problem Statement, 2) Objectives and Attributes, and 3) Alternative Floodproofing Strategies.

4.2.1 Problem Statement

The purpose of the applied research was to identify and evaluate floodproofing strategies for residential properties in historic settlement areas (HSA), which address public, stakeholder and decision maker (municipal leaders) preferences, and which meet current governmental regulations. For this analysis, a "floodproofing strategy" is defined as a package of methods that could be used to encourage homeowners (and possibly developers/local governments) to floodproof existing houses, or to incorporate floodproofing designs while renovating or redeveloping properties. For example, a potential floodproofing strategy might include a system of grants for floodproofing homes, and penalties for homes that are not floodproofed.[55]

[55] In certain communities constraints might exist on floodproofing strategies due to the existence of municipal or other regulations (e.g. local height restrictions).

4.2.2 *Objectives and Attributes*

The overall objective of the research project was to identify a floodproofing strategy (or strategies) that would likely produce the greatest net benefit for communities located in historic settlement areas. The net benefits of a floodproofing strategy should account for a variety of positive and negative impacts, which can be evaluated using the fundamental objectives associated with the decision problem.

To evaluate if a potential floodproofing strategy will provide net positive or negative outcomes for a community, potential strategies must be evaluated in terms of the key values or concerns of floodplain residents and decision makers. In developing the set of fundamental objectives, Keeney (1992) recommends a structuring process based on his approach called "Value Focused Thinking." Structuring helps to clarify the decision context, define the set of fundamental objectives, and to separate fundamental objectives from means objectives. A fundamental objective indicates an essential reason for interest in the decision problem; it is important for its own sake not because it is a means to achieving another objective (Gregory and Keeney 2002).[56] Two helpful tools for the objectives structuring process are fundamental objectives hierarchies and mean-ends networks. In a fundamental objectives hierarchy, objectives are structured such that an overall strategic objective is described by lower level sets of fundamental objectives. The objectives hierarchy is really a classification tool in which lower-level objectives completely describe the important aspects of the higher-level fundamental objectives (Keeney 1992). Conversely, means-ends networks indicate causal relationships between lower-level means objectives and the overall strategic or 'end' objectives and are not necessarily hierarchical. In a means-ends network, the lower level objectives indicate how the higher-level objectives may be achieved (Keeney 1992).[57] For this project,

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[56] In separating means from ends objectives it is useful to inspect every listed objective with the question, "why is achieving this objective important?" For example, consider a transportation problem involving transporting hazardous waste. One objective could be "to minimize the transport distance of trucks carrying hazardous waste," but asking "why" may reveal that this objective is important because it is a means to achieving two other objectives: to reduce opportunities for accidents involving trucks carrying hazardous waste, and to reduce transportation costs (Keeney 1992).

[57] The separation between means and ends objectives is not always clear (Keeney 1992). To some extent, even the lower level objectives in a fundamental objectives hierarchy could be defined as the 'means' to which the highest strategic level objective is achieved.

fundamental objectives were developed using Keeney's structuring concepts. Suggestions for potential objectives were derived from agency documents and reports (e.g. Arlington 2001) and discussions with floodplain managers during the two workshop sessions. The fundamental objectives hierarchy in Figure 9 summarises the output of the structuring process.

The objectives in Figure 9 were structured by separating economic and social impacts and by recognising that some objectives address impacts that would result in the event of a flood, while others describe impacts that would occur as a direct result of implementing a flood proofing strategy. The lowest level of the hierarchy defines the fundamental objectives that were used for this project as a basis for measuring the impacts of competing alternatives (Keeney 1992). The lowest level fundamental objectives are described in more detail below.

Economic Objectives

1. **Costs - To minimize the costs of implementing the flood proofing strategy for both public and private interests.**

   These are preventative costs incurred before a flood event and are directly related to the expense required to floodproof buildings (e.g. design, construction materials).

2. **Damages - To minimize the estimated monetary damages from flooding and associated liabilities to both public and private interests.**

   These are estimated damage costs incurred after a flood event and are directly related to the costs of repairing flood damage to structures and their contents.

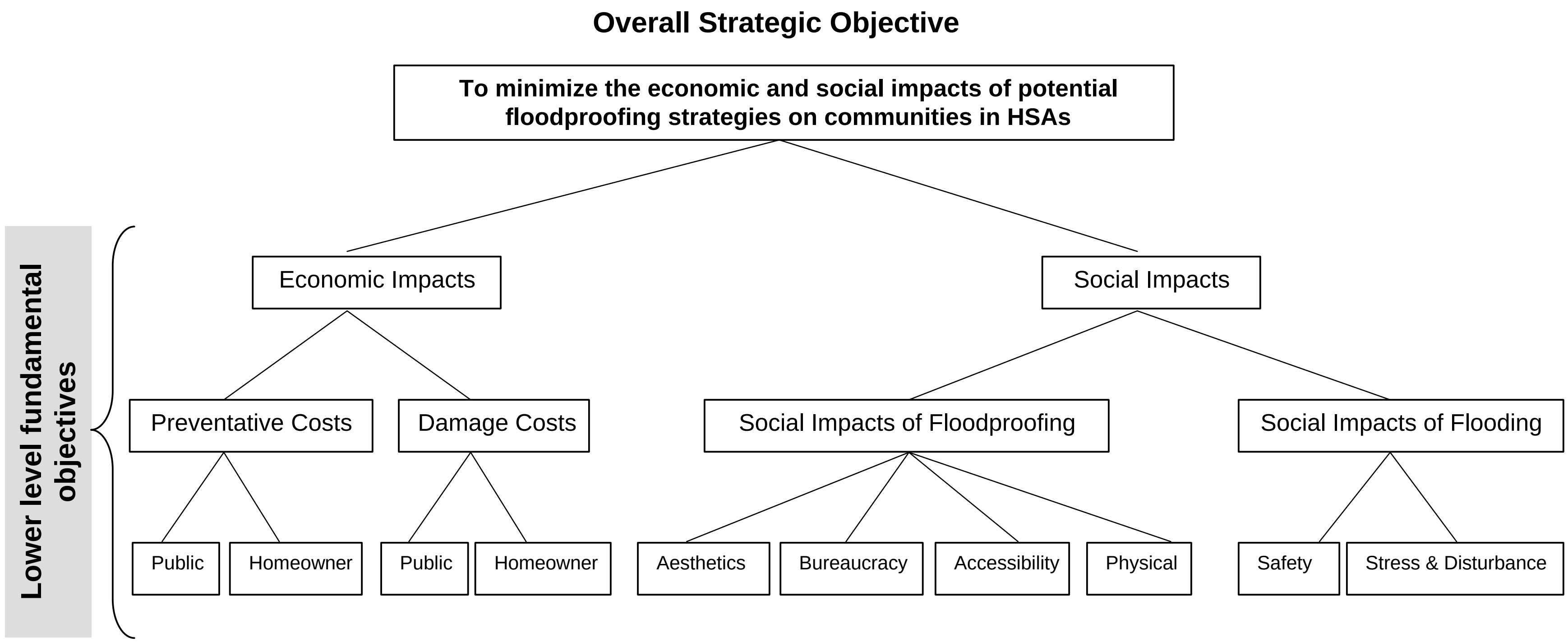

Figure 9 Fundamental objectives hierarchy associated with selecting a floodproofing strategy for residential properties located in HSAs of the lower Fraser River Basin.

Social Objectives

3. **Safety - To minimize flood related safety hazards in the community.**

   Floodproofed buildings may contribute to public safety by reducing the threat of injury or death due to drowning, electrocution, unsanitary conditions, and water born debris. The potential protection of floodproofing will be particularly important for vulnerable individuals such as the very young, old, or physically disabled.

4. **Stress and Disturbance - To minimize the stress and disturbance of flood events.**

   Floodproofing can reduce the stress and disturbance of flood events by reducing clean up and recovery time after a flood event and by preventing the damage to, or even loss of, homes and the valuable or irreplaceable items they contain.

5. **Bureaucracy - To minimize the inconvenience and the administrative burden associated with a flood proofing strategy.**

   Potential floodproofing strategies should not result in unreasonable administrative burdens such as numerous and lengthy approvals or excessive paperwork. Reducing "red tape" is a prime consideration given the deregulatory policies of the current provincial government.

6. **Aesthetics - To minimize the negative aesthetic impact of newly floodproofed homes on existing neighbourhoods.**

   It is important to try to maintain community character, historic aesthetic appeal, and neighbourhood continuity. Aesthetics may really be a transitory issue more appropriately dealt with at the design stage. Despite this, aesthetic impact (even short term) may be especially relevant in neighbourhoods were some houses have been elevated and others have not.

7. **Accessibility - To minimize the loss of accessible housing for the physically challenged (e.g. disabled and elderly citizens).**

   Floodproofing directed primarily at elevating structures (as it is in BC) may result in a net loss of single storey, at grade homes. Without structural modification to newly floodproofed homes (e.g. addition of ramps), which would require additional expense, the physically disabled may encounter loss of accessible housing.

8. **Secondary Impacts - To minimize secondary impacts of floodproofing designs.**

   Some floodproofing designs can negatively affect neighbouring properties. For example, drainage and soil displacement impacts can occur when the grade of an adjacent property is raised with fill. Secondary impacts are difficult to quantify at the strategy level because they are more of a design specific issue. As a result, for this project it was assumed that every effort would be made to avoid these impacts at the design stage so there would be no significant impact at the strategic level.

The success of a potential floodproofing strategy may be judged by how well it contributes to achieving each of the listed objectives. For this purpose, attributes or indicators can be developed that attempt to measure the impact of proposed floodproofing strategies in terms of each objective (Table 3). The attributes are based on a number of key assumptions as identified below.

Key assumptions that guided the development of attributes:

1. The decision context is that of the community. The decision to be made focuses on the costs and benefits of a floodproofing strategy for the community as a whole and not for the individual homeowner.
2. There will be discernable differences between the alternatives when impacts are considered for each objective.
3. The relevant time frame for consideration is that of a reasonable mortgage (20 years).

Table 3 Objectives and attributes for the floodproofing problem.

		Objective	Description	Attribute
ECONOMIC IMPACTS	Prevention Costs	Public Sector Costs of floodproofing	To minimize the costs to public interests of implementing a floodproofing strategy	Net amount that the government will spend to support floodproofing (AVERAGE $ per household).
		Homeowner Costs of floodproofing	To minimize the costs to homeowners of implementing a floodproofing strategy	Net amount that homeowners will spend on floodproofing or levies (AVERAGE $ per household).
	Flood Damages	Public Sector Damages of future floods	To minimize future flood damage costs to public interests	Average flood disaster assistance that governments will likely have to pay to each household after a major flood ($).
		Homeowner Damages of future floods	To minimize future flood damage costs to private interests	Average amount that homeowners will pay to repair damages to their homes after a major flood ($).
SOCIAL IMPACTS…	of Floodproofing	Aesthetics	To minimize the negative aesthetic impact of floodproofing building techniques.	% of homes that will be greater than two stories tall in any given neighbourhood.
		Bureaucracy	To minimize the inconvenience created by any new floodproofing requirements	Number of administrative steps added to the building permit application process.
		Accessibility	To minimize the loss of accessible housing for the physically challenged	% decrease in the availability of single storey homes built at ground level.
	of Flooding	Protection of Community Members (Safety)	To minimize the flood related safety hazards in the community	% of homes that will be floodproofed to the provincial standard.
		Flood Related Stress and Disturbance	To minimize the flood related stress and disturbance on community members	Average time that residents will be unable to occupy their homes after a major flood (weeks).

The objectives and attributes listed in Table 3 can be used to assess the positive and negative aspects of alternative floodproofing strategies.

4.2.3 Alternative Floodproofing Strategies

The set of feasible alternatives for a decision analysis can be derived in a variety of ways. For example, alternatives could arise from brainstorming sessions during a multiple stakeholder planning process. For the sake of simplicity, in this project six key policy levers were used to derive nine distinct alternative floodproofing strategies (Table 4).[58]

Policy Lever	Description	Options
1. Trigger	Under what circumstances will the owner be required (encouraged) to floodproof his/her building	▪ Any ▪ Major renovation (>$100,000) or rebuild ▪ Rebuild only ▪ None
2. Compliance	Will compliance with flood proofing standards be mandatory or voluntary for all property owners?	▪ Mandatory (given trigger) ▪ Voluntary
3. Support	What sort of cost sharing mechanisms or incentives will be provided to help/encourage owners to comply?	▪ None ▪ Municipal tax break ▪ One time grant
4. Penalties	What sort of penalties will be placed on owners of non-floodproofed homes?	▪ None ▪ Standard levy ($/yr) ▪ Variable levy dependent on flood risk ($/yr)
5. Liability	How are costs for flood damaged residential structures distributed between governments, homeowners, and developers?	▪ Current system ▪ Reduction in disaster assistance for non-floodproofed homes.
6. Standards/ Guidelines	What standards or guidelines will be used when designing floodproofed buildings?	▪ FCL[59] ▪ < or > FCL ▪ Phased standard

Table 4 Policy levers used to develop floodproofing strategies.

Given the range of options listed in the third column, the policy levers in Table 4 can be combined to derive a large number of potential alternatives. Nine representative alternatives were developed from this set, which describe reasonable combinations of the six policy levers. These nine alternatives are described in Table 5.

[58] For a similar approach in water resources planning, see Stewart and Scott (1995).

[59] FCL (Flood Construction Level) – for a definition refer to footnote 4.

Table 5 Nine representative floodproofing alternatives.

	ALTERNATIVES								
Policy Lever	**(A)** Do Nothing	**(B)** Carrot – Positive Incentives I	**(C)** Stick – Negative incentives I	**(D)** Carrot & Stick – Wealth transfer I	**(E)** Reduced Liability	**(F)** Strict Regulations only	**(G)** Wealth Transfer II	**(H)** Negative Incentives II	**(I)** Positive Incentives II
Compliance	Voluntary	Voluntary	Voluntary	Voluntary	Voluntary	Mandatory	Voluntary	Voluntary	Voluntary
Trigger	N/A	N/A	N/A	N/A	N/A	Redevelop-ment or major renovation[60]	N/A	N/A	N/A
Restrictions	Height, set back	Height, set back	Height, set back	Height, set back	Height, set back	Height, set back	Height, set back	Height, set back	Height, set back
Support	None	Property tax break	None	Property tax break	None	None	One time grant	None	One time grant
Penalties	None	None	Set levy paid yearly to local government	Set levy paid yearly to local government	None	None	Set levy paid yearly to local government	Set levy paid yearly to local government	None
Liability	Unchanged from current policy.[61]	Unchanged from current policy.	Unchanged from current policy.	Unchanged from current policy.	Reduction in disaster assistance for non-floodproofed homes	Unchanged from current policy.	Unchanged from current policy.	Reduction in disaster assistance for non-floodproofed homes	Unchanged from current policy.
Standard	FCL	FCL	FCL	FCL	FCL	FCL	FCL	FCL	FCL

[60] Major renovation is defined as >75% value of the house, or an addition of >25% of existing main floor area.

[61] Maximum payout is $100,000 with a $1,000 deductible; coverage is 80% of claimed damages and is subject to applicable restrictive covenants. Compensation only covers those items required to replace or restore the necessities of life (PEP 2001).

4.3 Step 2 – Determining the Impacts of Alternatives

A detailed, completely rigorous assessment of the impacts of the alternatives in terms of the stated objectives was beyond the scope this 699 project, since this sort of analysis could easily form the sole focus of one such project.[62] As a result, the impact models constructed for each alternative were relatively simple and somewhat limited in scope so that they could be developed within a reasonable timeframe. In addition, it was discovered that some crucial data were not available, which prevented a more complex analysis. For instance, the original intent was to build models that incorporated the probabilities associated with the occurrence of floods of various magnitudes and levels, resulting from a dyke breach, but information of this type simply did not exist for the study area (Neil Peters, personal communication, March 2003).

Spreadsheet models were constructed to estimate the impacts of potential alternatives for each of the objectives identified in the structuring phase. As result, a model was developed for each of the nine objectives: aesthetics, accessibility, bureaucracy, public sector costs, homeowner costs, safety, stress/disturbance, public sector damages and home owner damages. Of the nine models, those for costs and damages required the most complex algorithms, while those for the remaining objectives were based on much simpler equations.

According to Grant (1997), differential or difference equations can be used in simulation modelling. For this project, difference equations were used of the following general form.[63]

[62] Extensive research, analysis and modeling are often required for each objective of interest.

[63] See Grant (1997) for a review of simulation modeling techniques that utilize this model form.

Equation 9 $State_{t+1} - State_t = (system\ transfers\ in - system\ transfers\ out) = ?\ State$

In this equation, state is the condition of the system at any time (t). The state of the system could be described by a variable such as 'net costs' or 'impact on safety'. All the models used a time unit (t) of 1 year and simulations were run over a twenty-year time period. Parameters and other inputs into the models were compiled primarily from existing data sources including publicly available articles and reports, government agency internal documents and some expert opinion (Table 6).

Table 6 Primary sources of data used in the impact assessment models

Index	Description of Data Source	Reference
a	Decision support system based on the results of the personal floodproofing decision choice task of the public values survey.	This document, sections 4.4.2.2.3 and 5.1.2.3.
b	Data purchased from the Landcor Data Corporation.[64]	Landcor (2003)
c	Floodproofing costs data from the U.S. Federal Emergency Management Agency	FEMA (1998)
d	Data supplied by the City of Richmond planning department.[65]	City of Richmond (2003d), Jones (2003a, 2003b, 2003c, 2003d)
e	Greater Vancouver Taxation Survey	District of Pitt Meadows (2002)
f	Damage estimates for non-floodproofed homes based on height of flood water (depth – damage curves)	KGS Group (1999)
g	Damages estimates for floodproofed homes	Arlington Group (2001)
h	Disaster financial assistance guidelines	PEP (2001)

When discussing the parameters associated with each specific model, the data sources will be referred to using the appropriate letter in Table 6.

[64] The Landcor data describe a sample of homes in the Richmond area and was purchased from the Landcor Data Corporation (New Westminster, BC). Landcor has a long-term relationship with the British Columbia Assessment Authority that guarantees access to a wide range of data regarding real estate property in the province of BC (www.landcor.com). The data consisted of a sample of 700 homes in Richmond neighborhoods located inside the Urban Exempt Zone. The attributes listed for each sample home included total finished area, basement total area, foundation type, assessed structural value, assessed value of land, and house type. Many of the parameters used in the models were calculated using the information in this sample data set.

[65] Data obtained from the City of Richmond included elevation maps, maps showing the location of different FCL standards, data on the rate of renovation and redevelopment, etc.

A number of simplifying assumptions were used in the development of all the impact models:

- Models assume no change in housing density over time (e.g. a non-floodproofed house is replaced by another house not townhouses, condominiums, etc); and
- Models do not discount future costs and benefits.

4.3.1 Model 1 – Floodproofing Costs

The purpose of this model was to calculate estimated floodproofing costs over a twenty year time period for homeowners and for the public sector. For homeowners, the model calculates average homeowner spending per household on floodproofing and/or levies net of any financial aid. For the public sector, the model calculates the net amount that the government (at all levels) will spend to encourage floodproofing on average per household.

Functional form of model equations

Equation 10 and Equation 11 describe the general functional form of the model equations used to calculate the costs for homeowners and for the public sector:

Equation 10 $$HC_t = HC_{t-1} - HE*?t - HF*?t + HS*?t\ ,$$

where **HC** is homeowner costs ($), **HE** is average homeowner expenditure on floodproofing ($/yr), **HF** is homeowner fees (e.g. floodproofing levies) ($/yr), and **HS** is homeowner support (e.g. grants or tax breaks) ($/yr).

Equation 11 $$PC_t = PC_{t-1} + PF*?t - PS*?t\ ,$$

where **PC** is public sector costs ($), **PF** is public sector fees collected (e.g. floodproofing levies) ($/yr), and **PS** is public sector support provided (e.g. grants or tax breaks) ($/yr).

Furthermore, the terms in Equation 10 and Equation 11 represent sub-equations which are calculated as functions of numerous other parameters and variables. Equation 12, Equation 13, and Equation 14 describe the general functions for the sub-equations.

Equation 12 $$HE = f\,(PW, PE, F, WC, EC, S, B, C, FCL, FFS, FFB, FFC, E, SQ),$$

where **PW** is the proportion of floodproofed homes that are wet floodproofed, **PE** is the proportion of floodproofed homes that are elevated, **F** is the floodproofing rate of existing non-floodproofed homes (%/year)[66], **WC** is a matrix of the estimated costs of wet floodproofing for various foundation types and floodproofing heights ($/sqft), **EC** is a matrix of estimated elevation costs for various foundation types and floodproofing heights ($/sqft), **S** is the proportion of homes built on slab foundations, **B** is the proportion of homes built on basement foundations[67], **C** is the proportion of homes built on crawlspace foundations, **FCL** is the flood construction level for the area of interest (m, GSC), **FFS** is the average first floor elevation for homes built on slab foundations (m, GSC), **FFB** is the average first floor elevation for homes built on basements (m, GSC), **FFC** is the average first floor elevation for homes built on crawlspaces (m, GSC), **E** is the average elevation of homes above sea level (m, GSC), and **SQF** is the average footprint of homes in the area of interest (ft^2).[68]

Equation 13 $$HF = f\,(L, F) \quad \textit{and} \quad PF = f\,(L, F),$$

where **L** is the yearly levy applied to homes that are not floodproofed ($/year), and **F** is the floodproofing rate of existing non-floodproofed homes (%/year).

[66] The voluntary floodproofing adoption rates, F, are particular to each alternative floodproofing strategy and can be derived by analyzing homeowner responses to the personal floodproofing choice task (Chapter 5, section 5.1.2.5.1).

[67] True basements are extremely rare in Richmond (e.g. having the floor of the basement below ground level). Most foundation types described as basement are actually above ground basements, most of which have been finished as recreation rooms or secondary suites since they were built in the 1970s (Stuart Jones, personal communication, March 2003).

[68] Footprint is the basal surface area that the home occupies (e.g. the length multiplied by the width).

Equation 14 $\boldsymbol{HS = f\,(TG, G, MT, T, F)}$ *and* $\boldsymbol{PS = f\,(TG, G, MT, T, F)}$,

where **TG** is a logical selector that indicates whether a tax break or a grant is offered, **G** is the value of any floodproofing grant supplied ($), **MT** is the average value of municipal taxes paid in area of interest ($/year), **T** is the tax break offered to owners of floodproofed homes (%), and **F** is the floodproofing rate of existing non-floodproofed homes (%/year).

Parameters and Assumptions

The following list highlights important assumptions used in this model.

- The number of previously floodproofed homes in the area of interest is minimal and is approximately equal to 4% or less of existing housing stock.
- The majority of homes in the area of interest are of wood frame construction as opposed to masonry.
- The percentage of people who floodproof their homes per year is constant (e.g. the rate of floodproofing does not change over time).
- Grants are offered on a one time only basis.
- Municipal tax breaks are offered every year once a homeowner has floodproofed his or her home.
- Homes built on crawlspace or on slab foundations should be elevated (FEMA 1998).

Table 7 Parameters used in the floodproofing costs model.

Name	Value	Units	Source*
F	Variable, depends on alternative strategy	%/yr	a
PW	0.20	-	a,b
PE	0.80	-	a,b
WC	Matrix of values	$/sqft	c
EC	Matrix of values	$/sqft	c
S	0.40	-	b
B	0.37	-	b
C	0.23	-	b
FCL	3.5	m,GSC	d
FFS	0.9	m,GSC	d
FFB	3.2	m,GSC	FFS plus 8 ft basement
FFC	2.0	m,GSC	FFS plus 4 ft crawlspace
E	0.9	m,GSC	d
SQF	1000	ft2	b
L	200	$/yr	Assumption
G	10000	$	Assumption
MT	2000	$/yr	e
T	10	%/yr	Assumption

*Each letter given in the "Source" column refers to a specific data source as described in detail in Table 6.

4.3.2 Model 2 – Flood Damages

The purpose of this model was to estimate the average expenditures required to repair flood damaged residential structures if a major flood were to occur after twenty years of investment in floodproofing under a given floodproofing strategy by homeowners and by the public sector. The model calculates the average amount that homeowner will have to pay to repair flood damages to their homes after a major flood. For the public sector, the model calculates the average flood disaster assistance that the governments (all levels) would likely provide to the average household after a major flood.

Functional form of model equations

Equation 15, Equation 16, and Equation 17 describe the general functional forms of the equations used to calculate the average damages per household after a major flood.

Equation 15 $D_t = D_{t-1} + DNfp*?t - DLnfp*?t$,

where **D** is average flood damages ($), **DNfp** is the estimated average damage associated with new floodproofing converts in the time period ($/year), and **DLnfp** is the estimated average damages lost due to homeowner conversions to floodproofing ($/year). In effect, the difference between DNfp and DLnfp in a given time period is the reduction in damages due to new floodproofing recruits. Homeowner damages and public sector damages are calculated as shares in the overall damage value as follows.

Equation 16 $DNfp = f\,(PW, PE, F, SQ, DW, DE)$,

where **PW** is the proportion of floodproofed homes that are wet floodproofed, **PE** is the proportion of floodproofed homes that are elevated, **F** is the floodproofing rate of existing non-floodproofed homes (%/year), **SQ** is the average square footage of homes in the area of interest (ft^2), **DW** is the average damages estimated for wet floodproofed homes ($\$/ft^2$), and **DE** is the average damages estimated for elevated homes ($\$/ft^2$).

Equation 17 $DLnfp = f\,(SQ, SV_1, SV_{1.5}, SV_{2+}, P_1, P_{1.5}, P_{2+}, PD)$,

where **SQ** is the average square footage of homes in the area of interest (ft^2), SV_1 is the average structural value for homes that are 1 storey tall ($), $SV_{1.5}$ is the average structural value for homes that are 1.5 storey tall ($), and SV_{2+} is the average structural value for homes that are 2 or more stories tall ($), P_1 is the proportion of homes that are 1 storey tall, $P_{1.5}$ is the proportion of homes that are 1.5 stories tall, P_{2+} is the proportion of homes that are 2 or more stories tall, and **PD** is the estimated percentage damage to the residential structures at water levels greater than the FCL (% of structural value).

The equations above were used to calculate the homeowner damages (Equation 18), and public sector damages (Equation 19).

Equation 18 $$HD_t = D_t - PD_t\ ,$$

where **HD** is homeowner damages not covered by disaster financial assistance ($), **D** is the average flood damage ($), and **PD** is the public sector damage costs or the amount of damages covered by disaster assistance ($).

Equation 19 $$PDt = f\ (Dt, Cfp, Cnfp, DD, MP)\ ,$$

where **PD** is public sector damages ($), **Cfp** is the percentage disaster assistance available to floodproofed homes (%), **Cnfp** is the percentage disaster assistance available to non floodproofed homes (%), **DD** is the deductible required before disaster assistance is payable ($), and **MP** is maximum disaster assistance payable ($).

Parameters and Assumptions

The following list highlights important assumptions used in this model.

- No damages to homes can occur at flood levels less than the flood construction level of the dykes. In other words, this model assumes that dykes cannot be breached at water levels less than the design level of the dykes.
- Damage estimates for retrofitted floodproofed homes are equivalent to those associated with newly built floodproofed homes.
- Owners of non-floodproofed homes will have to find alternative accommodations after a flood for at least 12 weeks.
- Owners of wet floodproofed homes will have to find alternative accommodations after a major flood for at least 8 weeks.
- Disaster financial assistance will be paid out to all homeowners in need of assistance but no homeowner will receive more than the maximum assistance.
- Assistance levels for disaster aid will remain constant for the time period analysed.

Table 8 Parameters used in the floodproofing damages model.

Name	Value	Units	Source
F	Variable, depends on alternative strategy	%/yr	a
Cfp	0.8	-	h
Cnfp	0.5	-	Assumption
DD	1,000	$	h
MP	100,000	$	h
PW	0.20	-	Same as Cost model
PE	0.80	-	Same as Cost model
SQ	2000	ft2	b
DW	17.5	$/ft2	g
DE	1.6	$/ft2	g
SV1	35,000	$	b
SV1.5	28,000	$	b
SV2+	101,000	$	b
P1	0.18	-	b
P1.5	0.05	-	b
P2+	0.77	-	b
PD	100	%	f

4.3.3 Model 3 – Accessibility

The purpose of this model was to estimate, for a given floodproofing strategy, the impact on accessibility over twenty years time. Specifically the model calculates the estimated percentage decrease in single-level, at-grade homes as a proxy for accessibility. Single-level, at-grade homes were chosen as an indicator because they do not generally contain stairs and would not require as much retrofitting to become accessible for a person with a physical disability.

Functional form of model equations

Equation 20 describes the general functional form of the model equation used to calculate the percentage of single-level, at-grade homes:

Equation 20 $SL_t = SL_{t-1} - F * SL_{t-1} * ?t$,

where **SL** is the percentage of single level homes (%), and **F** is the floodproofing rate of existing non-floodproofed homes (%/year).

The percentage decrease in single-level, at-grade homes can then be calculated as described in Equation 21.

Equation 21 $DA_t = (SL_t - SL_0)/ SL_0$,

where **DA** is the percentage decrease in accessibility at time t, and SL_0 is the initial percentage of single-level, at-grade homes.

Parameters and Assumptions

The following list highlights important assumptions used in this model.

- All types of homes are floodproofed at the same rate e.g. single level homes are floodproofed at the same rate as two storey homes.
- The rate of floodproofing adoption remains constant over the time period.

Table 9 Parameters used in the accessibility model.

Name	Value	Units	Source
SL_0	0.18	-	b
F	Variable, depends on alternative strategy	%/yr	a

4.3.4 Model 4 – Aesthetics

The purpose of this model was to estimate, for a given floodproofing strategy, the aesthetic impact over twenty years time. Specifically the model calculates the estimated percentage of homes that will be greater than two stories tall as an indicator of aesthetic impact.

Functional form of model equations

Equation 22 through Equation 27 describe the general functional forms of the model equations used to calculate the percentage of homes that are greater than two stories tall in any given neighbourhood at any time, t.

Equation 22 $AS_t = E\_1.5_t + E\_2_t + E\_>2_t + W\_>2_t + N\_>2_t$,

where **AS** is the percentage of homes that are greater than 2 stories tall in any given neighbourhood, **E_1.5** is the percentage of 1.5 storey homes that were elevated, **E_2** is the percentage of 2 storey homes that have been elevated, **E_>2** is the percentage of homes that are 2 or more stories tall that have been elevated, **W_>2** is the percentage of homes that are 2 or more stories tall that have been wet floodproofed, and **N_>2** is the percentage of homes that are two or more stories tall that have not been floodproofed.

Equation 23 $E\_1.5_t = E\_1.5_{t-1} + F*PE*N\_1.5_{t-1}$,
Equation 24 $E\_2_t = E\_2_{t-1} + F*PE*N\_2_{t-1}$,
Equation 25 $E\_>2_t = E\_>2_{t-1} + F*PE*N\_>2_{t-1}$,
Equation 26 $W\_>2_t = W\_>2_{t-1} + F*PW*N\_>2_{t-1}$,
Equation 27 $N\_>2_t = N\_>2_{t-1} - F*N\_>2_{t-1}$,

where **F** is the floodproofing rate of existing non-floodproofed homes (%/year), **PW** is the proportion of floodproofed homes that are wet floodproofed, **PE** is the proportion of floodproofed homes that are elevated, **N_1.5** is the percentage of non-floodproofed 1.5 storey homes, **N_2** is the percentage of non-floodproofed 2 storey homes, and **N_>2** is the percentage of non-floodproofed homes that are greater than two stories tall.

Parameters and Assumptions

The following list highlights important assumptions used in this model.

- All types of homes are floodproofed at the same rate e.g. single level homes are floodproofed at the same rate as two storey homes.
- The rate of floodproofing adoption remains constant over the time period.

- Three categories of homes contribute to the stock of houses that are greater than two stories tall: elevated 1 ½ storey homes, elevated 2 storey homes, and homes that are already greater than two stories tall before any floodproofing.

Table 10 Parameters used in the aesthetic impact model.

Name	Value	Units	Source
PW	0.20	-	Same as Cost model
PE	0.80	-	Same as Cost model
F	Variable, depends on alternative strategy	%/yr	a

4.3.5 Model 5 – Bureaucracy

The purpose of this model was to estimate, for a given floodproofing strategy, the bureaucratic impact. The attribute used to approximate bureaucratic impact or regulatory burden was the administrative steps added to the building permit application process. Since it was difficult to obtain a realistic estimate on the exact number of steps added for any given floodproofing strategy, the model simply used a logical equation to analyse the compliance component of a given strategy to determine if any regulatory burden was added.

Functional form of model equations

Equation 28 describes the general functional form of the equation used to calculate the number of administrative steps added to the building permit application process:

Equation 28 $$\boldsymbol{BR} = \begin{cases} \geq 1.....if Compliance = "Mandatory" \\ 0.......if Compliance = "Voluntary" \end{cases}$$

where **BR** is the number of steps added to the building permit application process. The model analysed the compliance component of each alternative. If the word "mandatory" appeared in the compliance indicator cell for a given alternative, Bureaucracy was set to "1 or more". Conversely, if the word "voluntary" appeared, Bureaucracy was set to zero.

Parameters and Assumptions

- Bureaucracy will increase when floodproofing becomes mandatory in certain situations (e.g. when completing an expensive renovation on a home) because getting additional approvals for floodproofing plans will be necessary.

4.3.6 Model 6 – Safety

The purpose of this model was to estimate, for a given floodproofing strategy, the impact on safety - the protection of citizens from the negative effects from flooding in their own homes - over twenty years time. Specifically, the model used the estimated percentage of homes that are floodproofed as a proxy for safety. The percentage of floodproofed homes was chosen as an indicator for a number of reasons. First, both elevated and wet floodproofed homes will be resistant to flood damages during a flood, which will reduce the risk of structural failure. Secondly, floodproofed homes can be quickly and easily decontaminated after a flood, which will reduce the risk of illness and disease caused by water born pathogens. In addition, elevated homes offer the additional benefit of reducing the risk of drowning since the main living area is raised above the expected flood level. Reduction in the risk of drowning would be especially relevant for elderly and physically disabled people and during the event of an unexpected flood where prior evacuation is not possible.

Functional form of model equations

Equation 29 describes the general functional form of the equation used to calculate the number of homes that are floodproofed at any given time, t:

Equation 29 $$FP_t = FP_{t-1} + F*?t,$$

where **FP** is the percentage of homes that have been floodproofed at a given time (%), and **F** is the floodproofing rate of existing non-floodproofed homes (%/year).

Parameters and Assumptions

- Assumption - the rate of floodproofing conversion remains constant over time.

Table 11 Parameters used in the safety model.

Name	Value	Units	Source
F	Variable, depends on alternative strategy	%/yr	a

4.3.7 Model 7 – Stress and Disturbance

The purpose of this model was to estimate, for a given floodproofing strategy, the stress and disturbance on citizens from flooding in their homes if a flood was to occur in twenty years time. Specifically the model uses the estimated average time that homeowners will be unable to occupy their homes after a major flood has occurred as an indicator of stress and disturbance.

Functional form of model equations

Equation 30 describes the general functional form of the equation used to calculate the stress and disturbance experienced by homeowners after a major flood has occurred:

Equation 30 $$SD_t = SD_{t-1} - F*Tn + F*PW*Tw + F*PE*Te\ ,$$

where **SD** is the number of average number of weeks that homeowners will be unable to occupy their homes after a major flood, **F** is the floodproofing rate of existing non-floodproofed homes (%/year), **PW** is the proportion of floodproofed homes that are wet floodproofed, and **PE** is the proportion of floodproofed homes that are elevated, **Tn** is the average time that a home that has not been floodproofed will be uninhabitable after a flood, **Tw** is the average time that a wet floodproofed home will be uninhabitable after a flood, and **Te** is the average time that an elevated home will be uninhabitable after a flood.

Parameters and Assumptions

- Elevated homes will on average remain structurally sound in the event of a flood and require minimal clean up and restoration before home can be re-inhabited.

Table 12 Parameters used in the stress and disturbance model.

Name	Symbol	Units	Source
F	Variable, depends on alternative strategy	%/yr	a
PW	0.20	-	Same as Cost model
PE	0.80	-	Same as Cost model
Tn	16	weeks	Assumed double time for floodproofed homes
Tw	8	weeks	g
Te	2	weeks	g

4.3.8 Assessing Multi-attribute Outcomes of Selected Alternatives

After the models were developed, a testing and evaluation phase followed in which model outcomes for various alternatives were compared to prior expectations and assumptions. Subsequently, an overall assessment model was developed that combined the individual sub-models for each objective into a meta model capable of deriving a multi attribute assessment of any alternative as long as that alternative could be described using the policy levers outlined in Table 4. As reported in section 4.2.3, a number of alternatives were developed in the problem-structuring phase with the help of local flood management experts. The impact assessment models were used to evaluate the multi attribute impacts or consequences of the nine alternatives.

The impact assessment of the alternatives served two main purposes for this project. The first purpose was to provide an estimate of the range of impacts associated with each objective over the universe of feasible alternatives (e.g. costs could range anywhere from $0 to $40,000). The range estimates were required to develop suitable attribute levels for use in the stated preference survey. The second purpose was to provide an impact assessment for each of the nine alternatives developed in the problem-structuring phase. This assessment was used along with the output of the preference elicitation phase (Step 3) to calculate the overall evaluation of alternatives in step 4. The dual purpose of the impact model necessitated that model use occur in two phases. The first model runs were preliminary simulations intended to provide rough maximum and minimum estimates of the attribute values for each objective.[69] The second runs were used to derive the final impact estimates associated with each alternative, which were required for the final evaluation step. The first phase was run before the survey was developed while the second phase was run after the survey results had been analysed.

4.3.8.1 Preliminary model run and analysis

To enhance the outputs of the preliminary model run on the nine alternatives, a simple sensitivity analysis was performed by varying a few key parameters. Table 13 describes the parameters that were varied in the sensitivity analysis.

Table 13 Parameters levels varied for the preliminary sensitivity analysis.

Parameter	Levels used in Sensitivity Analysis
F – Floodproofing Conversion Rate (%/yr)	0.05, 5
Floodproofing Levies ($/yr)	50, 100, 200, 300
Tax Break (%/yr)	5, 10, 15
Liability (%)	80, 70, 60, 50
Grant ($)	5000, 10000, 15000

Using the results of the preliminary model runs and simple sensitivity analysis, estimates on the impact ranges for each of the nine objectives were derived (Table 14).

[69] Since many of the models required an estimate of the yearly adoption rate of floodproofing for each alternative, which was data that would ultimately be derived from one of the survey questions, in this initial run preliminary estimates of these rates for each alternative were used. The use of preliminary estimates was necessary to obtain a rough first pass evaluation of the selected floodproofing alternatives for the purposes of model evaluation and to derive an estimate of the impact ranges. Later these estimates were updated with actual data from analysis of the floodproofing survey and the models were run a second time to provide the final impact assessment for each of the nine alternatives (refer to Chapter 5, section 5.2.1).

Table 14 Range estimates derived from preliminary model runs and sensitivity analysis.

Attribute (for community over 20 years time…)		**Minimum**	**Maximum**
1	Net amount that the government will spend to support floodproofing (AVERAGE $ per household).	-$5,310.00*	$13,720.00
2	Net amount that homeowners will spend on floodproofing or levies (AVERAGE $ per household).	$310.63	$48,186.00
3	Average flood disaster assistance that the government will likely have to pay to each household after a major flood ($).	$5,537.19	$77,708.31
4	Average amount that homeowners will have to pay to repair damages to their homes after a major flood ($).	$3,214.88	$49,567.69
5	% of homes greater than 2 stories tall in any given neighbourhood.	0.65 %	41.60 %
6	Number of new regulations added to the building permit application process.	0	1 or more
7	% decrease in the availability of single storey homes built at ground level.	1.00 %	64.15 %
8	% of homes will be floodproofed to the provincial standard.	1.00 %	100.00 %
9	Average length of time that residents will be unable to occupy their homes after a major flood (weeks).	2.98 weeks	15.74 weeks

*The minimum for Public Sector Costs is actually negative (e.g. they make money) because under some alternatives levies actually generate ‘revenues’ for government.

4.3.8.2 Final model run and analysis

The final model runs were preformed after the survey results had been analysed. As a result, the presentation and discussion of the results of the final model impact assessment for each alternative will be left until Chapter 5 (section 5.2.1).

4.4 Step 3 - Preference Elicitation

The preference elicitation phase focused on exploring values with respect to each of the nine fundamental objectives. Using several evaluation tasks, critical information, such as the relative importance of objectives and the shape of the objective value functions, was derived. Preference elicitation focused on two key groups: floodplain managers (experts) and owners of single family detached homes (public). Furthermore, two different types of preference elicitation methods were used: 1) a decision analysis swing weighting task for floodplain managers and 2) a stated preference survey for homeowners which utilized discrete choice experiments and maximum difference conjoint analysis.

4.4.1 Expert Values – The Swing Weighting Preference Task

The purpose of the swing-weighting task was to derive relative attribute weights from the perspective of floodplain managers, for each of the nine objectives developed in the problem-structuring phase. Swing weighting is a preference elicitation method commonly used by decision analysts to derive preferences for key objectives in a decision problem. Although there are numerous 'weighting' techniques described in the decision analysis literature, swing weighting is preferred because it has been shown to promote 'range sensitivity' in responses (Fischer 1995, von Winterfeldt and Edwards 1986). Range sensitivity is an important property for the relative importance weights used in decision analysis that was discussed in Chapter 3 section 3.1.4.1.

4.4.1.1 The Instrument

Swing weighting is a relatively simple task that involves two key components: ranking and rating. The first step, ranking, requires respondents to order the attributes based on how important they think it is to move an attribute from its worst to its best level given the range of impacts provided for each attribute. The second step, rating, asks respondents to attach numerical values to their impact ranking to reflect how important it would be to swing each attribute from its worst to its best level (von Winterfeldt and Edwards 1986). For example, if 100 points is allocated to the most important attribute and 25 points to the second most important measure, then swinging the first attribute from its worst to best level is four times as important as swinging the second attribute from its worst to best level. Figure 10 shows the flood managers' swing-weighting task.

The managers' response task included a description of the objectives and attributes and provided additional information on the estimated range of impacts for each attribute.

4.4.1.2 Recruiting and Administration

Floodplain managers were recruited from the group of experts who participated in the problem-structuring phase (e.g. workshops). As a result, all respondents were familiar with the objectives and attributes used in the swing-weighting task.

Task:
Please enter your responses in the two columns on the right.

Step 1 Step 2

Objective	**Indicator Description** (for your community over 20 years time...)	**Units**	**Estimated Range**	**Your ranking**	**Your rating**
Visual Impact	Percentage of homes that will be greater than 2 stories tall in any given neighborhood.	%	0% to 45%		
Accessibility	Decrease (%) in the availability of single storey homes built at ground level.	% decrease	0% to 60% decrease		
Bureaucracy	Number of new regulations/administrative steps added to the building permit application process.	# steps	"None" to "4 or more"		
Public Costs	Net amount that the government will spend to support floodproofing (AVERAGE/household)	$	$0 to $15,000		
Homeowner Costs	Net amount that homeowners will spend on floodproofing or levies (AVERAGE/household).	$	$0 to $30,000		
Safety	Percentage of homes that will be entirely floodproofed to the provincial standard.	%	0% to 60%		
Inconvenience	Average length of time that residents will be unable to occupy their homes after a major flood.	months	1 to 4 months		
Public Damages	Average disaster assistance the government will likely pay to each household after a major flood.	$	$10,000 to $75,000		
Homeowner Damages	Average amount homeowners will likely pay to repair household damages after a major flood.	$	$5,000 to $40,000		

Figure 10 Response task for the swing weighting exercise on the nine objectives.

4.4.2 Public Values – The Multi Attribute Stated Preference Survey

The public values survey instrument[70] was designed for two primary purposes: 1) to obtain preference and trade-off information from the general public for the key objectives of the flood proofing problem and 2) to obtain data regarding expected floodproofing rates for homeowners under various hypothetical floodproofing strategies. The multi attribute stated preference survey will be described in four main sections: 1) survey development, 2) survey instrument, 3) survey administration, and 4) survey analysis.

4.4.2.1 Survey Development

The survey was developed based on the outcomes of the background research and problem structuring phases. In addition, the theoretical foundations of both traditional stated preference modelling and decision analysis guided the development of the survey. The survey was carefully planned and structured to accommodate the most recent ideas on value elicitation in both fields. Theories about the constructed nature of preferences (section 3.1.4.2) and comparative reviews of importance weighting methods (section 3.1.4.1) were particularly influential in the development of the public preferences survey. As discussed previously, these issues have led to a number of important suggestions for designing preference evaluation tasks (Gregory 2000, Payne *et al.* 1999). For example, multiple elicitation tools should be used if possible and information on the ranges of key variables or indicators should be provided to promote responses that are sensitive to the range of impacts. In addition, introductory tasks or preliminary values exploration exercises are useful for helping respondents to become familiar with the decision context and to determine their preferences.

These suggestions and others (section 3.1.4.2) were incorporated into the survey instrument in a variety of ways. For instance, the survey utilized three different approaches to preference elicitation for the same nine fundamental objectives. The first was an exploratory rating task intended to encourage respondents to begin thinking

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[70] Interested readers may view the survey by using the CD provided in Appendix D.

about their values with respect to the nine objectives. The second two exercises were stated preference tasks on the hypothetical outcomes of floodproofing strategies. For comparative purposes, the two stated preference tasks were completed on the same profiles. As a result, respondents could draw on evaluations made in the first task to help make trade-offs that were required for the second task. This type of question design is consistent with the idea that respondents learn about their values as they complete a response task. In addition, detailed information was provided on the attribute levels and ranges to encourage respondents to give answers that were sufficiently range sensitive. As mentioned in section 4.3.8 the ranges were derived from the preliminary model runs of the impact assessment model (refer to Table 14).

4.4.2.2 Survey Instrument

The body of the survey consisted of five sections which included, in order of appearance, a short section of introductory questions related to flooding and flood experience, an objective rating task, a stated preference task on the community outcomes of hypothetical floodproofing strategies, a second stated choice task on respondents' personal preferences for floodproofing alternatives, and a demographics section. The following sections will first briefly describe the main survey components (the objective rating task, the community outcomes choice task, and the personal floodproofing decision task) followed by a discussion of the supplementary introductory and demographics sections. The purpose of each survey component will be described and experimental design will be discussed if relevant. Each section will be accompanied by a screen shot that will provide an example of how the questions appeared on the computer screen. In addition, a version of the floodproofing survey has been provided as an appendix to this document (Appendix D) for those readers interested in viewing the full interactive survey.

4.4.2.2.1 The Objective Rating Task

The objective rating task solicited a separate preference rating for each of the nine fundamental objectives. The main purpose of this section was to introduce respondents to the nine key objectives and to entice them to think about their personal positions and values regarding each one of the objectives. Obtaining quantitative rating information for each objective was a secondary concern. The simple rating questions encouraged respondents to read the descriptions and to become familiar with the concepts associated with each objective. Using the rating scale, respondents were asked to indicate how important they thought each objective should be for developing a community floodproofing strategy. Answers were recorded on a Likert-scale, which ranged from 0 to 10, with 0 being "Not at all Important" and 10 being "Extremely Important" (Figure 11).

As shown in Figure 11, the objectives were classified into three categories (Community Effects, Expenses, and Flood Effects), which were also used in the subsequent stated preference tasks. The purpose of this grouping was to simplify the response task further by providing a natural organization and classification for the nine objectives.

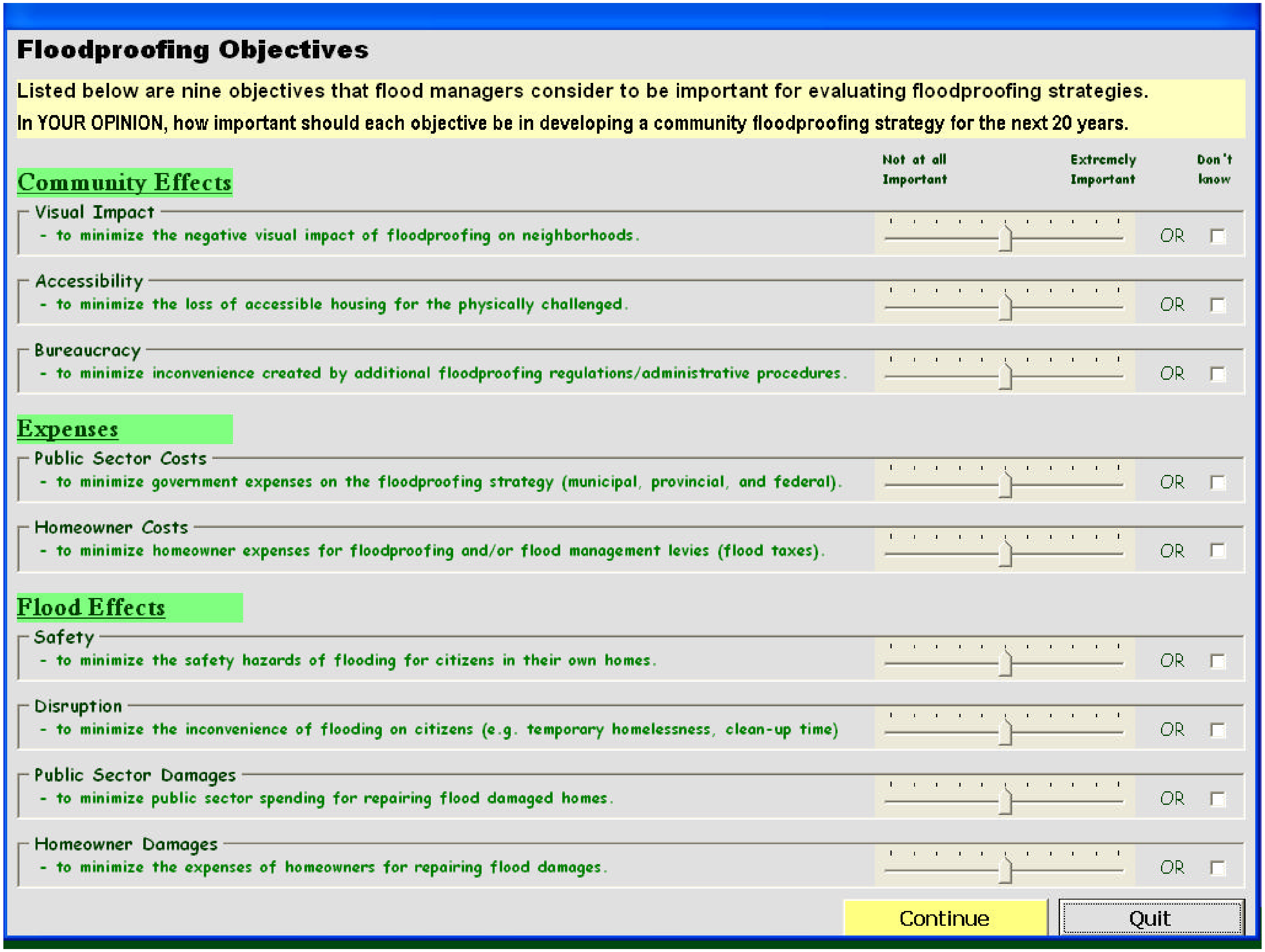


Figure 11 The objective-rating task for the nine study objectives.

4.4.2.2.2 Stated Preference Task I - Community Outcomes

The community outcomes stated preference tasks were the central questions in the survey. The purpose of the community outcomes tasks was to derive respondents' preferences for profiles that described the outcomes for the community in 20 years time resulting from implementing hypothetical floodproofing strategies. Outcomes were described using the nine fundamental objectives and attributes developed in the problem-structuring phase. The focus was on community wide implications and respondents were asked to consider what they thought would be best for their community. The community outcomes stated preference task consisted of two distinct parts: 1) a maximum difference conjoint (MDC) task, and 2) a discrete choice (DCE) task. Although they were separate questions, the MDC and DCE tasks are both described in this section because they were performed on the same profiles.

Before the two community outcomes stated preference tasks are discussed in detail, the issue of experimental design will be reviewed.

Experimental Design

A stated choice task requires respondents to assess distinct alternatives, which are described by a profile of attribute values (in this case the 'alternatives' were the outcomes of floodproofing strategies). These attribute values are discrete levels drawn from the entire range of values that the attribute could hypothetically span for a given problem. The community outcomes stated preference task involved nine attributes, each associated with one of the nine fundamental objectives (the same nine used in the objective rating task). Four discrete attribute levels were used to span the range of impacts associated with each attribute (Table 15).

Table 15 Attributes and levels for the community outcomes stated preference tasks.

Attribute (Objective)	**Levels**
Percentage of homes that will be greater than 2 stories tall in any given neighbourhood.	5, 15, 30, 45 %
Decrease (%) in the availability of single storey homes built at ground level.	5, 20, 40, 60 %
Number of administrative steps added to the building permit application process.	0,1, 3, 4 or more
Net amount that the government will spend to support floodproofing (AVERAGE/household)	\$0, \$5000, \$10000, \$15000
Net amount that homeowners will spend on floodproofing or levies (AVERAGE/household).	\$2000, \$10000, \$20000, \$30000
Percentage of homes that will be entirely floodproofed to the provincial standard.	5, 20, 40, 60 %
Average length of time that residents will be unable to occupy their homes after a major flood.	1, 2, 3, 4 months
Average disaster assistance the government will likely pay to each household after a major flood.	\$10000, \$25000, \$50000, \$75000
Average amount homeowners will likely pay to repair household damages after a major flood.	\$5000, \$15000, \$30000, \$40000

In a problem with a large number of attributes and levels, such as described in Table 15, it would be impossible to elicit preferences for the extremely large number of possible profiles that could be generated (e.g. to use a full factorial design). As a result, it is necessary to use an experimental design to systematically vary the attributes and levels to create hypothetical alternative profiles, in order to allow the efficient estimation of model parameters and the use of rigorous statistical tests (Louviere *et al.* 2000).

Early in survey development, it became clear that the values for the first two attributes, Aesthetics and Accessibility, were strongly related (e.g. as the number of homes greater than two stories tall increases there is a corresponding decrease in the available of single storey homes). As a result, the survey design used only one variable to describe the levels of both Aesthetics and Accessibility. The eight four-level attributes could be arranged into a total of $(4)^8$, or 65,536, possible profiles (a full factorial design).

Consequently, a resolution III fractional factorial[71] design plan was used, which allowed for the estimation of all main effects and selected two-way interaction effects (Raktoe *et al.* 1981). The design consisting of 64 choice sets (a choice set is a pair of attribute profiles e.g. Outcome A and Outcome B), which were blocked into 16 survey versions resulting in four choice sets per version.

The Community Outcomes Stated Preference tasks

In general, for each choice set, participants responded to the following series of evaluation questions. First, respondents completed a MDC task on Outcome A; then they completed a MDC task on Outcome B. Next, the same two outcomes (A and B) were compared in a choice task. Finally, the preferred outcome (A or B) was retained and compared to a base option in a second choice question.[72] The nesting of several evaluation tasks around one choice set took full advantage of the computerized presentation format.

In each survey, respondents evaluated six choice sets in a similar manner to that described above. The first two choice sets were simplified variations on the full choice sets in that they contained only five or six of the nine attributes. These two learning sets were not based on the experimental design plan described in the previous section but were the same for all survey versions (they were 'common sets'). Reducing the complexity of the first two questions allowed respondents to become comfortable with the question structure (e.g. the sequence of questions related to each choice set) and familiar with the information contained in the profiles (e.g. the detailed attribute descriptions and ranges) before they attempted a full profile question.

The first common choice set contained only five attributes: three describing social or community effects, and two describing expenses. The second common choice set

[71] A full factorial design involves all possible combinations of attribute values, while a fractional factorial design involves only a small sample or subset of the full factorial, which is selected to ensure that the main effects can still be estimated (Louviere *et al.* 2000).

[72] The base option was described as the outcome that could result in twenty years time if no floodproofing strategy was implemented in the community.

contained six attributes: two describing expenses, and four describing flood effects. Thereafter respondents evaluated the four full profile choice sets that were constructed using the experimental design. For the final two choice sets (the final two full profile sets), the MDC questions on outcomes A and B were omitted; respondents were only asked to answer the two choice questions (e.g. Outcome A vs. B, and previous choice vs. base).

4.4.2.2.2.1 Maximum Difference Conjoint task

In each MDC task, performed first on Outcome A and then on Outcome B, respondents were asked to select the one value that they thought was the most acceptable and then to select the one value that they thought was the least acceptable (Figure 12 and Figure 13). As mentioned previously, the MDC tasks were completed on two of the four full-profile choice sets resulting in a total of four MDC questions.[73] The task was kept uncluttered by removing the detailed attribute descriptions and ranges to a sidebar, which also gave respondents the option to 'hide' (or 'show') the information if they wished to simplify the information on the screen.

[73] There were also MDC questions in the common sets.

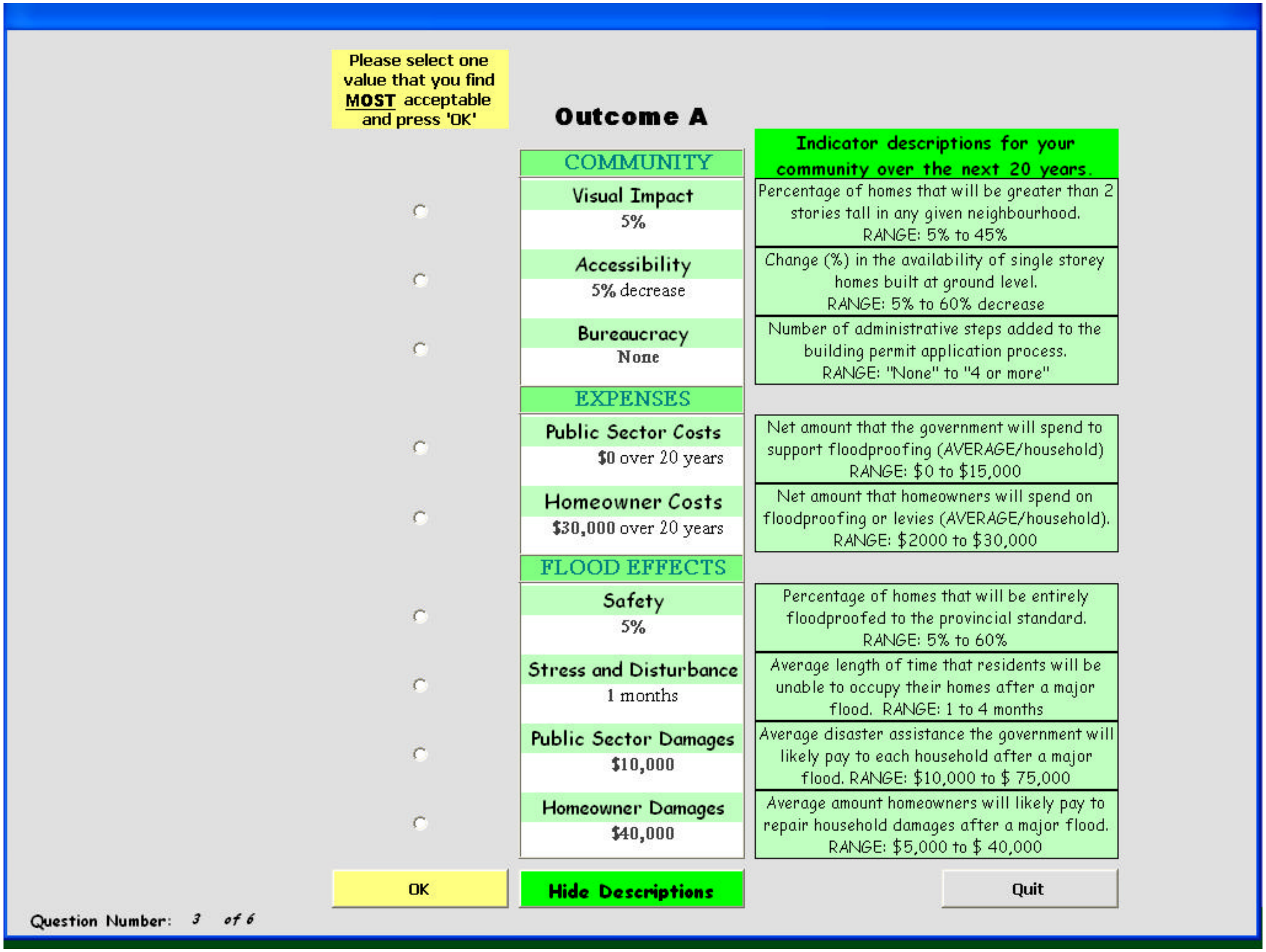


Figure 12 Community outcomes task example – MDC task Part I.
Respondents evaluate the nine attribute values in Outcome A and select the attribute value that they think is the most acceptable.

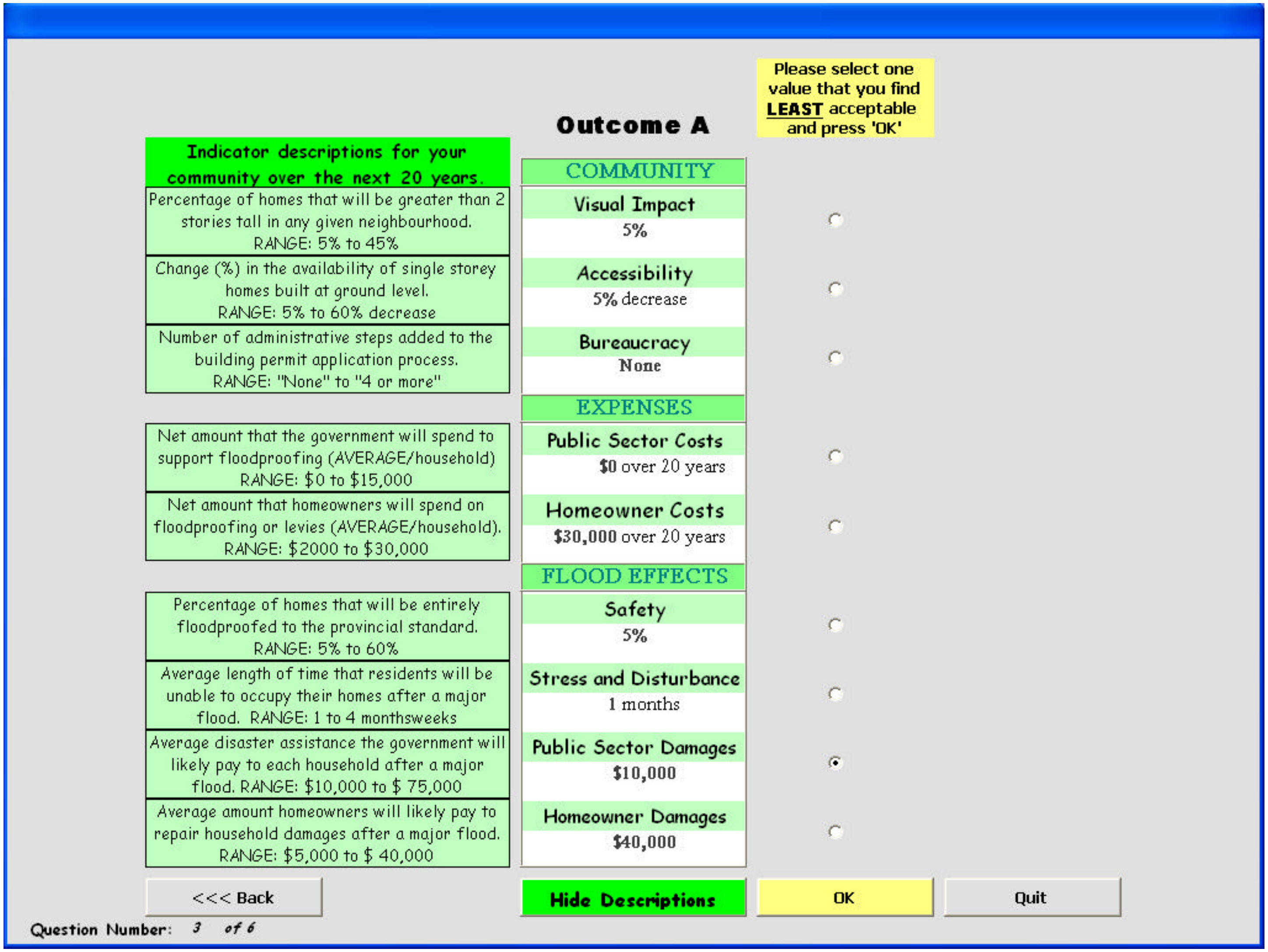


Figure 13 Community outcomes task example – MDC task Part II.
Respondents evaluate the nine attribute values in Outcome A and select the attribute value that they think is the least acceptable.

4.4.2.2.2.2 Community Outcomes Choice

After respondents completed the two MDC questions on Outcomes A and B respectively, the same two profiles were combined into one choice set (Figure 14). This sequence of questioning was helpful because it ensured that respondents had assessed each outcome in individual detail before being asked to perform the demanding choice task between two nine-attribute outcomes. In addition, respondents were reminded of their previous assessments of the positive and negative aspects of the two profiles with appropriate reminder statements.

After respondents had chosen between Outcome A and Outcome B (the 'Forced Choice'), they were presented with a second choice question: the choice between their previous selection and a base option ('Choice plus Base') (Figure 15). In this example, the participant has responded to the previous question by selecting Outcome B. As a result, Outcome B was retained and the respondent was then asked to choose between his or her previous selection (Outcome B) and the base option (the outcome of continuing current floodproofing policies).

Summary – The Community Outcomes Stated Preference Task

In summary, the community outcomes section contained six choice sets and each choice set was associated with up to four tasks. The sub-tasks for each of the first four questions included two MDC tasks (one on Outcome A and one on Outcome B), and two choice tasks (a first choice task between Outcomes A and B, and a second choice task between the respondent's previous selection and the outcome of continuing current floodproofing policies). The last two questions only included two sub-tasks each - the two choice questions as described above. The first two questions of the six were common to all survey versions and contained less than the full set of attributes, while questions three through six were full-profile. In total, the four full-profile questions included four MDC tasks, four choice tasks between Outcome A and B, and four choice tasks between the previous selection and the base option.

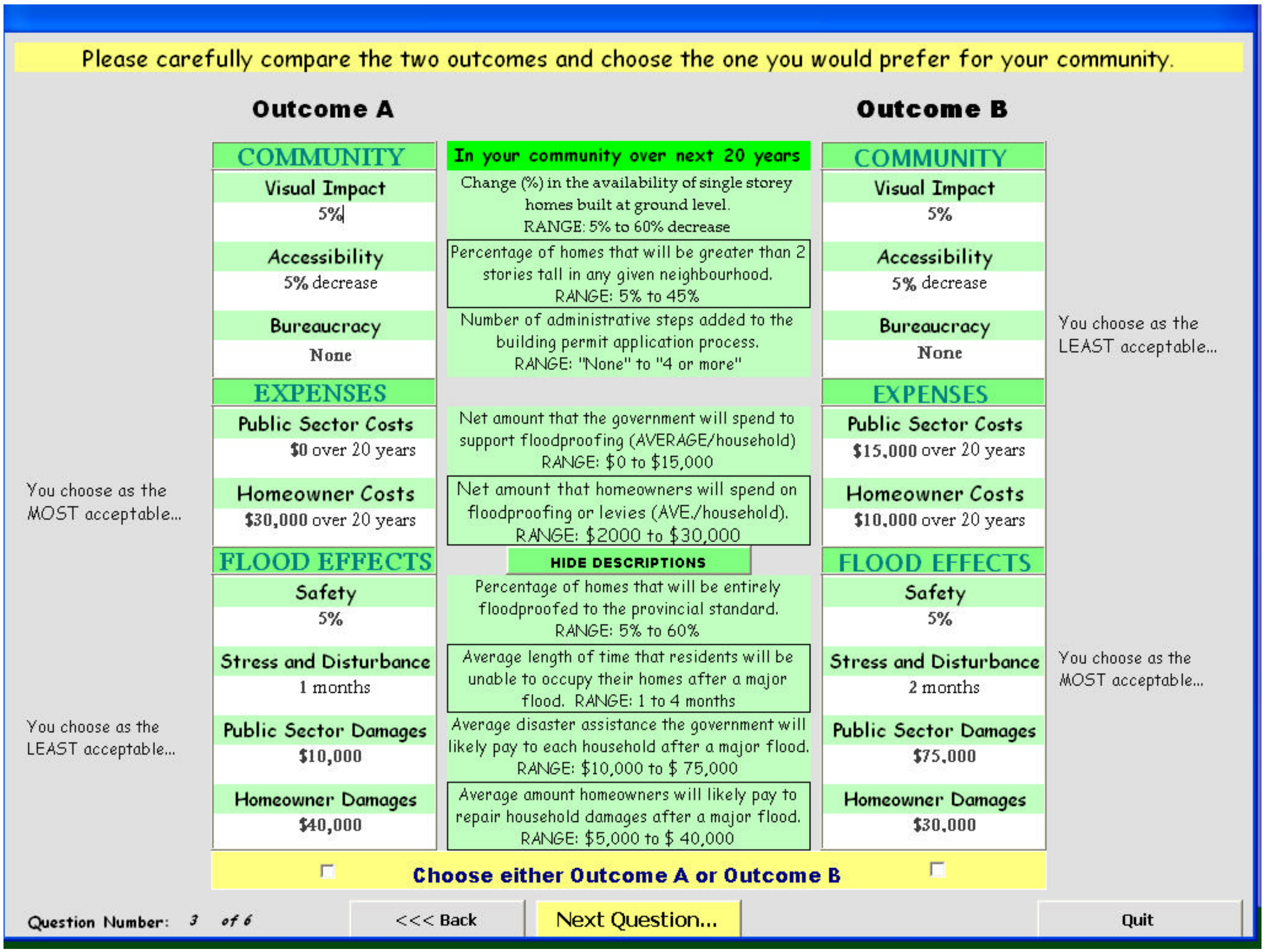


Figure 14 **Community outcomes task example – Choice Task I, Forced Choice. Respondents choose between Outcomes A and Outcome B**

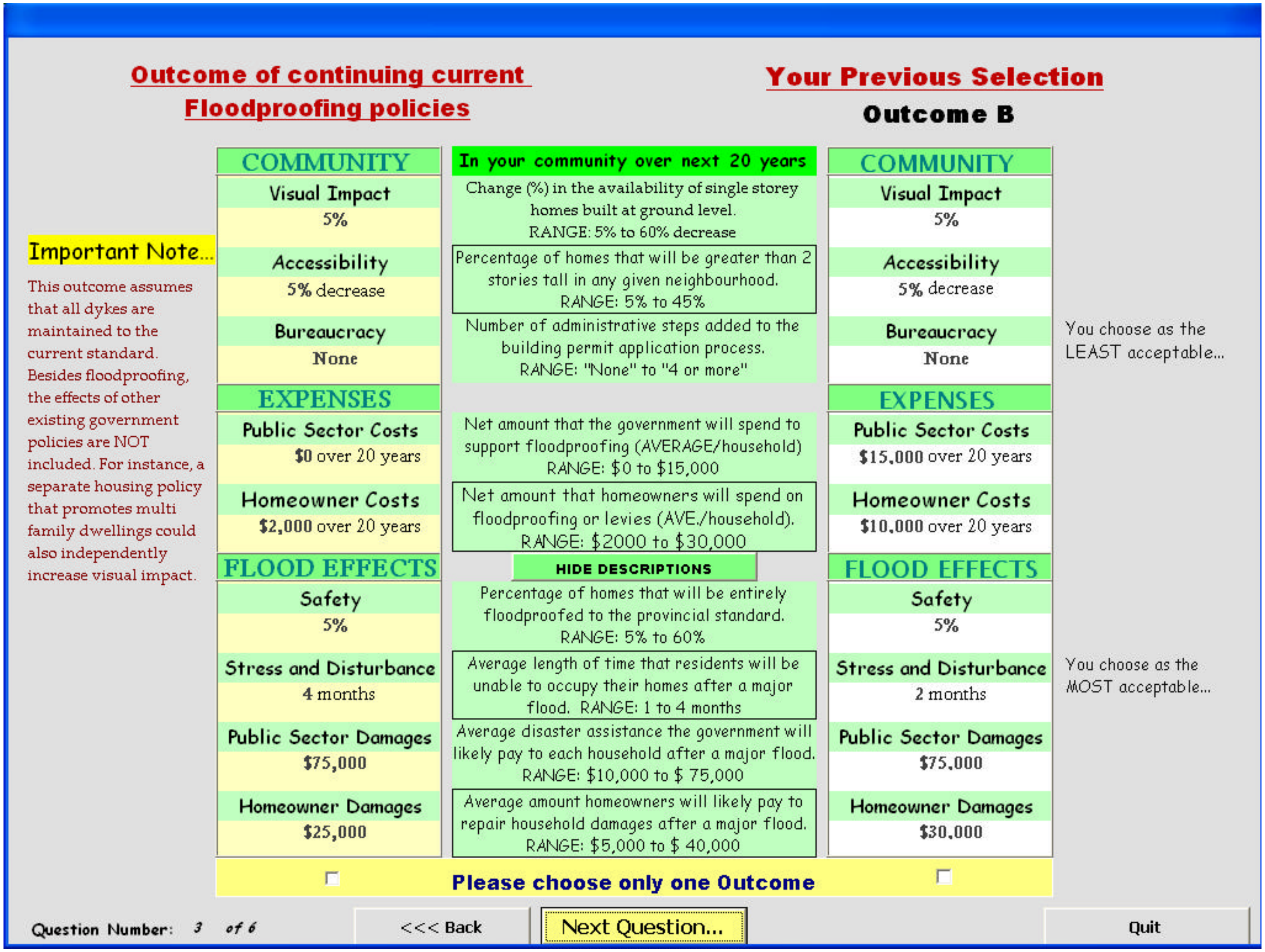


Figure 15 Community outcomes task example – Choice Task II, Choice plus Base.
Respondents choose between their previously selected outcome and the base outcome of continuing current floodproofing policies.

4.4.2.2.3 Stated Preference Task II - Personal Floodproofing Choice

The second discrete choice task in the survey focused on individual preferences for floodproofing options. The purpose of this final choice task was to obtain information on potential floodproofing adoption rates for various floodproofing strategies, which was supplemental information that would be used in the impact assessment models (4.3). Instead of outcomes for the community that could occur in 20 years time, the respondent was presented with three different floodproofing options that could apply to their own home (e.g. Elevation, Wet floodproofing and No floodproofing).

<u>**Experimental Design**</u>

The three floodproofing options for the personal floodproofing decision choice model were described by a number of salient attributes, which are described in Table 16.

Table 16 Attributes and levels for the personal floodproofing decision choice task.

	Floodproofing Option		
Attribute	**Elevation**	**Wet Floodproofing**	**None**
Costs – Estimated average costs to floodproof one existing moderately sized home ($1000s)	30, 40, 40, 50*	10, 15, 15, 20*	N/A
Damages – Estimated structural damage costs to an average home after a major flood which breaches the dykes ($1000s)	0.5, 5, 5, 10*	20, 35, 35, 50*	30, 60, 85, 100*
Inconvenience – Estimated minimum time required before home can be reoccupied after a major flood.	1, 2, 2, 3 weeks	1, 2, 2, 3 months	4 months average [Fixed]
Support – Municipal tax break or one time grant offered to owners of floodproofed homes. (%/yr if tax break, $1000s if grant)	0, 5, 10, 15	Same as Elevation	N/A
Support Type (1 = Tax Break, 2 = Grant)	1,2	Same as Elevation	N/A
Penalties – Levy applied to homes that have not been floodproofed ($/yr)	N/A	N/A	0, 100, 200, 300
Compensation – Percentage of flood damage repair costs covered by disaster financial assistance (%)	80% [Fixed]	80% [Fixed]	50, 60, 70, 80

* Star indicates the levels selected (default average values) when the task could not be individualized for the respondent's particular situation (see discussion below).

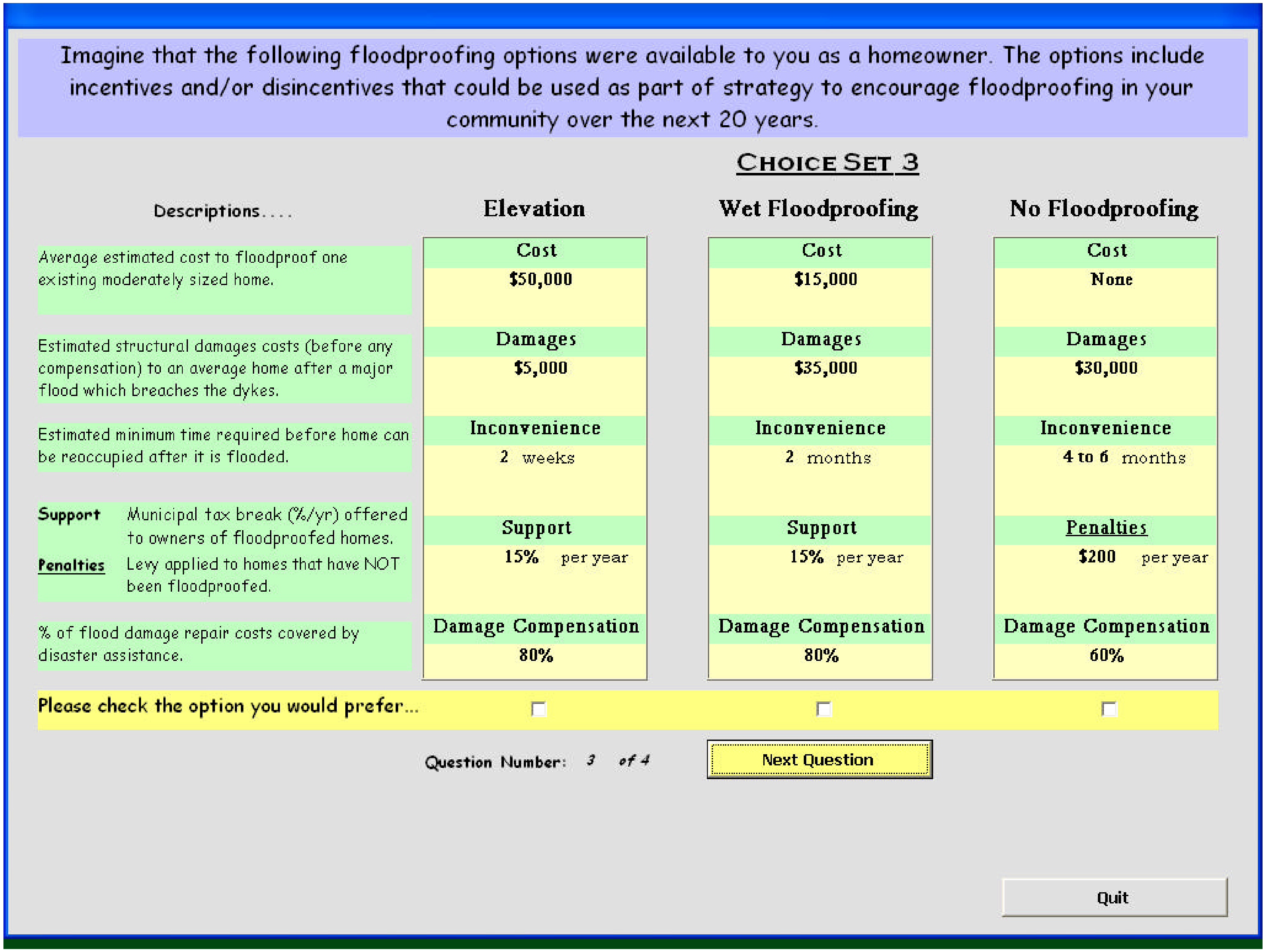
The attributes included in the personal floodproofing decision task were those expected to be important to a homeowner when deciding whether or not to floodproof his or her home. As illustrated by the distinctive labels (e.g. Elevation, Wet Floodproofing) associated with each alternative option, the personal floodproofing choice task was alternative specific; many of the attributes were unique to each alternative.[74] For instance, elevation cost is clearly a different attribute from wet floodproofing costs (the former being associated with significantly larger cost values). The values of the cost and damage attributes were individualized for each floodproofing option and for each respondent whenever possible. For this purpose, homeowners were first asked a series of questions about their home such as the estimated square footage and foundation type. This information was then used to calculate individualized estimates for the floodproofing costs and flood damages associated with each floodproofing option. If the respondent could not supply all the appropriate information, then average pre-calculated values for the attribute levels were used instead.

For the individual floodproofing choice task, a resolution III fractional factorial design plan was used, which allowed for the estimation of all main effects and selected two-way interaction effects (Raktoe *et al.* 1981).   Once again, 64 choice sets were developed and blocked into 16 survey versions resulting in four full profile choice sets per version.

The Personal Floodproofing Choice Task

Given the options of Elevation, Wet Floodproofing, and No Floodproofing, participants were asked to choose which option they would prefer (Figure 16) and then to indicate the priority they would give to completing such a project (e.g. respondents were asked what time frame they would allocate to such a project). Each respondent was asked to complete four of these choice sets.

[74] The 'alternative specific' nature of options in personal floodproofing choice question may be contrasted with the generic nature of Outcomes A and B in the community outcomes choice task.



Imagine that the following floodproofing options were available to you as a homeowner. The options include incentives and/or disincentives that could be used as part of strategy to encourage floodproofing in your community over the next 20 years.

CHOICE SET 3

Descriptions....	Elevation	Wet Floodproofing	No Floodproofing
Average estimated cost to floodproof one existing moderately sized home.	Cost: $50,000	Cost: $15,000	Cost: None
Estimated structural damages costs (before any compensation) to an average home after a major flood which breaches the dykes.	Damages: $5,000	Damages: $35,000	Damages: $30,000
Estimated minimum time required before home can be reoccupied after it is flooded.	Inconvenience: 2 weeks	Inconvenience: 2 months	Inconvenience: 4 to 6 months
Support Municipal tax break (%/yr) offered to owners of floodproofed homes. **Penalties** Levy applied to homes that have NOT been floodproofed.	Support: 15% per year	Support: 15% per year	Penalties: $200 per year
% of flood damage repair costs covered by disaster assistance.	Damage Compensation: 80%	Damage Compensation: 80%	Damage Compensation: 60%
Please check the option you would prefer...	☐	☐	☐

Question Number: 3 of 4

Next Question

Quit

Figure 16 Personal floodproofing discrete choice task example.
Respondents choose between three floodproofing options (Elevation, Wet Floodproofing, and No Floodproofing).

4.4.2.2.4 Supplementary Questions and Material

Introductory Questions

The purpose of the introductory questions (Figure 17) was to explore respondents' bonds to their community, to gauge their personal experiences with flooding, and to identify relative levels of concern regarding flooding and other natural hazards. Moreover, respondents who were inexperienced with computers got a chance to practice using the mouse to click on checkboxes and to use the slider rating-tool for the natural disaster rating-question. The natural disaster rating-question was used to gauge how respondents perceived various threats to their home, and to give respondents some perspective on issue of flood risk by reminding them of other hazards.

Demographic Questions

The purpose of the final demographics section of the survey (Figure 18) was to collect some socio-demographic information about the respondents.

Oral Presentations

Each survey session was also accompanied by two group presentations, both of which have been included on a CD in Appendix D. The introductory presentation, which opened each survey session, encouraged participants to start thinking about the issues and concerns associated with the floodproofing and flood management in their community. The presentation provided an accessible and factual review of floodproofing issues and flood management concerns in the lower Fraser Valley. In addition, the first presentation introduced participants to key terms and concepts that would be used throughout the survey.

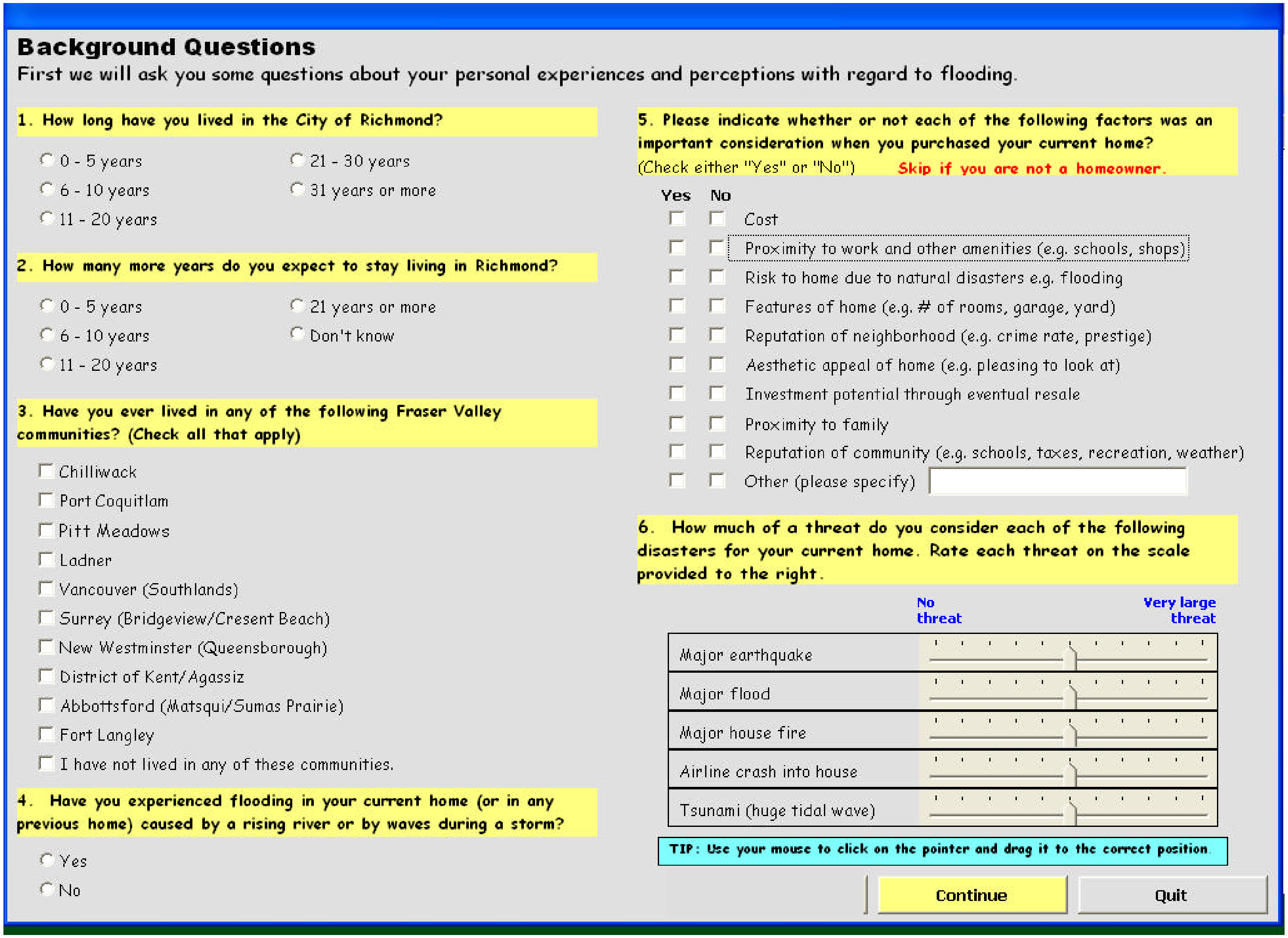
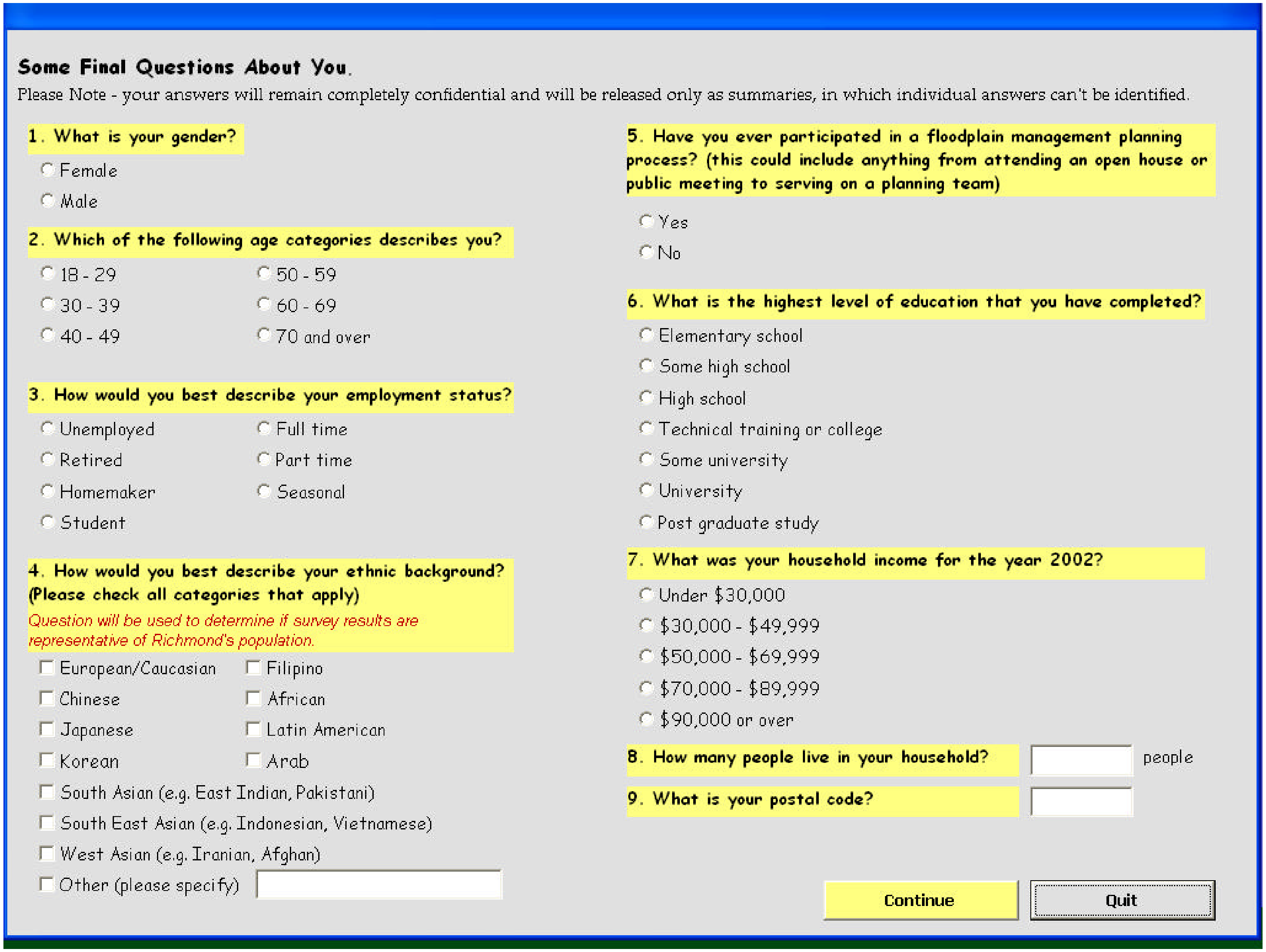


Figure 17 Introductory survey questions.



Some Final Questions About You.

Please Note - your answers will remain completely confidential and will be released only as summaries, in which individual answers can't be identified.

1. What is your gender?

Female
Male

2. Which of the following age categories describes you?

18 - 29
30 - 39
40 - 49
50 - 59
60 - 69
70 and over

3. How would you best describe your employment status?

Unemployed
Retired
Homemaker
Student
Full time
Part time
Seasonal

4. How would you best describe your ethnic background? (Please check all categories that apply)

Question will be used to determine if survey results are representative of Richmond's population.

European/Caucasian
Chinese
Japanese
Korean
Filipino
African
Latin American
Arab
South Asian (e.g. East Indian, Pakistani)
South East Asian (e.g. Indonesian, Vietnamese)
West Asian (e.g. Iranian, Afghan)
Other (please specify)

5. Have you ever participated in a floodplain management planning process? (this could include anything from attending an open house or public meeting to serving on a planning team)

Yes
No

6. What is the highest level of education that you have completed?

Elementary school
Some high school
High school
Technical training or college
Some university
University
Post graduate study

7. What was your household income for the year 2002?

Under $30,000
$30,000 - $49,999
$50,000 - $69,999
$70,000 - $89,999
$90,000 or over

8. How many people live in your household? people

9. What is your postal code?

Continue
Quit

Figure 18 Socio-demographics questions.

The second presentation was positioned after the introduction and objective rating sections and marked the transition point in the survey from the easy introductory questions to the more challenging stated preference tasks. Using an example, the second presentation provided a detailed visual 'walk-through' of the sequence of steps required to answer the MDC and choice questions in the community outcomes stated preference section of the survey. The presentation allowed the survey to be free of lengthy and complicated instructions.[75]

4.4.2.3 The Survey Platform

Although the survey was initially approached as a pen and paper task, early in the development process it became clear that a computerized format would facilitate the presentation of the multifaceted sets of questions and allow laypersons to be efficiently guided through the tasks. In addition, a computer platform, allowed instantaneous personalization of key sections of the survey based on information provided by the respondent. Furthermore, the programmed survey provided a responsive interactive environment for the participant. For example, the survey displayed helpful hints when necessary, gave reminders of previous responses and allowed the user to select a preferred language (e.g. English or Chinese). Finally, the appropriate survey version could be instantaneously loaded using information provided by the respondent.

The author programmed the entire survey using the Microsoft Visual Basic programming language. The object-oriented focus of this programming language was convenient as it allowed the author to produce a straightforward "windows" type program. Each page in the survey was first graphically designed as a windows "form" then code was added to each form to control the appearance and behaviour of the form and to perform various actions when objects on the form were manipulated by the respondent, such as checking a textbox or pushing a button.

[75] Evidently the presentations were successful since few participants required assistance with the stated preference questions.

4.4.2.4 Survey development issues

Survey development began in January 2003 and proceeded until June 2003. Through countless revisions and additions, the survey evolved from a simple pen and paper task to a sophisticated interactive computerized instrument with automatic data storage and availability in two different languages.

The Survey Environment

While early test versions of the survey were designed for independent survey administration via the Internet, it became clear from early pre-tests that the necessary written instruction material associated with such an instrument created an unreasonable burden on respondents. Participants found it much easier to comprehend the same information when a capable speaker guided them though a visual presentation. As a result, the survey was developed for a group environment in which approximately 10 to 15 people would complete the survey at the same time. The group environment also provided a consistent survey experience for each respondent and ensured that computer access (or lack of) did not create a sampling bias.

Data Storage

Since the survey was computerized, accurate and reliable data recording and storage processes were imperative considerations in the development of the survey. Selections made by the participant in response to information presented on the computer screen had to be recorded and stored in the computer's memory to be later retrieved and compiled by the analyst. Upon launching the survey, respondents were asked to enter their personal survey number (provided by the survey administrators). Subsequently, variables were created for each survey question so that the respondents' answers could be saved. For each question, the respondent's choice was associated with the appropriate variable as a numerical code and/or text data. At the end of the survey, the values of the survey variables were recorded in a comma delimited text file along with the respondent's personal survey number and saved to the hard disk. At the end of each survey session, the files were backed up and saved to a master file.

Multicultural access

As noted in section 2.5, the City of Richmond is a highly integrated community with a large diversity of cultural backgrounds. In addition to English, a large proportion of the population speaks the Chinese language. In order to ensure that the survey was accessible to as many people as possible, the survey was designed so that respondents could choose to take the survey in either English or Chinese.

4.4.2.5 Pre - testing

The survey was tested numerous times with various audiences to determine how participants would respond to the survey. In addition to many tests with staff and students at the School of Resource and Environmental Management at Simon Fraser University, three sessions were completed with residents from the City of Richmond. The first pre-testing session was conducted with eight staff members from various departments at Richmond City Hall. The second and third pre-testing sessions were completed with seven volunteers from a local non-profit organization. The survey testing sessions contributed immensely to clarifying individual questions as well as to simplifying and adjusting the overall structure of the survey from the perspective of a lay audience. Using feedback from the testing sessions, the survey was significantly revised until respondents of all ages and abilities could comprehend and complete the entire survey in 45 – 60 minutes (including the presentations).

4.4.2.6 Sampling and Survey Administration

4.4.2.6.1 Target Populations

The primary intent of the survey was to explore homeowner preferences for the outcomes of floodproofing strategies in historic settlement areas. The scope of the project was limited to strategies directed at existing single-family dwellings in order to exclude the complications presented by strata ownership and other alternative ownership arrangements. As a result, the primary target population for the survey consisted of owners of single-family detached homes living in the City of Richmond. To a lesser extent, owners of other housing types and some renters were also accepted, since these individuals could potentially buy single-family detached homes in the future, but these participants only represented a minor proportion of the sample. It should be noted that all respondents lived in a designated floodplain area.[76]

4.4.2.6.2 Recruiting Methods

Since the ultimate aim of the research was to investigate the application of complementary decision tools to a flood management problem, the research was more exploratory than confirmatory, which made obtaining a truly random sample less important. In addition, since identifying random samples is expensive and time consuming, a convenient sampling method was used that was practical given the limitations inherent with a Master's research project. Consequently, the recruiting approach used for the survey was more practical than systematic.

Non-profit organizations operating in the City of Richmond were offered $20 for every survey participant that they could provide, given the eligibility restrictions described in the previous section. Contacts were made with as many non-profit groups as possible and included sports teams, church groups, youth groups and other charitable organizations. Appendix E provides a list of the non-profit groups who participated in the survey. Each non-profit group recruited its own participants and booked meeting rooms for mutually agreeable times. This recruiting method was efficient since incentive money paid for completed surveys - almost 100% of participants who arrived for a survey session ended up completing the entire survey. In addition, the survey benefited the community by leaving the money with local charitable organizations.

[76] Another interesting target group for this survey would have been individuals living outside of the floodplain, although the survey would have had to be modified to accommodate respondents who were not at risk of flooding. Homeowners living outside the floodplain would likely have a different view regarding how costs and damages due to flood risk should be shared between governments and individuals inhabiting the floodplain, especially if cost sharing programs would result in higher taxes for those not at risk of flooding.

4.4.2.6.3 Survey Administration

Since the survey was computerized, the decision was made to rent laptop computers. The use of laptops provided control over the computing environment and a mobility, which could not be achieved by renting space in computer labs. The laptops allowed the survey sessions to be administered in any location with suitable room space and power supply, which in all cases were supplied free by the hosting non-profit group. The computers were rented for a total of one and a half months in the summer and fall of 2003.

Upon arriving at a survey session, each respondent was given a handout that provided important information such as their personal survey number, the purpose of the research, and information about research ethics (Appendix F). As noted previously, the session began with an introductory presentation given by the researcher. After the first presentation, respondents spent approximately ten minutes completing the first two 'pages' of the survey on the computer. After reconvening briefly as a group for the second presentation, respondents were free to complete the rest of the survey at their own pace.

4.4.2.7 Survey Data Analysis

A total of 221 responses were obtained and compiled into a master spreadsheet file. Subsequently the data were recoded for analysis as appropriate. The primary statistical package used to analyse the stated preference data was LIMDEP (Greene 1998). Other statistical procedures were performed in Excel and SPSS. The primary results and analysis of the survey data will be presented in Chapter 5 .

4.5 Step 4 - Comparison and Evaluation of Alternatives

The final stage in a decision analysis process is the comparison and evaluation of alternatives. In this phase, all the information derived in the previous three steps is combined to derive an overall evaluation of each alternative. Specifically the alternatives developed in step 1 are evaluated using the objectives (also developed in step 1), by combining the multi attribute impact assessment information (step 2) with the preference information for objectives and attributes (step 3). In line with the comparative and exploratory nature of this research project with respect to the complementarities of multi attribute decision analysis and stated preference modelling, two different approaches were used in the evaluation and comparison step: 1) decision analysis and 2) discrete choice analysis. While the next chapter will present most of the analysis completed for step 4, the following sections will highlight the primary methods.

4.5.1 Evaluation using a Decision Analysis Approach

The decision analysis software package, Criterium Decision Plus (CDP)[77], was used to evaluate and rank the alternative floodproofing strategies. Criterium Decision Plus is a user-friendly decision analysis software provided by InfoHarvest Inc that is capable of assisting in all steps of the decision making process, from problem structuring to evaluation of alternatives. The software allows the user to choose between two different decision analysis techniques, AHP and SMART, for rating alternatives by attribute (e.g. providing the multi attribute impact assessment), for weighting attributes, and for evaluating the alternatives.[78] Both of the decision analysis methods available in CDP rely on simple additive summation of attribute values and weights to derive the overall

[77] Criterium Decision Plus is a product of InfoHarvest Inc., PO Box 25155, Seattle, WA, 98125-7150. As of February 2004, InfoHarvest provides a limited version of CDP on their website at www.infoharvest.com.

[78] As mentioned in Chapter 3 , the analytical hierarchy process (AHP) is a technique developed by Saaty (1992) that relies heavily on full pairwise comparisons between attributes for performing weighting and for scoring attributes and alternatives. The simple multi attribute rating technique (SMART) is a practical implementation of multi attribute utility theory (von Winterfeldt and Edwards 1986).

score for each alternative (Yoe 2002).[79] In CPD, linear, exponential, or custom defined value functions can be defined for each attribute.

Since the attribute weighting and impact assessment for the alternatives was completed independently, the decision analysis software was used solely for the purpose of evaluation and analysis of alternatives. Consequently, for this project, the benefit of using a decision analysis package was the opportunity to use CDP's tools for completing various sensitivity and uncertainty analyses on the results.

To complete the final analysis, the preference information (e.g. weights and value functions) of flood managers and homeowners, and the impact assessment information for the nine alternatives were entered into Criterium Decision Plus. Subsequently, the alternatives were scored and ranked from two perspectives: homeowners and flood managers. A number of additional analyses were also performed including exploring uncertainty in decision scores, sensitivity by weights, contributions to scores by criteria, and contributions to uncertainty (Chapter 5, section 5.2.2).

4.5.2 Evaluation using a Discrete Choice Modelling Approach

The second available method to evaluate the alternative floodproofing strategies is to use the results of the community outcomes discrete choice experiment for comparing alternatives. The multinomial logit model (Equation 4) can be used to calculate overall probabilities of choice or the proportion of respondents expected to choose a given alternative (e.g. the 'market share'), if that alternative can be described by the attributes and levels used in the choice experiment.[80] The required calculations can be easily accomplished using Microsoft Excel or within a program that runs a decision support system (DSS) (e.g. if a more formal tool is required for distribution to experts, managers, or the public). A DSS is often accompanied by a graphical user interface, which can be

[79] It is not necessary to use a decision analysis software to perform these calculations since they can be easily reproduced using any standard spreadsheet program

[80] To calculate market shares, the individual part worth utility estimates derived from the choice model and the descriptions of the alternatives (using the attribute levels) are substituting into the multinomial logit equation.

developed using a programming language such as Microsoft Visual Basic. Usually within a DSS, the user can compare two or more alternatives at once. In this case, the user would construct the alternatives he or she is interested in evaluating, using the appropriate attribute values, and the program would calculate the expected market shares.

A decision support system was built using the part-worth utility estimates derived from the analysis of the community outcomes discrete choice task. The nine alternatives were evaluated by entering the multi attribute impact assessment associated with each alternative into the DSS to derive a market share for each alternative. As will be discussed in section 5.2.3, the results were then used to rank competing alternatives.

Chapter 5 Results and analysis

This chapter will present the results of Step 3 - Preference Assessment and Step 4 - Comparison and Evaluation of Alternatives. In addition, the final results of Step 2 (Impacts of Alternatives) will be briefly reviewed.

5.1 Step 3 - Preference Assessment

Two different perspectives were used in the preference assessment phase: floodplain managers and homeowners. Consequently, the preference assessment section will be sub-divided into the results of the expert and public preferences tasks.

5.1.1 Expert Values – The Swing Weighting Preference Task

Of the managers who had participated in the floodproofing workshops, three agreed to complete the swing weighting objective evaluation task. As discussed in section 4.4.1.1, the managers were first asked to rank and then rate the listed objectives and attributes. Using the rating scores, the relative importance weights for each objective were derived.[81] The results for the three managers are shown in Table 17.[82]

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[81] The weights were derived using the formula $W_i = \frac{Rt_i}{\sum_{i=1}^{n} Rt_i}$, where W_i is the relative weight for attribute *i*, *Rt* is the rating for attribute *i*, and *n* is the total number of attributes (Jia *et al.*1998).

[82] For reasons of confidentiality the identity of the three participants will not be revealed.

Table 17 Results of the floodplain managers' swing-weighting task.

Attribute	Respondent 1			Respondent 2			Respondent 3			Aggregate Weights		
	Rk	Rt	W	Rk	Rt	W	Rk	Rt	W	Average	Min	Max
Aesthetics	9	10	0.02	9	10	0.02	9	30	0.05	**0.03**	0.02	0.05
Accessibility	8	10	0.02	8	20	0.04	8	35	0.06	**0.04**	0.02	0.06
Bureaucracy	7	40	0.08	7	30	0.06	7	40	0.07	**0.07**	0.06	0.08
Public Sector Costs	5	50	0.10	6	60	0.12	1	100	0.18	**0.13**	0.10	0.18
Homeowner Costs	6	45	0.09	5	50	0.10	3	75	0.14	**0.11**	0.09	0.14
Safety	1	100	0.19	1	100	0.20	6	60	0.11	**0.16**	0.11	0.20
Stress and Disturb.	4	85	0.16	4	70	0.14	2	80	0.14	**0.15**	0.14	0.16
Public Sector Damages	2	95	0.18	2	90	0.18	4	70	0.13	**0.16**	0.13	0.18
Homeowner Damages	3	90	0.17	3	80	0.16	5	65	0.12	**0.15**	0.12	0.17

Rk = Rank from 1 to 9, Rt = Rating from 0 to 100, W = calculated weight

As shown in Table 17, two of the managers had very similar preferences. These two individuals placed the highest relative importance on the attributes for Safety and Public Sector Damages followed by Homeowner Damages, while both cost attributes were deemed of average relative importance. In contrast, the third manager placed the highest relative importance on Public Sector Costs, followed by Homeowner Costs, and Stress and Disturbance, while the damage attributes were given average importance. Overall, the managers' preference is to reduce negative future flood effects by minimizing damages, and stress and disturbance, while maximizing safety.

5.1.2 Public Values – The Multi Attribute Stated Preference Survey

The results of the public values survey will be presented in six sections: objective rating task, community outcomes discrete choice task, maximum difference conjoint task, personal floodproofing decision task, and general/miscellaneous.

5.1.2.1 Objective Rating Task

Respondents were asked to rate each of the nine objectives developed in the problem-structuring phase (refer to Table 3 – Descriptions column) on a scale of 0 to 10. Frequency distributions for the responses are graphed in Figure 19, while the average ratings are summarized in Table 18.

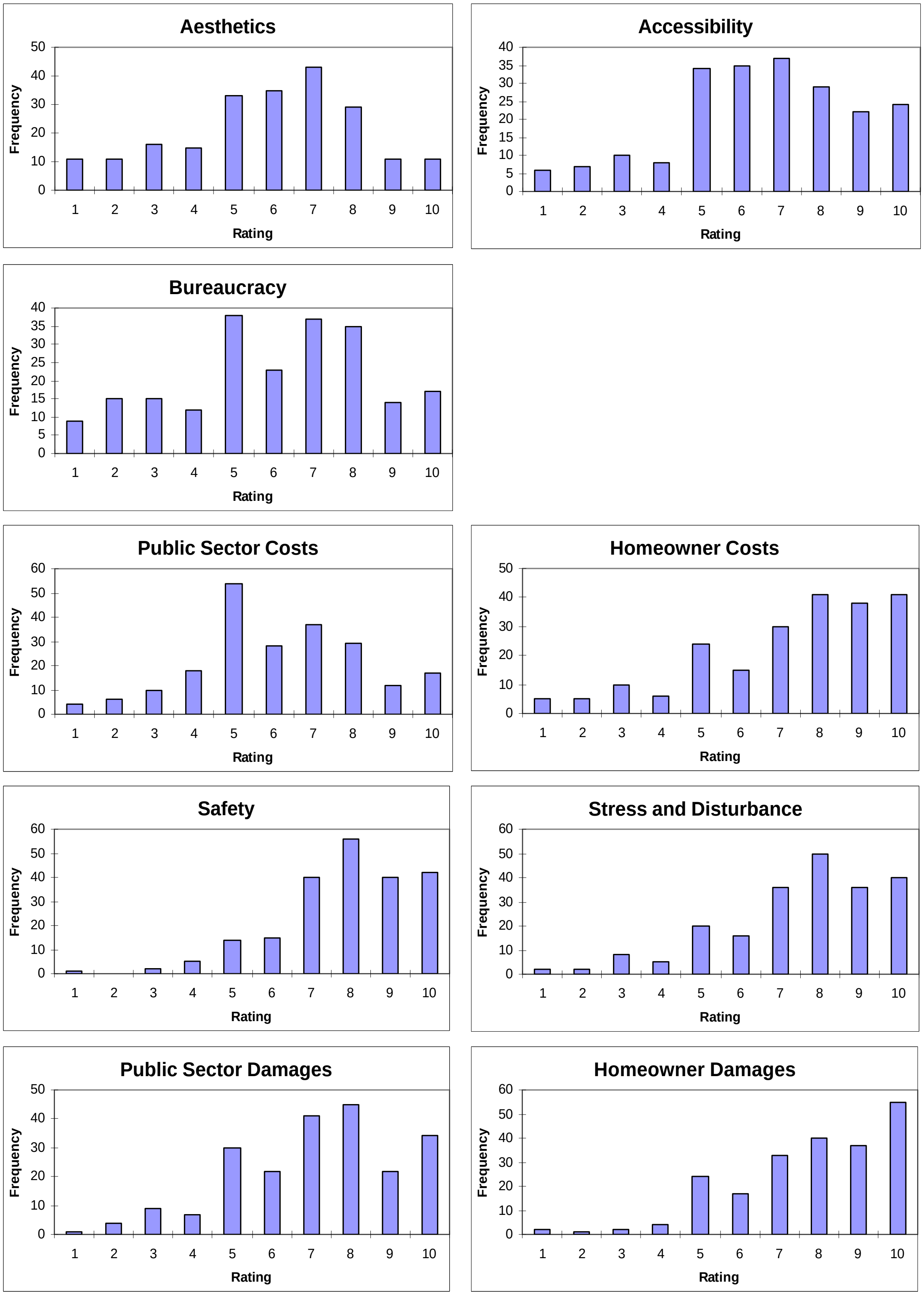

Figure 19 Frequency distributions of response data for the objective-rating task.

Table 18 Results of the objective-rating task – average ratings and standard deviations.

Attribute	Mean Rating	Standard Deviation
Safety	7.90	1.7
Homeowner Damages	7.83	1.9
Stress and Disturbance	7.57	2.0
Homeowner Costs	7.29	2.4
Public Sector Damages	7.14	2.1
Accessibility	6.54	2.3
Public Sector Costs	6.15	2.1
Bureaucracy	6.01	2.5
Aesthetics	5.82	2.3

As shown by the predominant skew to high numbers in the distributions in Figure 19 and the fact that all the average rating were greater than 5 (Table 18), respondents tended to give high importance ratings for all attributes, which is not surprising since a simple Likert rating task does not force respondents to make any trade-offs (e.g. respondents could indicate that all nine objectives were extremely important).[83] Despite this tendency, there are still clear indications of attribute preference in the data. The top four objectives were Safety, Homeowner Damages, Stress and Disturbance, and Homeowner Costs, an ordering which may be contrasted to the managers' aggregate preference order of Safety, Public Sector Damages, Homeowner Damages, and Stress and Disturbance.

5.1.2.2 Stated Preference Task I – Community Outcomes

5.1.2.2.1 Community Outcomes Choice Task

In the community outcomes choice task, respondents were faced with two choice questions. The first was a forced choice between two hypothetical outcomes of potential floodproofing strategies (labelled Outcome A or Outcome B). The second question asked respondents to choose between their previous choice (either A or B) and the base alternative, which was described as the outcome of continuing current floodproofing policies. Analysis was conducted in two parts to reflect the two choice questions seen by respondents. Consequently, the results will be presented using two headings, namely "Forced Choice" and the "Choice plus Base". Choices were aggregated over all

[83] The tendency for ratings to be toward the top end of the scale often occurs with Likert style rating questions (Cohen 2003).

respondents and categorized by version and by question number. For the Forced Choice analysis, choice frequencies for Outcomes A and B were calculated. While for the Choice plus Base analysis, choice frequencies were calculated for Outcome A, Outcome B, and the Base option.

Similar analyses were performed for both choice questions. The experimental design was coded in two different ways for use with the aggregate choice frequencies. The basic model used effects coding (see Louviere *et al.* 2000, pg. 100), which uniquely identifies each discrete attribute level by a series of ones, negative ones, and zeros. In addition, since all the attributes were specified using variables with continuous numerical scales, a second model was developed in which the attributes were modelled with linear and quadratic codes (Louviere *et al.* 2000, pg. 268).

For both the Forced Choice and Choice plus Base questions, the two model types were run using maximum likelihood estimation and a discrete choice multinomial logit model. For the effects coded models, the output was a series of part-worth utility values for the three of the four levels for each attribute (the value for the fourth level could be calculated as the negative sum of the other three levels). For the linear and quadratic coded models, utility coefficients were derived that described linear and quadratic value functions for each attribute. For example, the linear coefficients are the slopes of linear value functions describing the utility of each attribute as attribute level increases.

The Forced Choice

The part-worth utility coefficients including standard error estimates, t-values, and p-values derived from the results of the Forced Choice task are described in Table 19.

Table 19 Community Outcomes Choice Task I, Forced Choice – Results (multinomial logit model and effects coding).

Model Statistics:					
Log Likelihood Function (with coefficients) – L(ß)*			-483.09		
Log Likelihood Function (no coefficients) – L(0)**			-607.20		
MacPherson's rho-squared (?^{2})***			0.20		
rho-squared Adjusted****			-0.31		
Number of respondents			221		
Attribute Name	**Level**	**Part-worth Utility**	**Standard Error**	**t-values**	**p-values**
Aesthetics/	1	0.125			
Accessibility	2	0.130	0.132	0.990	0.322
	3	-0.156	0.125	-1.246	0.213
	4	-0.100	0.155	-0.644	0.520
Bureaucracy	0	0.030			
	1	0.165	0.109	1.517	0.129
	3	-0.177	0.118	-1.502	0.133
	4	-0.019	0.115	-0.166	0.868
Public Sector	0	-0.212			
Costs	5000	-0.020	0.103	-0.193	0.847
	10000	0.054	0.094	0.570	0.569
	15000	0.178	0.103	1.723	0.085
Homeowner	2000	0.524			
Costs	10000	0.285	0.100	2.851	0.004
	20000	-0.280	0.103	-2.718	0.007
	30000	-0.529	0.103	-5.150	0.000
Safety	5	-0.797			
	20	-0.286	0.135	-2.120	0.034
	40	0.436	0.121	3.614	0.000
	60	0.647	0.151	4.289	0.000
Stress and	1 Month	0.124			
Disturbance	2 Month	0.107	0.098	1.089	0.276
	3 Month	0.004	0.102	0.037	0.970
	4 Month	-0.234	0.118	-1.987	0.047
Public Sector	10000	-0.429			
Damages	25000	-0.078	0.110	-0.711	0.477
	50000	0.215	0.115	1.863	0.062
	75000	0.293	0.139	2.100	0.036
Homeowner	5000	0.701			
Damages	15000	0.397	0.126	3.165	0.002
	30000	-0.479	0.114	-4.191	0.000
	40000	-0.620	0.113	-5.472	0.000
Intercept		0.066	0.082	0.812	0.417

* All explanatory variables are included (e.g. the attribute levels).

** No explanatory variables included, just choice of alternative.

*** Likelihood-ratio index - a goodness of fit measure for log likelihood estimation (refer to Louviere *et al.* 2000 pg. 54).

**** The likelihood-ratio index adjusted for the degrees of freedom in the model (Louviere *et al.* 2000).

The results for the Aesthetics and Accessibility objectives are shown jointly because they were treated as collinear in the design (see Chapter 4 , section 4.4.2.2.2) which meant that only one joint estimate of the utility parameters could be developed for both attributes (e.g. the estimates for these two attributes are perfectly confounded and thus cannot be separated in the choice analysis).[84]

The intercept for the forced choice model was positive but insignificant, which means that Outcome A was not significantly preferred over Outcome B (or B over A). Since the experimental design was balanced for this model, a preference for either outcome should not occur unless there is some type of bias in the results. The p-values for the attribute level coefficients in the model showed varying degrees of significance.

The statistics provided at the top of Table 19 provide some indication of model fit. For example, if the attribute values contribute to explaining the choices made by respondents then the log likelihood value for the model with the explanatory values included, L(ß), should be greater than the log likelihood value calculated with the explanatory variables excluded, or set to zero, L(0). For this model, it is clear that L(ß) is greater than L(0) indicting that the attribute values contribute to explaining choice. In addition, the rho-squared value can be interpreted as a type of psuedo-R^2, which measures the goodness of fit of the MNL model (R^2 values are calculated to indicate goodness of fit for ordinary regression analysis) (Louviere *et al.* 2000).[85] The rho-squared value for this model was calculated to be 0.20 indicating a very good correspondence since values between 0.20 and 0.40 are considered indicative of extremely good model fits (Louviere *et al.* 2000, pg. 54). To aid in further interpretation, the part-worth utility coefficients have been plotted separately for each attribute in Figure 20.

[84] Note that co-linearity is not a concern in the analysis of the MDC results (section 5.1.2.2.2) because the most and least frequencies for each attribute are analyzed as distinct choices. In contrast, choice models analyze choices between profiles of attribute levels.

[85] According to Train (2003), the interpretation on the rho-squared values used in choice modeling and the R^2 values used in regression analysis is not the same. While R^2 values are an indication of the percentage of variation in the dependent variable that is explained by the estimated model, the rho-squared value indicates the percentage increase in the log-likelihood function above the value taken at zero parameters. Furthermore, models estimated with different samples or different sets of alternatives (e.g. with different L(0) values) cannot be compared using their rho-squared values (Train 2003).

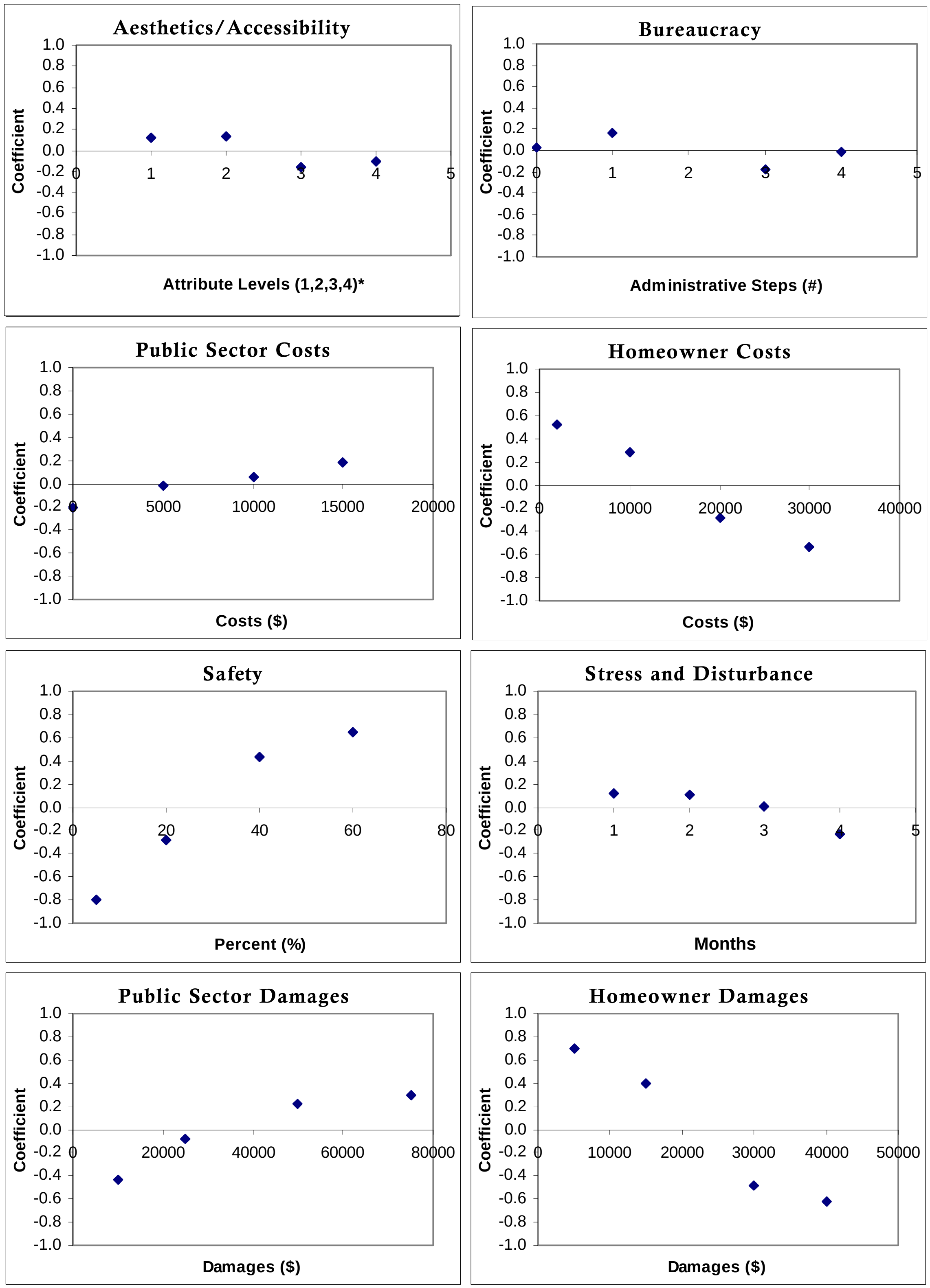

Figure 20 **Community Outcomes Choice Task I, Forced Choice - Graphs of the part-worth utilities derived for each attribute level.**
***Aesthetics (levels = 5,15,30,45%), Accessibility (levels = 5,20,40,60% decrease)**

For each attribute, the trend in utility values with increasing attribute level is consistent with prior expectations and assumptions with the exception of two attributes: Public Sector Costs and Public Sector Damages. In the initial problem-structuring phase, it was assumed that minimization would be the suitable direction of preference for these two value functions. This assumption was reflected in objective rating task of the public preference survey (e.g. the objective Public Sector Costs was described as "to minimize government expenses on the floodproofing strategy (municipal, provincial, and federal)". In contrast, the stated choice questions provide profiles of attributes and levels but do not assume a direction of preference. As shown in Figure 20, the overall public preference derived from the stated choice questions appears to favour maximization and not minimization of Public Sector Costs and Damages. This result is interesting for two reasons. First, it suggests some strategic behaviour on the part of respondents. In the objective rating task, respondents were quite willing to say that minimizing Public Sector Costs or Damages should be important in developing a community floodproofing strategy. On a scale of 0 to 10 where 0 is 'not at all important' and 10 is 'extremely important', the average rating for minimizing Public Sector Costs was 6, while that for minimizing Public Sector Damages was 7 (Table 18). In contrast, when respondents were asked to make trade-offs between impacts in the stated choice task, they found high values of Public Sector Costs and Damages quite acceptable in comparison to accepting impacts for other attributes. To choose low government costs or low government damages as being acceptable may have been perceived as letting the government "off the hook" for responsibilities related to flood hazard mitigation in favour of increased individual liability for flood costs and damages. A response strategy designed to ensure the government doesn't "get away with" paying nothing could have resulted in the positive signs on the value function for the public costs and damages attributes. The unexpected results of this task are also interesting for a second reason; they show that considerable background research and expert opinion cannot be a substitute for letting respondents inform the researcher of his or her interests, which is only possible in a task which minimizes pre-emptive assumptions about preferences.

As illustrated in Figure 20, most of the part-worth utility coefficients display clear linear and some quadratic trends in the overall value function for each attribute. For instance, the Homeowner Costs coefficients show a clear linear decrease in utility as costs increase, while Public Sector Damages seem to be associated with declining marginal utility as attribute level increases. As a result, the use of linear and quadratic coding, which allows each attribute to be modelled as a continuous value function (as opposed to a set of discrete utility points), is a legitimate simplification (Table 20).

Table 20 Community Outcomes Choice Task I, Forced Choice – Results (multinomial logit model and linear (L) /quadratic (Q) coding).

Model Statistics:					
Log Likelihood Function (with coefficients) – L(ß)			-488.88		
Log Likelihood Function (no coefficients) – L(0)			-607.20		
MacPherson's Rho Squared ($?^2$)			0.20		
Rho Squared Adjusted			0.05		
Number of Respondents			221		
Attribute		**Part-worth Utility**	**Standard Error**	**t-value**	**p-value**
Aesthetics/Accessibility	L*	-0.030	0.036	-0.835	0.404
Bureaucracy	L	-0.057	0.036	-1.576	0.115
Public Sector Costs	L	0.104	0.054	1.935	0.053
Homeowner Costs	L	-0.149	0.021	-7.191	0.000
Safety	L	0.269	0.043	6.195	0.000
	Q	-0.031	0.018	-1.754	0.080
Stress and Disturbance	L	-0.163	0.053	-3.047	0.002
Public Sector Damages	L	0.108	0.027	4.014	0.000
Homeowner Damages	L	-0.074	0.009	-8.542	0.000
Intercept		0.073	0.078	0.933	0.351

*Only the most significant linear (L) and quadratic (Q) estimates were retained.

The linear trends suggested by Figure 20 are corroborated by the results described in Table 20. The linear model was the best-fit model for all the attributes, with the exception of the Safety attribute, which also contained a significant quadratic effect (at $p < 0.10$). With the exception of the linear coefficients for the Aesthetics/Accessibility and Bureaucracy attributes, all other coefficients were significant at the 5% level. As in the previous model (effects coded), the intercept is not significant. The improvement in log likelihood value for the model with explanatory variables included (e.g. L(ß) vs. L(0)) indicates that the variables included in the model are useful for explaining the choices made by respondents. Furthermore, the rho-squared value of 0.20 indicates a good model fit.

Choice plus Base

The following results describe the analysis of the community outcomes stated choice task with the base option included in the analysis (in addition to the choice between Outcomes A and Outcome B). The results derived using effects coding and the MNL model are shown in Table 21 and are displayed graphically in Figure 21.

Instead of the choice between Outcomes A and B, for this model, the intercept describes a comparison between the choice of the base option and either of the two alternative outcomes (A and B). In this case, the small insignificant intercept value indicates that, all other things being equal, there is no significant difference in preference between the status quo and the alternative strategy outcomes (A and B). Although the results of the 'Choice plus Base' analysis and the 'Forced Choice' are similar, it should be noted that in a number of instances the t-value and p-values associated with individual estimates show a higher level of significance in the 'Choice plus Base' model (e.g. Bureaucracy).

Once again the L(ß) value is greater than L(0) indicting that the attribute values contribute to explaining choice. In addition, the rho-squared values although not as high as in the 'Forced Choice' model, still indicate a reasonably good fit.

Table 21 Community Outcomes Choice Task II, Choice plus Base – Results (multinomial logit model and effects coding).

Model Statistics:					
Log Likelihood Function (with coefficients) – L(ß)			-837.18		
Log Likelihood Function (no coefficients) – L(0)			-962.38		
MacPherson's Rho Squared (?[2])			0.13		
Rho Squared Adjusted			-0.08		
Number of Respondents			221		
Attribute Name	**Level**	**Part–worth Utility**	**Standard Error**	**t-value**	**p-value**
Aesthetics/	5	0.125			
Accessibility	15	0.056	0.119	0.473	0.636
	30	-0.035	0.113	-0.313	0.754
	45	-0.146	0.136	-1.069	0.285
Bureaucracy	0	0.145			
	1	0.272	0.095	2.851	0.004
	3	-0.265	0.103	-2.572	0.010
	4	-0.152	0.101	-1.498	0.134
Public Sector	0	-0.111			
Costs	5000	-0.033	0.096	-0.347	0.728
	10000	-0.054	0.092	-0.584	0.559
	15000	0.198	0.094	2.111	0.035
Homeowner	2000	0.429			
Costs	10000	0.206	0.092	2.226	0.026
	20000	-0.183	0.097	-1.877	0.061
	30000	-0.452	0.099	-4.564	0.000
Safety	5	-0.756			
	20	-0.233	0.124	-1.876	0.061
	40	0.476	0.115	4.133	0.000
	60	0.513	0.136	3.758	0.000
Stress and	1	0.116			
Disturbance	2	0.137	0.091	1.514	0.130
	3	-0.105	0.097	-1.074	0.283
	4	-0.149	0.118	-1.261	0.207
Public Sector	10000	-0.160			
Damages	25000	-0.145	0.100	-1.454	0.146
	50000	0.117	0.102	1.146	0.252
	75000	0.188	0.119	1.581	0.114
Homeowner	5000	0.747			
Damages	15000	0.382	0.100	3.810	0.000
	30000	-0.505	0.103	-4.923	0.000
	40000	-0.624	0.107	-5.836	0.000
Intercept		0.079	0.080	0.984	0.325

Note: Base was coded using zeros for all attribute levels.

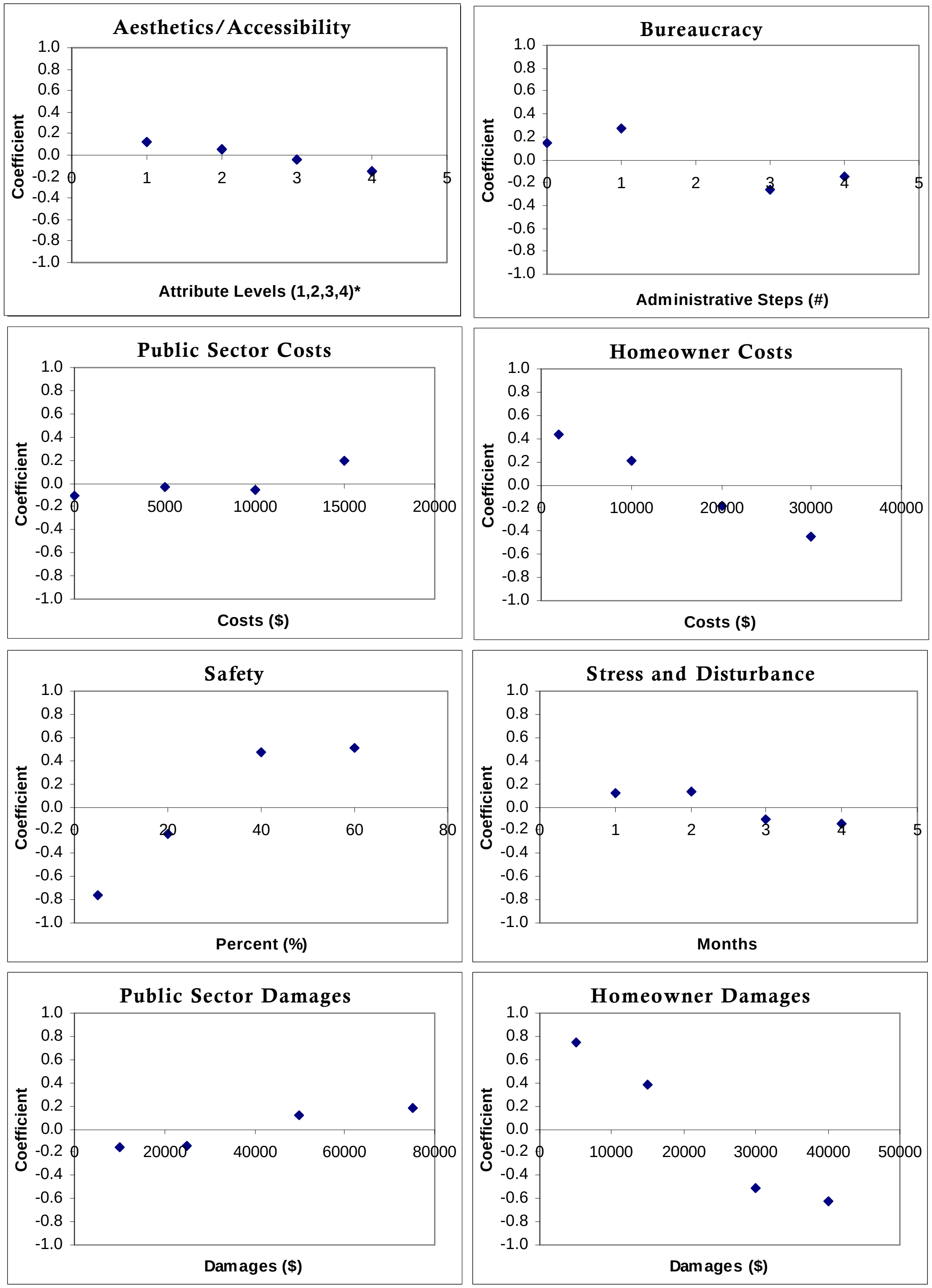

Figure 21 Community Outcomes Choice Task II, Choice plus Base - Graphs of the part-worth utilities derived for each attribute level.
***Aesthetics (levels = 5,15,30,45%), Accessibility (levels = 5,20,40,60% decrease)**

As for the 'Forced Choice' model, the trend in utility values with increasing attribute level is consistent with prior expectations with the exception of the Public Sector Costs and Public Sector Damages attributes. A comparison of Figure 20 and Figure 21 validates the overall similarity in the results of these two models. In addition, clear linear and quadratic trends in the value functions are again evident. As a result, the use of linear and quadratic coding is a reasonable simplification (Table 22).

Table 22 Community Outcomes Choice Task II, Choice plus Base – Results (multinomial logit model and linear (L) /quadratic (Q) coding).

Model Statistics:					
Log Likelihood Function (with coefficients) – L(ß)			-843.43		
Log Likelihood Function (no coefficients) – L(0)			-962.38		
MacPherson's Rho Squared (?^{2})			0.12		
Rho Squared Adjusted			0.05		
Number of Respondents			221		
Attribute	**Model**	**Part-worth Utility**	**Standard Error**	**t-value**	**p-value**
Aesthetics/Accessibility	L	-0.032	0.034	-0.959	0.338
Bureaucracy	L	-0.109	0.035	-3.135	0.002
Public Sector Costs	L	0.087	0.049	1.765	0.078
Homeowner Costs	L	-0.127	0.021	-6.179	0.000
Safety	L	0.264	0.044	5.989	0.000
	Q	-0.047	0.017	-2.703	0.007
Stress and Disturbance	L	-0.137	0.053	-2.561	0.011
Public Sector Damages	L	0.060	0.025	2.438	0.015
Homeowner Damages	L	-0.081	0.008	-9.759	0.000
Intercept		0.043	0.079	0.547	0.584

The linear trends suggested by Figure 21 are corroborated by the results described in Table 22. Once again, with the exception of Safety, the linear coding provided a better model for the data than did quadratic coding. In addition, most of the coefficients were significant at the 5% level, with the exception of Public Sector Costs (significant at the 10% level) and Aesthetics/Accessibility (not significant). As in the effects coded model, the intercept is not significant.

<u>Summary</u>

The previous pages summarized the results of the first stated preference task in the survey - the community outcomes choice task. Various models using both discrete and continuous coding types were presented and analysed. The trends observed in part-worth utility with increasing attribute level were as expected for all attributes with the exception of Public Sector Costs and Public Sector Damage, which showed increasing utility with increasing costs or damages. The overall results for the 'Forced Choice' and the 'Choice plus Base' were very similar, but the 'Choice plus Base' model contained significant parameter estimates for the Bureaucracy attribute and showed more evidence of quadratic trends for the Safety attribute. For both the 'Forced Choice' and 'Choice plus Base' models, the more efficient linear/quadratic coded models provided a similar model fit to the effects coded models. Furthermore, in comparison to the effects coded models, a higher proportion of the model parameters (e.g. part-worth utility estimates) were significant when linear or quadratic coding was used to analyse the results.

5.1.2.2.2 Maximum Difference Conjoint Task (MDC)

As described in Chapter 4 , in addition to choosing a preferred option between two hypothetical outcomes of floodproofing strategies, respondents were also required to analyse each profile separately and choose one attribute value in the set of nine that was the most acceptable and one value that was the least acceptable. The use of the MDC task allowed the part-worth utility values derived from the analysis of respondents' most and least choices to be directly compared on a general scale with a common origin.

The MDC data can be analysed as an aggregate data set with the multinomial logit model (MNL) model just like other choice data. In contrast to a choice experiment where the dependent variable is the frequency of choice for each alternative profile (e.g. A vs. B), for a MDC task, the dependent variable is the frequency of selection of each <u>attribute level</u> as either the best or the worst (or the most and least acceptable for this project). As in a DCE, the independent variables are the attribute levels, which were expanded into a dummy coded matrix for the MDC analysis (Louviere *et al.* 2000). The best and worst data were combined by stacking the coding matrixes and the aggregate selection frequencies (using a negative coding matrix for the least frequencies) and analysed using maximum likelihood estimation and a MNL model. The intercept was set to the least preferred attribute level (which in this case was Homeowner Damages at $40,000) but any attribute level could have been legitimately used as the zero level. The output was a series of utility estimates (and associated standard errors, and t-values) for each attribute level used in the survey (Table 23). For continuity with the presentation of the community outcomes choice results, the utilities are also shown in separate graphs for each attribute (Figure 22).

Table 23 Community Outcomes MDC Task – Results (MNL model and dummy coding).

Model Statistics:	
Log Likelihood Function (with coefficients) – L(ß)	-3367.67
Log Likelihood Function (no coefficients) – L(0)	-3847.34
MacPherson's Rho Squared ($?^2$)	0.13
Rho Squared Adjusted	0.09
Number of Respondents	221

Attribute Name	Level	Utility	Standard Error	t-value	Frequencies Most	Frequencies Least
Aesthetics	5	2.267	0.216	10.500	26	8
	15	2.239	0.215	10.430	21	7
	30	2.350	0.217	10.841	24	11
	45	2.353	0.218	10.780	18	5
Accessibility	5	1.878	0.219	8.563	19	16
	20	2.166	0.215	10.056	16	5
	40	1.832	0.217	8.457	10	17
	60	1.554	0.213	7.314	10	27
Bureaucracy	0	2.202	0.217	10.149	18	8
	1	2.461	0.214	11.489	28	9
	3	1.965	0.218	8.997	19	16
	4	1.889	0.216	8.748	23	24
Public Sector Costs	0	0.900	0.199	4.525	13	51
	5000	1.853	0.216	8.566	22	24
	10000	2.562	0.211	12.134	37	14
	15000	2.698	0.212	12.736	35	7
Homeowner Costs	2000	3.238	0.198	16.328	64	8
	10000	2.349	0.218	10.753	31	17
	20000	1.377	0.209	6.576	19	39
	30000	0.542	0.191	2.834	9	66
Safety	5	0.559	0.195	2.867	9	61
	20	1.512	0.210	7.213	22	37
	40	2.499	0.208	12.028	34	10
	60	3.850	0.195	19.774	92	3
Stress and Disturbance	1	2.831	0.208	13.590	40	7
	2	1.916	0.208	9.226	15	17
	3	0.998	0.195	5.128	8	51
	4	1.040	0.227	4.586	7	28
Public Sector Damages	10000	1.972	0.218	9.040	17	14
	25000	2.302	0.207	11.107	26	9
	50000	2.423	0.209	11.595	39	18
	75000	2.620	0.225	11.622	35	14
Homeowner Damages	5000	2.746	0.210	13.094	44	17
	15000	1.553	0.213	7.297	12	30
	30000	0.332	0.193	1.723	7	85
	40000*	0.000	0.000	0.000	8	94

*Homeowner Damages at $40,000 was used as the base value (the zero point).

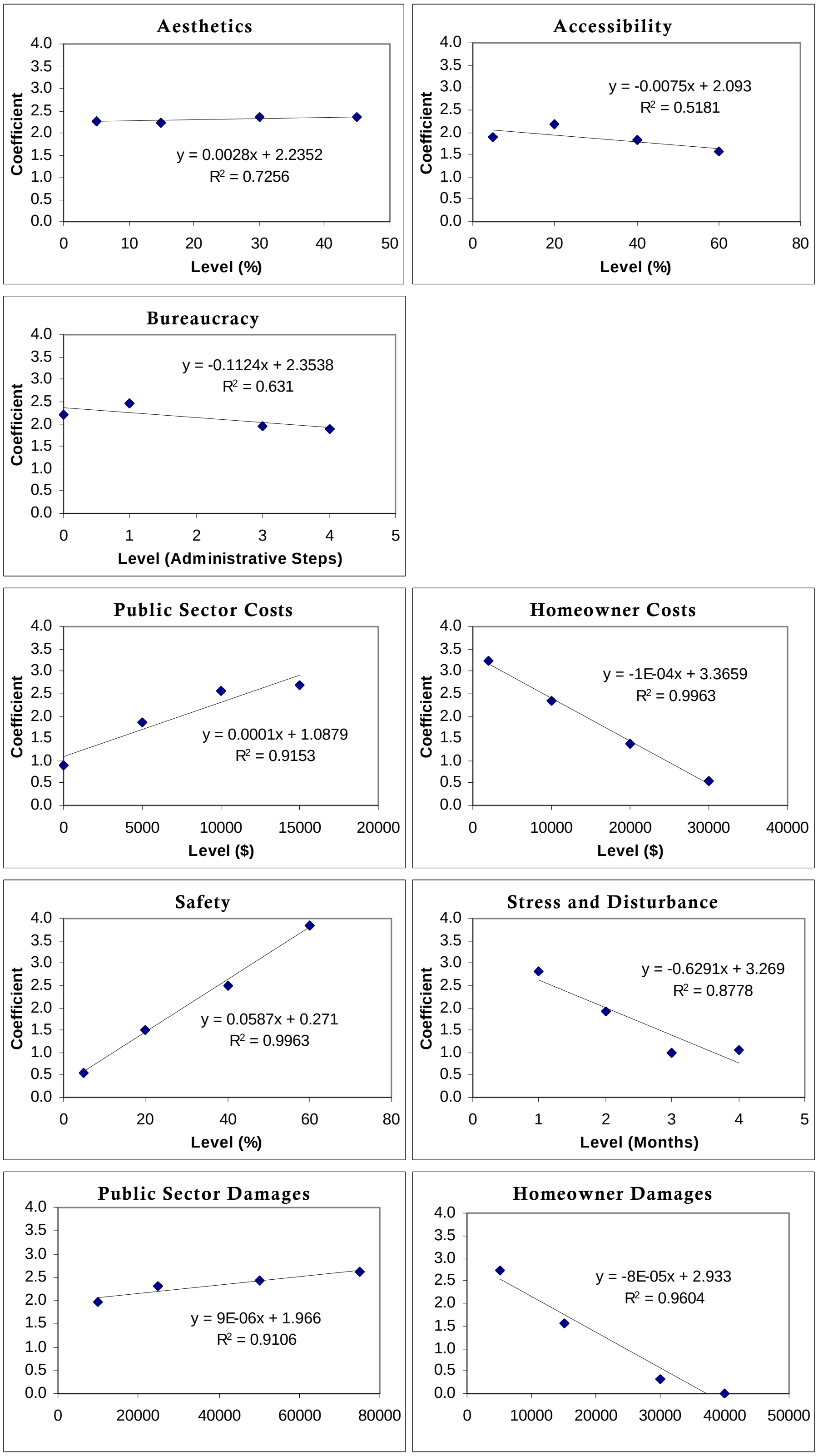

Figure 22 Community Outcomes MDC Task - Graphs of the utilities derived for each attribute and level.

The analysis of the MDC results revealed highly significant values as evidenced by the very large t-values for all of the attribute levels. As illustrated by Figure 22, the trends in utility values established for each attribute are very similar to those found using the discrete choice data. Once again, maximization is the direction of preference for the attributes Public Sector Costs and Public Sector Damages. In addition, the tendency towards linear functional forms is again obvious. Linearity was explored further by fitting trend lines to the utility estimates for each attribute. The primary purpose of this exercise was to establish the slope of the line (the marginal change in utility with increasing attribute level) for use in later calculations to derive the relative weight for each attribute. As indicated by the high R^2 values associated with most of the linear trend lines, linear functional forms provide a very good fit to the utility estimates for each attribute, although a linear fit for Aesthetics, Accessibility, and Bureaucracy is less convincing. This outcome can be reasonably explained by considering the flat aspect of the value function for these attributes. The small change in value with increasing attribute level indicates that these three attributes had minimal impact on the choices made by respondents. In other words, changing one of these attributes from its worst to its best level results in a minimal increase in value compared to other attributes. As a result, respondents were probably more likely to make inconsistent responses with respect to individual attribute levels because they were not very concerned with the value of the level. This inconsistency could result in coefficient estimates with no clear trend or functional relationship.

As mentioned previously, the MDC task provides utility estimates for each attribute and attribute level, which may be directly compared on a general scale with a common origin. In order to highlight the ability to make inter-attribute comparisons, the utility estimates for each attribute and level are plotted together in Figure 23.

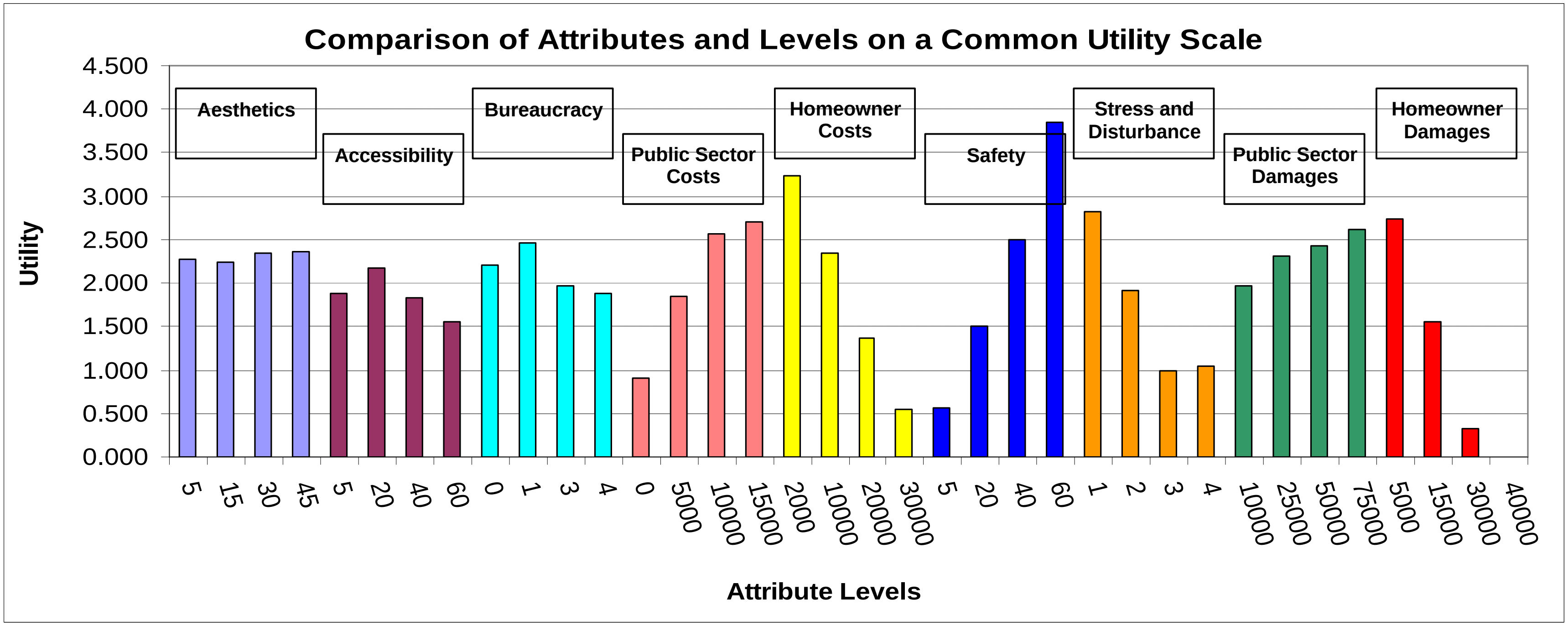

Figure 23 Community Outcomes MDC Task – Graph of utility estimates comparing all attribute levels on a common scale.

Figure 23 shows the same utility estimate information for each attribute level as Figure 22 but uses a common scale to highlight the fact that the interpretation of the results can now be extended to comparisons between attributes levels. For the purposes of discussion, it is important to understand that, in the stated preference literature, total value or utility is assumed to be composed of two distinct components: a scale value and a 'weight' (Louviere *et al.* 1993, Haider and Rasid 1998). The scale value is the utility associated with changes in attribute level. For instance, the scale indicates how much utility is gained by moving from level one of an attribute to level two. Conversely, the 'weight' is the inherent value or overall importance of an attribute and is a constant utility value that <u>does not change</u> with attribute level or range. In contrast, decision analysts also derive what are often called 'weights,' but most analysts are careful to state that these are relative weights (e.g. not absolute weights) that should be sensitive to the range (or scale) used for each attribute (refer to section 3.1.4.1, in Chapter 3). As discussed in section 3.1.4.1, concern over the potential for confusion between the concept of relative weights and overall importance weights led Keeney and Raiffa (1976) to call the relative weights used in their equations "scaling constants." As a result, it seems clear that what decision analysts often call relative weights and sometimes even importance weights are rely more akin to the utility scale values derived by stated preference researchers, since both are sensitive to the range of attribute impacts. In turn, it is clear that the 'weights' derived from MDC tasks are not the same as decision analysis 'weights' and should not be compared as such. To the author's knowledge, there is nothing akin to the 'weights' derived from MDC tasks in the domain of decision analysis practice.[86] Consequently, the most meaningful comparison between the preference information is between the relative 'weights' of decision analysis and the scale values of choice modelling. As a result, the analysis will focus on the interpretation of the utility scale values and their comparison to the relative scale weights as derived from a decision analysis methodology (e.g. swing weighting). Figure 24 presents the utility scale values calculated for each attribute level for the MDC task.

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[86] The reason for this is that decision analysts normalize their models to the local decision context; they are rarely concerned with global weights (Fisher 1995). See footnote 31.

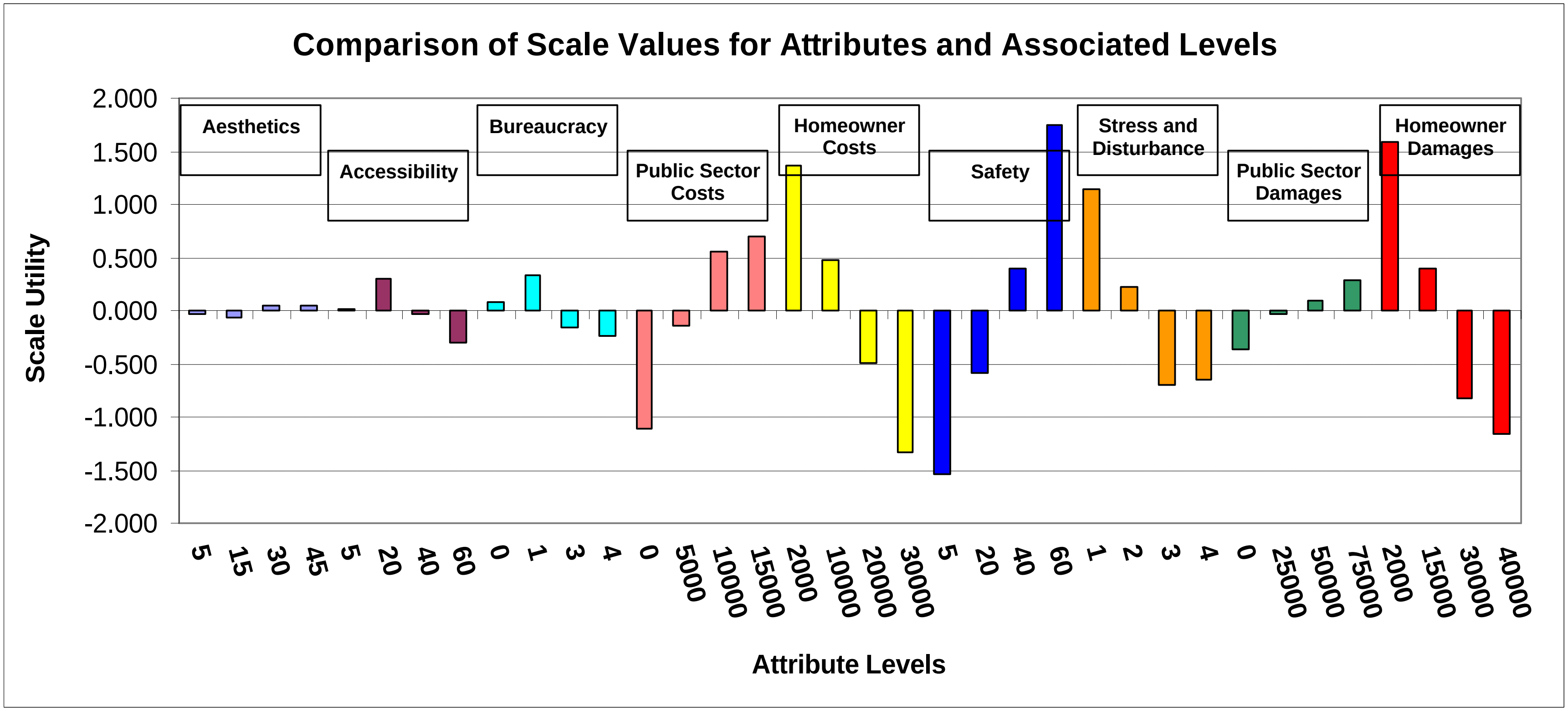

Figure 24 Community Outcomes MDC Task - Graph of the utility scale values for each attribute level on a common scale. Scale values were separated from the overall utility values shown in Figure 23.

5.1.2.2.3 Derivation of Relative Attribute Weights

The utility values provided by a DCE or a MDC task essentially combine the relative weights and the attribute value functions into one preference estimate. Recall that decision analysis attempts to simplify the decision making process by first decomposing it into key elements such as weights, value functions, and impact information and then recomposing the information to provide an evaluation of competing alternatives. A simple way to estimate the relative weights for each objective from the utility values derived from a stated preference survey can be used when the relationship between attribute level and utility value is found to be approximately linear. As discussed previously, linear relationships fit the observed data very well for most of the attributes (Figure 20, Figure 21, and Figure 22). The following equation[87] can be used to translate the utility values, from an effects or dummy coded stated preference model, into a relative weight, $W_R(i)$, for each attribute (i):

Equation 31

$$W_R(i) = \frac{ABS(S_i * \Delta L_i)}{\sum_{i=1}^{j} ABS(S_i * \Delta L_i)},$$

where S_i is the linear slope for each attribute, i, of the best fit line to the utility values for each attribute level (e.g. Figure 22), ? L_i is the difference between the maximum and minimum levels of attribute i, j is the total number of attributes in the analysis, and ABS signifies absolute value.

Using Equation 31, the relative weights for each attribute were derived. The weights calculated for the results of the MDC and the DCE models are described in Table 24.

[87] This equation is equivalent to those commonly used in conjoint analysis applications for calculating relative attribute importance weights (Bragge 2001, Green and Wind 1975, Market Vision Research 2002).

Table 24 Comparison of relative weights and ranks for objectives – MDC and DCE tasks.

	MDC Results		DCE results*	
Objective	Relative Weight	Rank	Relative Weight	Rank
Safety	0.230	1	0.259	1
Homeowner Damages	0.200	2	0.253	2
Homeowner Costs	0.192	3	0.175	3
Stress and Disturbance	0.134	4	0.061	5
Public Sector Costs	0.130	5	0.059	6
Public Sector Damages	0.044	6	0.094	4
Bureaucracy	0.032	7	0.055	7
Accessibility	0.029	8	0.044	8/9**
Aesthetics	0.008	9		

*The weights for the 'Forced Choice' and the 'Choice plus Base' models were averaged to obtain results.
**The values for Aesthetics and Accessibility were correlated in the DCE results (see section 4.4.2.2.2). As a result, the weights for Aesthetics and Accessibility could not be separated for these models.

The relative weights are quite similar between the MDC and DCE models for the top three alternatives, which account for approximately 60 to 70% of the relative weights on the attributes, although the DCE results tend to give more weight to the top two attributes. Other differences are also apparent. For instance, the DCE results allocate less relative weight to 'Stress and Disturbance' and 'Public Sector Costs' and more relative weight to 'Public Sector Damages'. Bureaucracy receives slightly more relative importance under the DCE model but its rank does not change. Interestingly, the joint weight associated with Aesthetics and Accessibility in the DCE model is greater than the sum of the weights associated with these objectives under the MDC model.

The weights derived from the MDC model (and not those from the DCE model) were used in final decision analysis evaluation of the nine floodproofing strategies for two reasons (section 5.2.2). First, the MDC model provided separate relative weight estimates for the Aesthetics and Accessibility objectives. Second, it was assumed that the MDC method is more appropriate for deriving relative weights because it forces respondents to choose between attribute levels and thus places more focus on inter-attribute comparisons. Although the DCE weights were not used in the final analysis, a sensitivity analysis was completed that investigated the effect that changes in relative attribute weights could have on the ranking of alternatives.

Further comparisons can be made between the relative weights derived from the public preference MDC task, and the results of the objective-rating task, and the manager's swing weighting task[88] (Table 25).

Table 25 Comparison of relative weights and ranks for objectives – Public (MDC task and objective rating task) and Expert (manager's swing weighting task).

	Public – MDC Results		Public – Objective Rating	Average Expert - Swing Weighting	
Attribute	Relative Weight	Rank	Average Rank	Relative weight	Rank
Safety	0.23	1	1	0.16	1
Homeowner Damages	0.20	2	2	0.15	3
Homeowner Costs	0.19	3	4	0.11	6
Stress and Disturbance	0.13	4	3	0.15	4
Public Sector Costs	0.13	5	7	0.13	5
Public Sector Damages	0.05	6	5	0.16	2
Bureaucracy	0.03	7	8	0.07	7
Accessibility	0.03	8	6	0.04	8
Aesthetics	0.01	9	9	0.03	9

As shown in Table 25, the ranking of objectives based on the results of MDC task and the objective-rating task confer quite closely for attributes ranked 1 though 4. Both tasks showed Safety and Homeowner damages as the number 1 and number 2 ranked attributes. Homeowner Costs and Stress/Disturbance compete for the 3rd and 4th ranking but the order is reversed between the two tasks. Both tasks ranked Aesthetics as the least important attribute. The similarity between the results is interesting, especially given the difference in direction of preference between the two tasks for the attributes Public Sector Costs and Public Sector Damages as discussed in the previous two sections. In fact, if the direction of preference had been the same for these two attributes, the rankings likely would have been closer. For example, consider the attribute Public Sector Costs. In the rating task, respondents gave a low importance to the objective "minimize Public Sector Costs" but gave a higher importance to this objective in the MDC task when they were not confined to minimize but could by their choices show that they preferred to maximize this objective.

[88] As discussed in section 3.1.4.1, swing weighting is a decision analysis method often recommended for its range sensitivity property. As a result, the weights derived from the swing-weighting task can correctly be termed relative weights.

Table 25 also shows that the manager's relative weights are, perhaps surprisingly, quite similar to those associated with homeowners. Three main differences should be discussed. First, the rankings for the attributes Public Sector Damages and Homeowner Costs are practically reversed between the two sets. It is not surprising that homeowners are more concerned with Homeowner Costs than Public Sector Damages, while the reverse is true for managers. The second difference between the two weight sets is the fact that the relative weights of homeowners seem to be focused on three main attributes (Safety, Homeowner Damages, and Homeowner Costs), while the average relative weights for managers tend to be more evenly spread across the attributes. Conversely, this comparison does not hold as well if one compares the weight set of the public to that of each individual manager (Table 17). The third and final difference between the weight sets is subtle and is based on the 'direction of preference' issue discussed previously. In the swing-weighting task, the managers were asked to rank and rate the objective "to minimize the costs of the floodproofing strategy to the public sector". In contrast, the results of the MDC task indicated that the public preferred to maximize Public Sector Costs (recall that prior assumptions on direction of preference were not used in the stated preference tasks). As a result, since the direction of preference is different for this objective between the two weight sets, the fact that the weights and ranks are the same in both sets is misleading. It should be made clear that the public gives a weight of 0.13 to maximizing Public Sector Costs, while managers give a weight of 0.13 to minimizing Public Sector Costs. On the issue of Public Sector Costs, it appears that the public and managers are diametrically opposed.

5.1.2.2.4 Overall Comparison of Utility Estimates

Since the community outcomes stated preference tasks were completed on the same profiles, it makes sense to briefly compare the utility estimates derived from the different tasks.

A correlation analysis between the part-worth utility estimates derived from the two stated choice models (e.g. the Forced Choice the Choice plus Base) yield a correlation coefficient of 0.96, which indicates that the results were highly correlated. In addition, the part-worth utility estimates derived from the two choice questions (e.g. 'Forced Choice' and 'Choice plus Base') were also compared to the utilities estimated from the MDC task. Correlation coefficients between the Forced Choice and the MDC data, and between the Choice plus Base and the MDC data, were 0.87 and 0.79 respectively. Although the correlations between the MDC data and the choice data were not as strong as the correlation between the two choice models, the correlation coefficients still indicate a high degree of similarity. A graphical comparison between the three effects coded models developed for the community outcomes stated preference task is presented in Figure 25, which contrasts the two sets of discrete part-worth utilities (Forced Choice and Choice plus Base) with the MDC utilities for each attribute level.

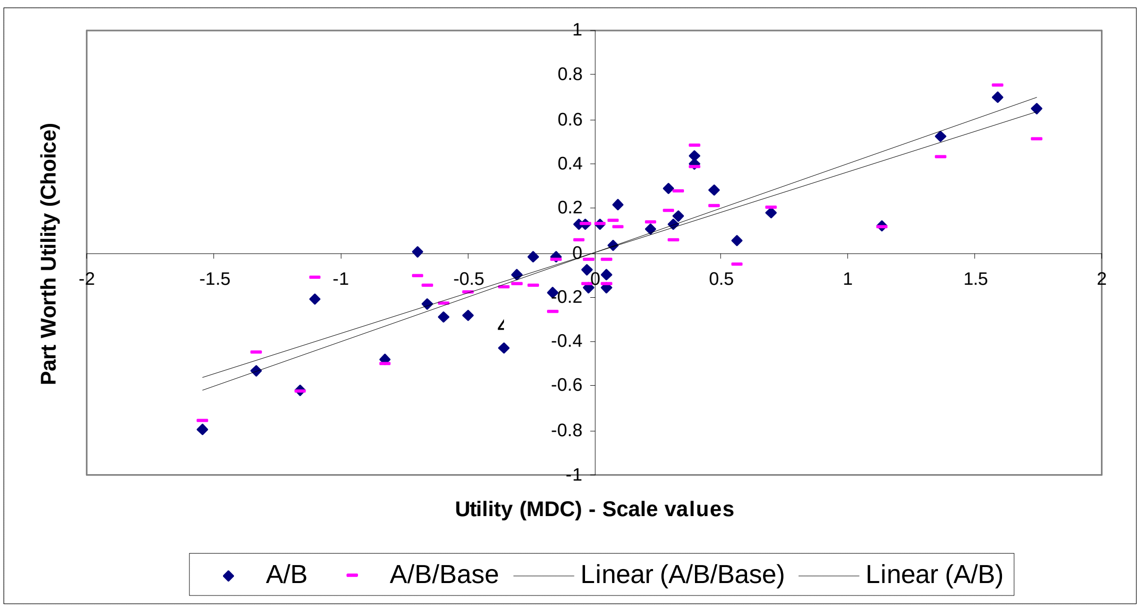

Figure 25 Graphical comparison of the utility coefficients for the three effects coded models in the community outcomes survey.
(A/B = Choice between Outcome A and B (Forced Choice), A/B/Base = Choice between outcomes A, B, and Base (Choice plus Base), MDC = maximum difference conjoint)

According to Louviere and Swait (1996), a general way to test for parameter equality between two data sets suspected to reflect the same tastes but possessing different scales is to plot the vector of utility parameters from one source against the other.[89] If the two taste vectors are equal, the plot should have a positive slope equal to the ratio of the two

[89] These plots are useful exploratory tools but only a rigorous statistical test that takes into account differences in scale between two data sets can prove parameter equality (Adamowicz *et al.* 1998).

scale parameters (?) associated with each data source (e.g. $ß_1 = (?_2/?_{1)}) ß_2$) (Adamowicz *et al.* 1998). Although the scale is different between the MDC task and the two choice tasks (e.g. the choice utilities range from –1 to 1 while the MDC utilities range from –2 to 2), the relationship between the parameters tends to be linear with an origin at (0, 0), which provides further evidence of a strong relationship between the MDC and choice data (Adamowicz *et al.* 1998).

<u>Summary – Stated Preference Task I</u>

The results of the first stated preference tasks focused on public preferences with regards to nine key attributes that described future hypothetical community-wide outcomes of potential floodproofing strategies. The nine attributes were associated with nine fundamental objectives that defined the key interests and concerns associated with the floodproofing problem. With a few minor exceptions, the various analyses produced very similar results. The second stated preference task was concerned with the personal or individual decision to floodproof based on information about the positive and negative aspects associated with adopting one of three floodproofing options.

5.1.2.3 Stated Preference Task II - Personal Floodproofing Decision Task

The personal floodproofing task involved the choice between three floodproofing options: elevation, wet floodproofing, and no floodproofing. As a result, the decision context was changed from a community level to the specific level of an individual homeowner's floodproofing decision. As discussed in Chapter 4, section 4.4.2.2.3, in order to provide a more realistic response environment, some attribute values used in this section of the survey were calculated based on answers a respondent had given to previous questions. For instance, Elevation Costs were approximated based on estimates given for foundation type, house size and house type. The use of survey questions in which values seen by respondents were tailored to each individual's situation necessitated the use of an individualized coding matrix (as opposed to the aggregate frequency models used for the community outcomes choice task).[90,91]

Analysis of the results of the personal floodproofing decision task presented unanticipated challenges, as the trends in the data were not immediately clear.[92] Visual inspection of the data revealed that a large proportion of the respondents showed dominance with respect to one of the options (e.g. wet floodproofing or elevation). Individuals with dominant response patterns contribute very little to the analysis, because their responses do not help to differentiate among attribute levels; they primarily contribute to the intercept values. There are a number of reasons that could explain the high number of dominated responses in this last task. First, respondents had already spent approximately 45 minutes on the survey when they were presented with the personal floodproofing task. Most likely many respondents were tired and perhaps unwilling to give the quality of response that they had provided in earlier tasks. Second, while administering the survey it was noted that some participants did not seem to notice when the screen had changed and they had proceeded to another question. Despite the fact that a question counter was used and the numbers and colours on the screen changed, many remarked that they thought they were answering the same question repeatedly.[93] Although some of the respondents probably used this task to express truly dominant preferences, it seemed quite likely that a combination of the two preceding factors reduced the quality of the data collected for this task. Due of these

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[90] An aggregate effects coded model contained only the general attribute levels was also developed to help visualize trends in the utility values but this model was inferior to the model obtained using individualized cost and damage attributes.

[91] Using a simple computer program written by the author, for each respondent and each question, the values of the individualized variables actually seen in the survey were recorded along with the general codes for other non-individualized variables and the choices made between alternatives.

[92] Unlike the analysis of the choice and MDC results from the community outcomes section of the survey, clear trends in the data did not appear immediately. Many different segmentations were applied to the data in an attempt to identify groups of respondents may have displayed different and contradictory response behaviour. For instance, models based on income, sensitivity to costs and sensitivity to damages were tried in an endeavour to reveal potential motivations responsible for the observed behaviour. Unfortunately, none of these alternative models provided significant insight into the results.

[93] The ambiguity of the question change in this task is a survey design issue that was not noted as a significant problem during the pre-testing sessions. Unfortunately, the personal floodproofing task was a late addition to the survey and so there was not time to undertake as much testing on this section as the rest of the survey sections.

concerns, a data set was derived that excluded all respondents that picked the same option (e.g. elevation) in all four choice sets.[94] Unfortunately this approach also excludes any individuals who meant to pick the same option four times, but for the purposes of investigation it was assumed that this group was a minority compared to the respondents who mistakenly picked the same response four times. Analysis of the non-dominated response set yielded greater success than did any other analysis on the personal response data. Unfortunately, the smaller total number of responses reduced the possibility of finding highly significant utility coefficients in the results.

The model used to analyse the data was a combination model on the non-dominated data set that contained both individualized and general variables and used both continuous (linear/quadratic) and effects coding. As for the community outcomes analysis, maximum likelihood estimation and multinomial logit models were used to derive the utility estimates (Table 26).

[94] The number of individual that displayed dominance on one option was significant; over ½ of the sample was removed when dominance was considered. Of the 205 individuals who completed the personal floodproofing questions (individuals whose homes were already floodproofed did not complete this section), 47 were dominant on elevation, 54 were dominant on wet floodproofing, while 7 were dominant on the no floodproofing option.

Table 26 Personal Floodproofing Discrete Choice task – Results (multinomial logit model with linear (L)/quadratic (Q) and effects coding).

Model Statistics:	
Log Likelihood Function (with coefficients) – L(ß)	-361.83
Log Likelihood Function (no coefficients) – L(0)	-430.66
MacPherson's Rho Squared ($?^2$)	0.16
Rho Squared Adjusted	0.14
Number of Respondents	98

Alternative	Attribute	Model/Level	Part-Worth Utility	Standard Error	t-value	p-value
Elevation	*Costs*	Linear*	-0.00002105	0.000	-4.898	0.000
Elevation	*Damages*	Quad*	0.00000003	0.000	2.455	0.014
Elevation	*Inconvenience*	Linear	-0.24418697	0.155	-1.576	0.115
		Quad	0.11643689	0.074	1.565	0.118
Elevation/**W**et Floodproofing	Support *– Tax Break*	No	-0.41133920			
		Yes	0.41133920	0.211	1.952	0.051
	Support *– Grant*	Linear	0.10132734	0.193	0.524	0.600
Elevation/**W**et Floodproofing	*Preferred Support type*	Tax Break	-0.33598088			
		Grant	0.33598088	0.152	2.205	0.027
Wet Floodproofing	*Costs*	Linear*	-0.00004311	0.000	-2.295	0.022
Wet Floodproofing	*Damages*	Linear*	-0.00003259	0.000	-3.791	0.000
Wet Floodproofing	*Inconvenience*	Linear	-0.19838160	0.149	-1.331	0.183
No Floodproofing	*Damages*	Linear*	-0.00001272	0.000	-3.408	0.001
No Floodproofing	*Penalties*	No	0.30680680			
		Yes	-0.30680680	0.157	-1.957	0.050
No Floodproofing	*Compensation*	Linear	0.14145448	0.131	1.078	0.281
Intercepts		Elevation	0.51436495	0.197	2.615	0.009
		Wet Floodproofing	1.00820626	0.171	5.882	0.000
		No Floodproofing	0	0	0	0

*Indicates a variable that was individualized for each respondent.

As described in Table 26, many of the highly significant coefficients are associated with the cost and damage attributes for each alternative. Clearly, prior floodproofing costs and projected flood damages had a large influence on respondents' choices between the three floodproofing options. Readers should note that the utility coefficients for many of the attributes should be interpreted as per unit values. For example, the linear utility coefficient for elevation costs is -0.000021 utility units for every dollar increase in cost. Due to the large attribute ranges associated with many attributes and the use of linear and quadratic coding, many of the coefficients are very small. With the exception of elevation damages, the signs of all of the coefficients are as expected. For instance, 'no penalties' are preferred over 'some penalties' and increasing costs and damages are associated with negative utility. Interestingly, grants are significantly preferred over tax breaks but the linear coefficient for grants (e.g. the utility associated with increases in the value of grants) is not significant. Clearly, respondents would far rather see a grant than a tax break but they do not readily discern between different amounts for the grant. Two intercepts were used for this model: one for elevation and one for wet floodproofing. Both of the coefficients calculated for these intercepts are positive and significant, indicating a strong preference for both of the floodproofing options over the base option of no floodproofing, with everything else being equal. In other words, there is a large value associated with the floodproofing options themselves regardless of the associated attribute values.[95]

5.1.2.4 Other Survey Results

In addition to the main survey questions described in the previous sections, survey respondents were asked numerous additional questions. The main purpose of these general questions was to characterize respondents in greater detail for the purposes of segmentation and to provide additional information on awareness of floodplain management issues. The most interesting or insightful results will be presented in this section, while the more mundane results (e.g. demographics) will be left to the appendices (refer to Appendix G).

[95] The relatively large intercepts values may indicate that strong preferences patterns still existed in the 'non-dominant' response set. Although individuals who chose the same option four out of four times were removed, some respondents remaining in the sample may have not realized that the question was changing until the second, third or fourth question appeared. As a result, the sample is still subject to response patterns that favour a single option The effect of this pattern will be discussed in section 5.1.2.5, which provides further insight into the results of the personal floodproofing decision task through a decision support system.

Flood Experience

Only 6.3% of respondents indicated that they had experienced flooding in their current home (or in any previous home) caused by a rising river or by waves during a storm.

Important considerations in home purchase

Table 27 describes the percentage of respondents who considered each listed factor as an important consideration when they purchased their home.

Table 27 Home purchase considerations of Richmond, BC residents.

FACTOR	IMPORTANT?
Cost	85 %
Proximity to work and other amenities (e.g. schools, shops)	82 %
Features of home (e.g. # of rooms, garage, yard)	81 %
Aesthetic appeal of home (e.g. pleasing to look at)	74 %
Neighbourhood Reputation (e.g. crime rate, prestige)	73 %
Community Reputation (e.g. schools, taxes, recreation, weather)	73 %
Investment potential through eventual resale	61 %
Proximity to family	48 %
Risk to home due to natural disasters (e.g. flooding)	15 %
Other	7 %

Obviously, the more immediate and practical concerns, such as cost and location, were far more likely to be considered by homeowners when they purchased their home. In contrast, only 15% of respondents considered the potential threat of natural disasters an important consideration – a result that is somewhat surprising given the location of Richmond on a delta island of a major river and in an area near key earthquake fault lines.

Risk perception of natural disasters and other threats

Respondents were asked to rate five hazards according to how much of a threat they considered each to be to their current home. A scale of 0 to 10 was used with "0" being "No threat" and "10" being a "Very Large Threat".

Table 28 Hazard perceptions of Richmond, BC residents for five potential threats.

Hazard to Home	Average Rating	Standard Deviation	Ranking
Major earthquake	6.3	2.2	1
Major flood	5.6	2.2	2
Major house fire	4.2	2.4	3
Tsunami (large tidal wave)	3.7	2.8	4
Airline crash into house	2.4	2.4	5

Richmond residents perceive earthquakes followed by floods to be the largest threats to their homes.

Floodproofing in the current population

Homeowners were asked if their current home had been floodproofed and if so, what type of floodproofing was utilized (Table 29).

Table 29 Occurrence and type of floodproofing among residents of Richmond, BC.

			Floodproofing Type		
Response	**Number**	**% of responses (SFD*)**	**Elevation**	**Wet**	**Other/Don't Know**
Yes	13	6 % (5 %)	77 %	0 %	27 %
No	124	59 % (63 %)			
Don't know	72	35 % (32 %)			

*single family detached only

As indicated in Table 29, only a small percentage of the individuals sampled are certain that their home is floodproofed. This result should not be too surprising given that most of the residential area of Richmond is located inside an urban exempt area where floodproofing regulations are not applied (88% of the population)[96]. Of the respondents who indicated that their home was floodproofed (13), five lived outside Richmond's current urban exempt zone, while seven lived inside.[97] Assuming that the sample is representative of the general population of single-family detached homes, these results suggest that the rate of floodproofing inside the exempt zone is less than the rate outside the exempt zone. For example, if the rates of floodproofing were equal in both zones the actual percentages of people reporting floodproofing could be expected to match the

[96] As calculated from data on residential housing units provided by the City of Richmond planning department (Jones 2003d).

[97] Two of the seven respondents did not live in single-family detached homes (e.g. they lived in townhouses or apartments).

general distribution of residency inside and outside the exempt zone (88% and 22% respectively). In contrast, the results of this survey indicate that only 54% of floodproofed homes were located inside the exempt zone. Assuming that the results above are representative of the general population in Richmond, the rate of floodproofing outside of the exempt zone can be estimated using the following formula (the rate of floodproofing inside the exempt zone can be similarly calculated).

Equation 32 $$x = fp * \frac{(Actual\#Outside)}{(Expected\#Outside)} = fp * \frac{(Actual\#Outside)}{a*(\#\ fp)},$$

where **x** is the percentage of people floodproofed outside the exempt zone, **fp** is the overall percentage of people floodproofed, '**a**' is the proportion of people living outside of the exempt zone, and **#fp** is the total number of individuals floodproofed.

Using Equation 32, the proportion of people floodproofed inside and outside the exempt area was estimated to be 3.7% and 23% respectively.

Although space does not permit a full description of all the survey results, Appendix G covers a few additional results not reviewed in the main body of document.

5.1.2.5 Decision Support Systems (DSS)

An additional benefit of conducting choice experiments is that the results (e.g. part-worth utility coefficients) can be used to develop a DSS (refer to section 4.5.2 for a summary of how a DSS is built). A DSS can be used to evaluate any alternative that can be configured with the attributes and levels utilised in the survey. In other words, the evaluation of alternatives is not limited to a predefined set, such as the nine alternatives used in this project.

Two decision support systems were built to supplement the analysis of the two choice models (the community outcomes choice model and the personal floodproofing choice model). The primary purpose of the decision support system for the personal floodproofing decision choice model was to derive an estimate of the proportion of homeowners expected to floodproof under each of the eight voluntary floodproofing strategies. This information was used to improve the outputs of the multi attribute impact assessment model as described in section 4.3, since a key parameter in the calculation of most of the objective models was the proportion of people who would floodproof under a given strategy. The purpose of decision support system for the community outcomes choice model was to derive a ranking of the nine floodproofing alternatives, which could be compared to the evaluation and ranking of the same nine alternatives derived using decision analysis techniques.

5.1.2.5.1 DSS for the Personal Floodproofing Choice Task

A simple user interface was developed for the Personal Floodproofing DSS (Figure 26).

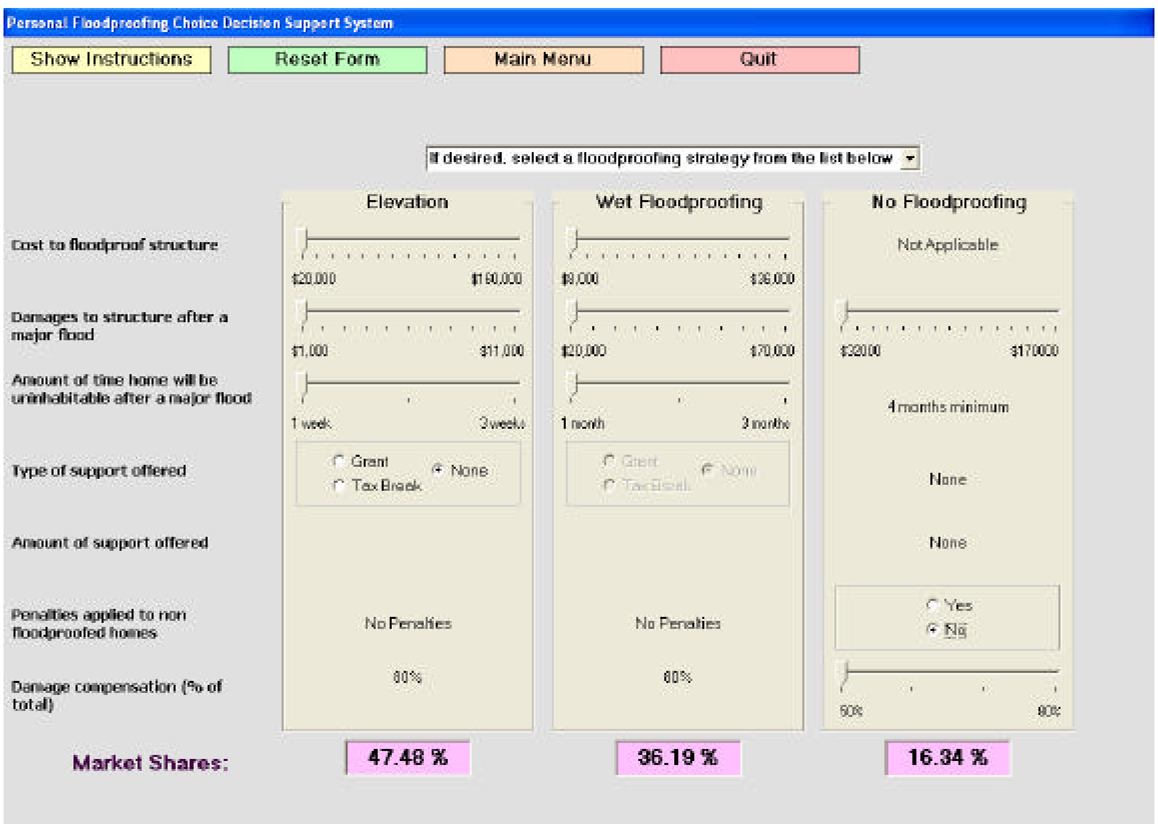

Figure 26 Simple graphical user-interface for the Personal Floodproofing DSS.

As shown in Figure 26, the user enters in values for each attribute in order to describe the particular alternatives he/she is interested in analysing. Using the utility estimates and attribute coding, the DSS then translates the information entered for the attribute levels into a 'market share' for each alternative - the percentage of respondents in a sample that would be expected to support or choose each alternative. Of the nine alternatives outlined in section 4.2.3, eight are voluntary. In other words, it would be up to individual homeowners to decide whether or not to floodproof their homes under these strategies. These eight alternatives are of the most interest for analysis with the DSS, because it is critical to have a reasonable estimate of the proportion of people who could be expected to floodproof under each voluntary floodproofing strategy for use in the impact assessment models. The DSS results for the eight voluntary alternatives are summarized in Table 30.[98]

Table 30 Personal Floodproofing Choice Task - DSS results comparing market share between three floodproofing options (Elevation, Wet Floodproofing, No Floodproofing) for the eight voluntary floodproofing strategies.

	Market Shares (%) by floodproofing type		
Floodproofing Strategy	**Elevation**	**Wet**	**None**
G (Wealth Transfer II)	53.34%	28.67%	17.99%
D (Carrot & Stick - Wealth transfer I)	50.63%	27.21%	22.16%
I (Positive Incentives II)	46.29%	24.87%	28.84%
B (Carrot - Pos. Incentives I)	42.63%	22.91%	34.46%
H (Negative Incentives II)	41.62%	22.37%	36.01%
C (Stick - neg. incentives I)	39.47%	21.21%	39.33%
E (Reduced Liability)	34.19%	18.38%	47.43%
A (Do Nothing)	29.60%	15.91%	54.49%

As presented in Table 30, all of the strategies appear to be at least somewhat successful at encouraging floodproofing. The most successful strategies appear to be those that combine policy levers, especially levies and tax breaks, to provide the maximum amount of incentive for homeowners (e.g. strategies D and H). In addition, it appears that positive incentives (strategies B and J) are more effective than negative incentives (strategies C and I), as measures to encourage voluntary floodproofing. The most ineffective strategies are E (reduced liability) and A (do nothing). Even under the "Do Nothing" strategy (A), a significant proportion (45.51%) of respondents would still be

[98] The DSS settings used to calculate these market shares are described in Appendix H.

willing to floodproof. Clearly, this number seems high given that the actual number of floodproofed single-family detached homes in Richmond's urban exempt zone was estimated to be around 4% (section 5.1.2.4). In other words, if 45.51% of residents are truly willing to floodproof when no floodproofing strategy is utilized, then why have so few done so?" It seems likely that the results shown in Table 17, overestimate the percentage of people who would floodproof under each voluntary floodproofing strategy.[99] Although there are concerns with the absolute validity of the numerical results of the personal floodproofing model, the output of the DSS is still extremely useful because it identifies which of the voluntary strategies would be <u>relatively</u> more successful at encouraging floodproofing.

If the voluntary floodproofing rates are inaccurate, there could be two key effects on the final evaluation of alternatives (e.g. the final scoring and ranking of the floodproofing strategies). First, since the floodproofing rate (the proportion of homeowners expected to floodproof under each floodproofing strategy) is used as a parameter in many of the impact assessment models, the floodproofing rates will affect the model outcomes, which could in turn influence final ranking of the floodproofing strategies. Second, not all of the alternative floodproofing strategies are voluntary. One strategy, (F) – strict regulations, invokes mandatory floodproofing of homes under redevelopment or major

[99] There are several explanations for the existence of overestimation in the personal floodproofing DSS results. First, the survey had a strong educational or informative component because the personal floodproofing decision problem occurred at the end of the survey. By this point participants had spent almost an hour viewing presentations on flooding and floodproofing and thinking about the impacts of flooding as they answered various survey questions. In this situation, it seems probable that individuals would overstate their willingness to floodproof because their attention was focused on the issue of floodproofing, while the multitude of other competing demands and concerns in life were not at the forefront. Secondly, the survey was obviously a hypothetical environment. Individuals are not held financially accountable for their answers to any of the questions, so it seems possible that many respondents who indicated that they would like to floodproof would not actually do so when asked to undertake the expense and inconvenience associated with carrying out the project. Finally, although the model used in the development of the decision support system was based on the non-dominated response set, individual respondents still tended to favour one option, which contributes to the sizeable intercept values calculated for the two floodproofing options. In many cases, the large intercepts contribute significantly to the calculation of the market share and as a result the market shares for the two floodproofing options are likely overstated in relation to the "No floodproofing" option. The three reasons given above to explain the potential overestimation of the market shares for floodproofing options in the personal floodproofing choice task suggest that the results cannot be used directly as absolute estimates of the proportion of homeowners who would be willing to floodproof under each strategy. In other words, the results must be utilized and interpreted cautiously.

renovation. If the floodproofing rates for the eight voluntary floodproofing strategies are overestimates, the final ranking of strategy F in relation to all the voluntary floodproofing strategies could be affected. Due to these two concerns, a sensitivity analysis was performed to investigate the effect (if any) that overestimation of the adoption rates for various floodproofing strategies could have on the final ranking of alternatives, and will be discussed in section 5.2.2.4.

Using the market shares derived from the personal floodproofing DSS, the following estimates for the rate of floodproofing adoption in homeowners were calculated (Table 31).[100]

Table 31 Voluntary floodproofing adoption rates used in the objective impact assessment models.

Alternative Floodproofing Strategy	Floodproofing Rate (%/year)
Alternative A (Do Nothing)	2.28
Alternative B	3.28
Alternative C	3.03
Alternative D	3.89
Alternative E	2.63
Alternative H	4.10
Alternative I	3.20
Alternative J	3.56

5.1.2.5.2 DSS for the Community Outcomes Choice Task

The results of the decision support system for the community outcomes choice task will be discussed in the following section, since this DSS is concerned with the evaluation and comparison of the floodproofing strategies.

[100] As mentioned previously, the adoption rate for the one non-voluntary strategy (F – strict regulations) was not calculated using the results of the personal floodproofing DSS. The rate (0.93 %/year) was instead based on the rates of redevelopment and renovation in the community as calculated from data provided by the City of Richmond planning department (Jones 2003a, 2003b, 2003c).

5.2 Step 4 - Comparison and Evaluation of Alternatives

The last stage in the decision analysis process combines the outputs of the three previous steps: problem structuring (Chapter 4, section 4.2), impacts of alternative (Chapter 4, section 4.3), and preference elicitation (section 5.1) to arrive at an overall ranking of the alternatives. The comparison and evaluation of alternatives can be approached in several ways. Given the interest in investigating the complementarities of multi attribute decision analysis and stated preference modelling in this research project, two different approaches were used: 1) decision analysis and 2) discrete choice analysis.

Before discussing the final comparison and evaluation of alternatives, it is necessary to briefly present the final impact assessment, which was calculated using the floodproofing adoption rates estimated from the survey (Table 31).

5.2.1 Final Impact Assessment for Selected Alternatives

Table 32 shows an objectives-by-alternatives matrix[101] in which the estimated model outcomes for each objective are compared for each of the nine alternatives developed in the problem structuring phase (refer to Chapter 4, section 4.2.3 to review the alternatives).

Monte Carlo Simulations on model results

Monte Carlo simulations (Robert and Casella 1999) were performed on the impact assessment models in order to provide an indication of the effect that uncertainty in the model parameters might have on the model results. For each alternative of interest, Monte Carlo simulations were performed[102] using the input assumptions described in Table 33. Two thousand trials were executed and, for each trial, the input values were varied by drawing numbers from the appropriate probability distribution. The impact

[101] This type of output is also referred to as a payoff/value/performance/decision matrix, or a consequence table (Goicoechea *et al.* 1982, von Winterfeldt and Edwards 1986, Dodgson *et al.* 2000, Yoon and Hwang 1995).

[102] Monte Carlo simulations were carried out using Crystal Ball, a simulation and forecasting program that can be used with Microsoft Excel.

estimates (e.g. the output of the models) for each objective were monitored during the simulations, which allowed the program to compile a forecasted probability distribution for each objective impact estimate for each alternative. The simulations allowed each impact estimate (e.g. Table 32) to be described by a probability distribution with a mean and standard deviation. Since these forecasts were produced for every alternative and for every objective, the results will not be described in this document. However, the Monte Carlo results were incorporated into the final evaluation of alternatives by including the probability distributions for each impact in the analysis. As a result, the sensitivity and uncertainty analyses performed on the results reflect the information provided by the Monte Carlo simulations.

As noted previously, once the final alternative impact assessment had been performed, the evaluation of the alternatives was completed using two distinct approaches: decision analysis and discrete choice modelling.

Table 32 Impacts-by-alternatives matrix – the objective impacts for each of the nine alternatives.

Attribute	Description	A *Do nothing*	B *Positive Incentives*	C *Negative Incentives I*	D *Wealth Transfer I*	E *Reduced Liability*	F *Strict Regulations Only*	G *Wealth Transfer II*	H *Negative Incentives II*	I *Positive Incentives II*
Public Costs	Net amount that the government will spend to support floodproofing (AVERAGE $ per household).	$0.00	$1,513.00	$0.00	$0.00	$0.00	$0.00	$6,070.00	$0.00	$7,100.00
Homeowner Costs	Homeowner spending on floodproofing or levies (AVERAGE $ per household, NET of financial aid).	$18,399.54	$24,486.35	$26,970.39	$31,627.22	$21,199.47	$7,477.23	$26,729.18	$28,107.36	$21,299.29
Public Damages	Average flood disaster assistance that the government will likely have to pay to each household after a major flood ($).	$43,840.26	$30,626.85	$33,408.62	$21,586.10	$30,484.95	$62,830.34	$18,804.33	$24,991.19	$26,454.20
Homeowner Damages	Average amount that homeowners will have to pay to repair damages to their homes after a major flood ($).	$11,960.06	$8,656.71	$9,352.16	$6,396.52	$19,230.25	$16,707.58	$5,701.08	$15,161.68	$7,613.55
Aesthetics	% of homes greater than 2 stories tall in any given neighbourhood.	27	34	33	38	30	15	39	34	36
Bureaucracy	Number of new regulations added to the building permit application process.	None	None	None	None	None	1 or more	None	None	None
Accessibility	% decrease in the availability of single storey homes built at ground level.	37	48	46	55	42	17	57	48	51
Safety	% of homes that are floodproofed to the provincial standard.	50	69	65	82	57	22	86	68	75
Stress and Disturbance	Average length of time that residents will be unable to occupy their homes after a major flood (weeks).	10	7	8	5	9	13	5	7	6

Table 33 Monte Carlo assumptions used for model input values

Variable	Distribution Type	Mean	Standard Deviation (10 to 25% of mean)
F (Alternative A), floodproofing rate (%/yr)	Normal	2.30	0.58
F (Alternative B)	Normal	3.25	0.81
F (Alternative C)	Normal	3.05	0.76
F (Alternative D)	Normal	3.90	0.98
F (Alternative E)	Normal	2.65	0.66
F (Alternative G)	Normal	4.10	1.03
F (Alternative H)	Normal	3.20	0.80
F (Alternative I)	Normal	3.55	0.89
Municipal Taxes ($/yr)	Normal	2000	200
Proportion of homes built slab-on-grade	Normal	0.40	0.10
Proportion of homes built on basements	Normal	0.37	0.04
Proportion of homes built on crawlspaces	Normal	0.23	0.02
Average grade of homes in community (m)	Normal	0.90	0.09
Rate of redeveloped in community (homes/yr)*	Normal	220	100
Rate of major renovation (>$100,000) (homes/yr)*	Normal	4.5	1
Damages for floodproofed homes ($/sqft):			
- Entire structure above the FCL	Normal (>0)	0	0.5
- All habitable space above the FCL	Normal	0.25	0.06
- Habitable space above a carport	Normal	2.5	0.63
- Habitable space above a garage	Normal	3.5	0.88
Average assessed structural value of homes ($):			
- Homes 1 storey tall	Normal	35000	3500
- Homes 1.5 stories tall	Normal	30000	3000
- Homes 2 or more stories tall	Normal	10000 0	10000
Percent damage to structure at 8.5 ft	Normal	100	10
Number of at risk homes in community	Normal	24000	2400
Average costs of floodproofing per home ($/sqft): **			
- wet floodproofing, basement to 2 ft	Normal	1.70	0.43
- wet floodproofing, basement to 4 ft	Normal	3.50	0.88
- wet floodproofing, basement to 8 ft	Normal	10	1.00
- elevation, basement to 2 ft	Normal	17	1.70
- elevation, crawlspace to 2 ft	Normal	17	1.70
- elevation, slab-on-grade to 2 ft	Normal	47	4.70

*used to define F for non-voluntary floodproofing strategies
**other floodproofing costs are calculated using these six base values.

5.2.2 Evaluation using Multiple Attribute Decision Making

The decision analysis software, Criterium Decision Plus, was used to compare the nine alternatives from three perspectives: floodplain managers, public preferences (1), and public preferences (2). The two different public perspectives were used to compare the effect that a change in direction of preference for the public costs and public damage attributes had on the analysis.[103] Comparing the results of the different public

[103] As mentioned in section 5.1.2.2, the initial assumption that value would be maximized when Public Sector Costs and Public Sector Damages were minimized did not hold when the results of the two stated preference tasks were analysed.

preference models provided an indication of the effect that the subtle difference in preferences had on the final ranking of alternatives. In the following sections, the title 'public preferences 1' will represent a decision making model that assumes that the public prefers to minimize Public Sector Costs and Public Sector Damages (the original assumption as reflected in the objective-rating task and the flood managers' swing weighting task), while 'public preferences 2' will represent a decision making model that assumes that the public prefers to maximize Public Sector Costs and Public Sector Damages (the direction indicated by the results of the community outcomes stated preference tasks).

To evaluate each alternative, a simple scoring algorithm was used in which each objective weight was combined with the assessed impact for that objective and summed over all objectives:

Equation 33 $$Vi = \sum_{m=1}^{M} w_m v_m (x_{im}) \quad ,$$

where Vi is the value of alternative i; w_m is the vector of weights for the attributes; v_m is the value function for attribute m; and x_{im} is the level of attribute m for alternative i; and M is the number of attributes.

Given the primarily linear value functions observed for each attribute from the results of the community outcomes stated preference survey and the robustness of the linear model as claimed by decision analysts (von Winterfeldt and Edwards 1986), linear value functions were assumed for each attribute.[104] The same weight sets (e.g. w_m) were used for both the public preferences 1 and public preferences 2 decision models and were based on the MDC survey results (Table 24). The weight set for the expert preferences decision model was based on the results of the flood managers' swing weighting task (Table 17). All of the calculations and analysis were performed using the decision

[104] Due to the limited scope of this project, the expert group was not given a task designed to derive preferences for the shape of the value functions associated with each objective. Instead for the sake of simplicity, it was assumed that these value functions would be linear.

analysis software Criterium Decision Plus. To derive the x_{im} values, the impacts in Table 32 were re-scaled from 0 to 1 to ensure compatible measurement scales.[105] In addition, the weight sets (both public and expert derived) were also scaled from 0 to 1. Since the weights and value functions were all scaled between 0 and 1, the score for each alternative falls between 0 and 1. Appendix I provides tables that describe in detail how the basic results shown in the three following sub-sections were calculated.

5.2.2.1 Decision Model I – Public Preferences 1

Figure 27 shows a graphical comparison, exported from Criterium Decision Plus, of the overall decision scores calculated for each alternative. In addition, the contribution of each attribute (a combination of weight and attribute value) to the total score of each alternative is displayed as shading within each horizontal bar.

The top three ranked alternatives are the two wealth transfer alternatives (D and G) followed by alternative B – the tax break incentive alternative. The alternative that performs the worst in this model is alternative F (Strict Regulations).

Sensitivity Analysis

To investigate the effect that uncertainty in the model parameters could have on the ranking of the alternatives, the probability distributions associated with each attribute value (as derived from the Monte Carlo simulations) were entered into Criterium Decision Plus. CDP then integrated this information by calculating the probability of various scores given the uncertainties in the information about that alternative. The results of this analysis are displayed in (Figure 28).

[105] In other words, for the range of attribute values describing the set of alternatives for each objective, the 'best' impact was scaled to equal '1' while the 'worst' impact was scaled to '0' and the rest of the values were scaled between 0 and 1 depending on the magnitude of their impact on the original scale.

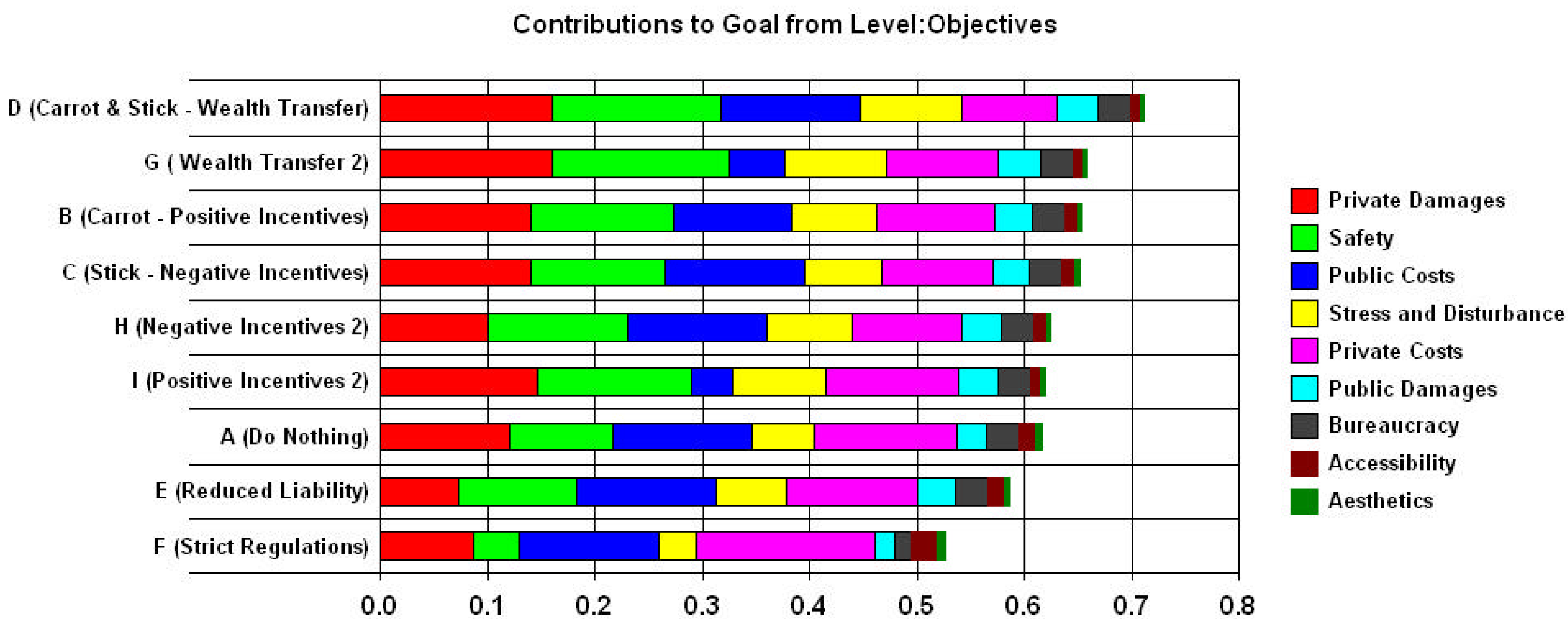

Figure 27 Decision scores for the public preference decision model 1.

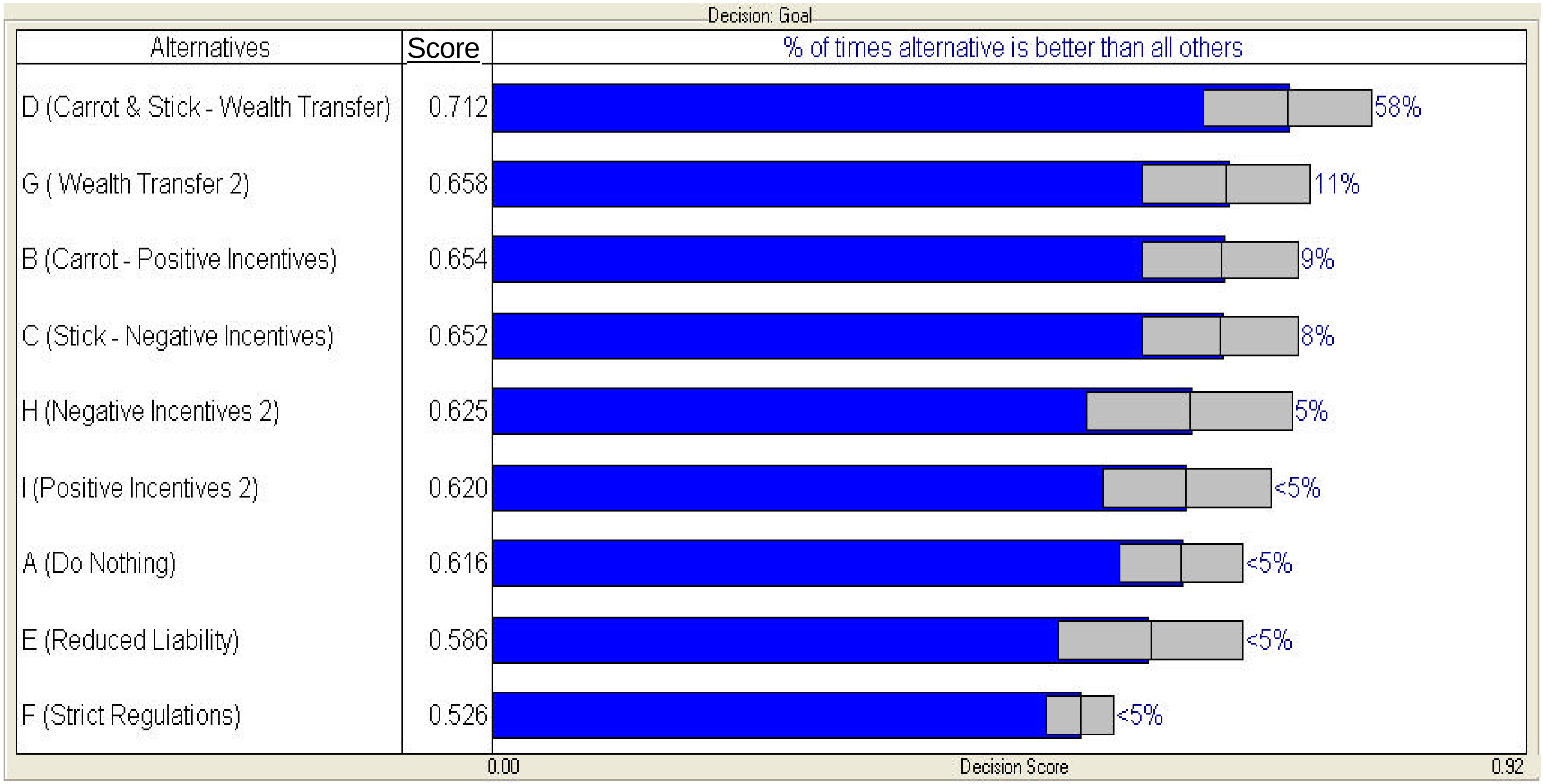

Figure 28 Decision scores and uncertainty information for the public preference decision model 1.

The total score for each alternative is listed in the second column of Figure 28, and the lengths of the dark shaded horizontal bars reflect the magnitude of this score. This information is the same as shown in the previous figure but with less detail regarding the contribution of each attribute to the total score. The light shaded bars to the far right of each horizontal bar represent the range of scores that could result given the uncertainty contained in the Monte Carlo derived probability distributions. The left edge of the light grey rectangle shows the decision score value corresponding to the lower 5th percentile of the overall uncertainty distribution. In other words, there is a 95% probability that the alternative's decision score is higher than this value. The right hand side of the grey box shows the 95th percentile, and the vertical line within the grey rectangle is the mean decision score for the alternative when uncertainty is taken into account, which in general is the same as the scores calculated without uncertainty.

The percentage value at the far right of Figure 28 indicates the percentage of time that the alternative would be a better choice than all of the other alternatives taken together – a number which is calculated using the range of the uncertainty distributions. As shown in Figure 28, the top alternative (D) is better than all the other alternatives 58% of the time, while the second place alternative is only a better choice 11% of the time. Furthermore, only alternatives in the top four are better than all others more than 5% of the time.

The second sensitivity analysis involved observing how changes in the relative weights effect the ordering of the alternatives. In this analysis, the relative weight for one objective is increased at the expense of an equal decrease in the weights of all of the other objectives. The weight at which the number one ranked alternative changes to another alternative is noted as the transition point. For each objective, Table 34 summarizes four key pieces of information: 1) the objective's original relative weight, 2) the weight at which a new alternative became ranked first overall (transition point), 3) the percentage change in the objective weight required to achieve this transition, and 4) the alternative that was preferred after the transition occurred.

Table 34 Public Preferences Decision Model 1 – Sensitivity table for relative attribute weights.

Top Scoring Alternative: D (Wealth Transfer I)				
Attribute	**Relative Weight**	**Transition Point**	**% Change**	**Preferred Alternative After Transition**
Homeowner Costs	0.19	0.42	121 %	A (Do Nothing)
	0.19	0.46	142 %	F (Strict Regulations)
Public Damages	0.05	0.67	1240 %	G (Wealth Transfer II)
Public Costs	0.13	0.05	-62 %	G (Wealth Transfer II)
Aesthetics	0.01	0.33	3200 %	F (Strict Regulations)
Accessibility	0.03	0.30	900 %	F (Strict Regulations)
Safety	0.23	0.72	213 %	G (Wealth Transfer II)

The sensitivity analysis on the relative weights for the public preferences model shows that in most cases the relative weights must increase significantly (more than double in most cases) before the original preferred alternative (strategy D – wealth transfer I) is no longer the top ranked alternative. The preferred alternative after the transition point is almost equally split between strategy F (Strict Regulations), which originally ranked ninth, and strategy G (Wealth Transfer II), which originally ranked second.

5.2.2.2 Decision Model II – Public Preferences (2)

Figure 29 shows a graphical comparison of overall floodproofing strategy scores for public preferences model 2, which makes a different assumption about public preferences (see section 5.2.2). Again, the contribution of each attribute (a combination of weight and attribute value) to the total score of each alternative is displayed as shading within each horizontal bar.

The top three alternatives again include the two wealth transfer alternatives (D and G). In contrast to the public preferences decision model 1, strategy I (Positive Incentives II) is the number one scoring alternative, while strategy D (Wealth Transfer I) is ranked third (instead of first). Strategy G (Wealth Transfer II) remains in second place but its score is almost equivalent to that of strategy I. Although the ordering is slightly different, the top three strategies still include both wealth transfer alternatives and a positive incentive strategy (I instead of B). The changes in ordering observed between the two public preferences models are not surprising given the changes in direction of preference for the Public Sector Costs and Public Sector Damages attributes between the two decision models.

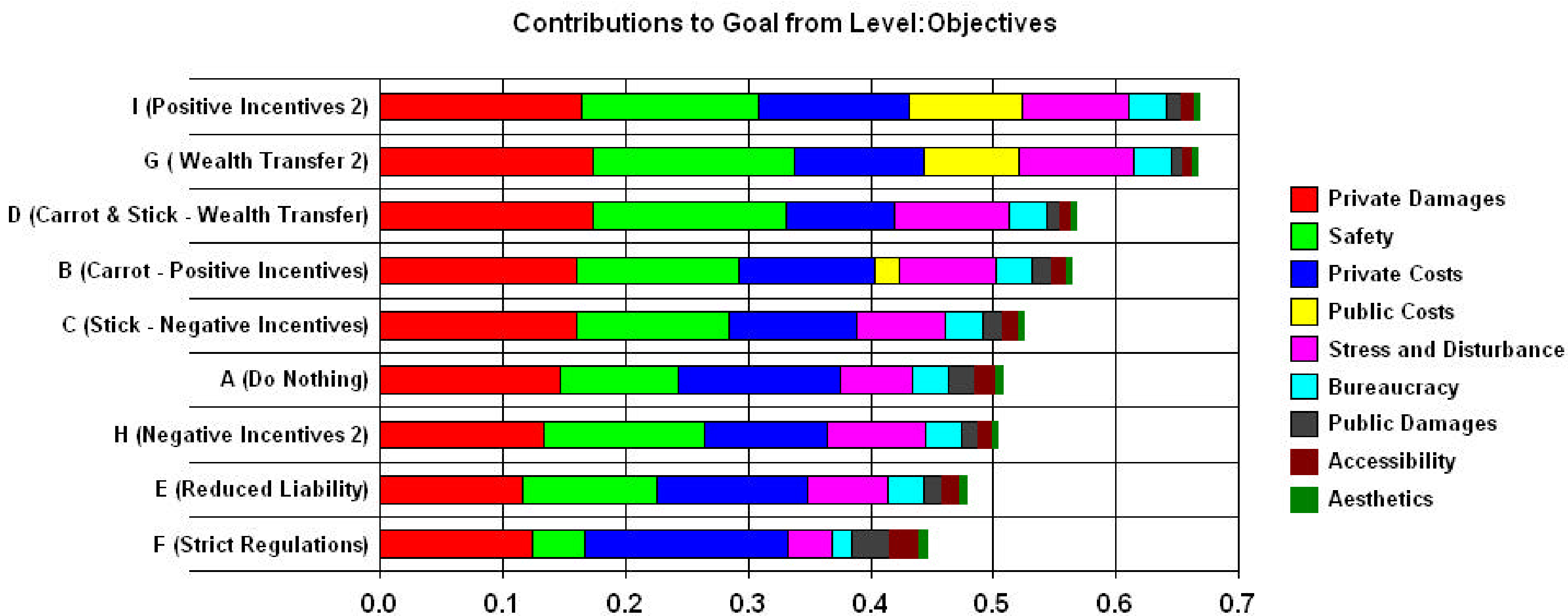

Figure 29 Decision scores for the public preference decision model 2.

In the public preferences decision model 1, the direction of preference for public costs and damages was assumed to be minimization whereas in the public preferences decision model 2, the direction of preference for these two attributes was maximization. Consequently, alternatives that put a higher cost and/or damage burden on the public sector (e.g. strategy I contains a substantial government funded floodproofing grant) move up in the ranking relative to other strategies.

Sensitivity Analysis

As with public preferences decision model 1, two primary sensitivity analyses were performed (Figure 30, Table 35). Refer to section 5.2.2.1 for a detailed explanation regarding how to interpret the results.

As shown in Figure 30, the two alternatives with the highest scores (I and G) are better choices than all of the other alternatives combined 49% and 46% of the time respectively. None of the other alternatives ever scores better than the all the other alternatives more than 5% of the time. In this decision model, it is clear from the uncertainty analysis that there is really no clear distinction between the number one and two ranked alternatives but both these alternative are significantly preferred to any of the remaining alternatives.

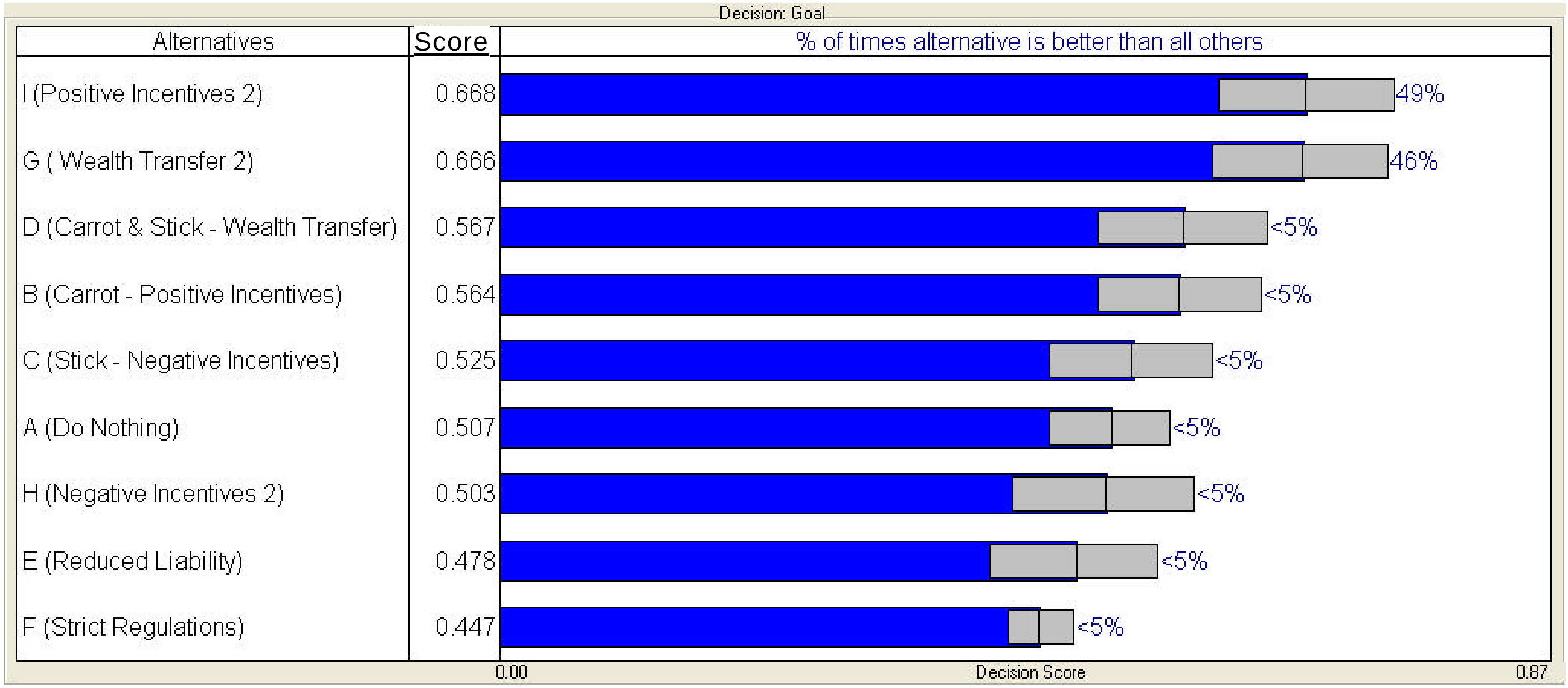

Figure 30 Decision scores and uncertainty information for the public preference decision model 2.

Table 35 Public Preferences Decision Model 2 – Sensitivity table for relative attribute weights.

Top Scoring Alternative: I (Positive Incentives II)				
Attribute	**Relative Weight**	**Transition Point**	**% Change**	**Preferred Alternative After Transition**
Public Costs	0.13	0.10	-23 %	G (Wealth Transfer II)
Safety	0.23	0.27	17 %	G (Wealth Transfer II)
Homeowner Costs	0.19	0.18	-5 %	G (Wealth Transfer II)
	0.19	0.59	210 %	F (Strict Regulations)
Public Damages	0.05	0.03	-66 %	G (Wealth Transfer II)
	0.05	0.41	720 %	F (Strict Regulations)
Homeowner Damages	0.20	0.25	25 %	G (Wealth Transfer II)
Stress and Disturbance	0.13	0.17	31 %	G (Wealth Transfer II)
Aesthetics	0.01	0.40	3900 %	F (Strict Regulations)
Accessibility	0.03	0.36	1100 %	F (Strict Regulations)

In the sensitivity analysis on the relative weights for the public preferences 2 decision model, only two alternatives are preferred after the transition point: strategy F and strategy G. Significant increases in the relative weight of a given attribute are required before strategy F becomes preferred (a minimum 210% increase with the Public Sector Damages attribute). Conversely, the transition to strategy G (Wealth Transfer II) is observed when attribute weight decreases by as little as a 5% (for the attribute Homeowner Costs).

5.2.2.3 Decision Model III – Expert Preferences

Similarly to Figure 27 and Figure 29, which displayed the results for the two public preference decision models, Figure 31 compares, from the expert perspective, the overall decision scores calculated for each alternative floodproofing strategy. As displayed in Figure 31, the top three alternatives again include the two wealth transfer alternatives (D and G), which are ranked first and second respectively. For this model, alternative C (the floodproofing levy strategy) is the third place alternative. As with both preceding models, the alternative that performs the worst is alternative F (Strict Regulations).

<u>**Sensitivity Analysis**</u>

As for the previous public preference decision models, two primary sensitivity analyses were performed (Figure 32, Table 36).

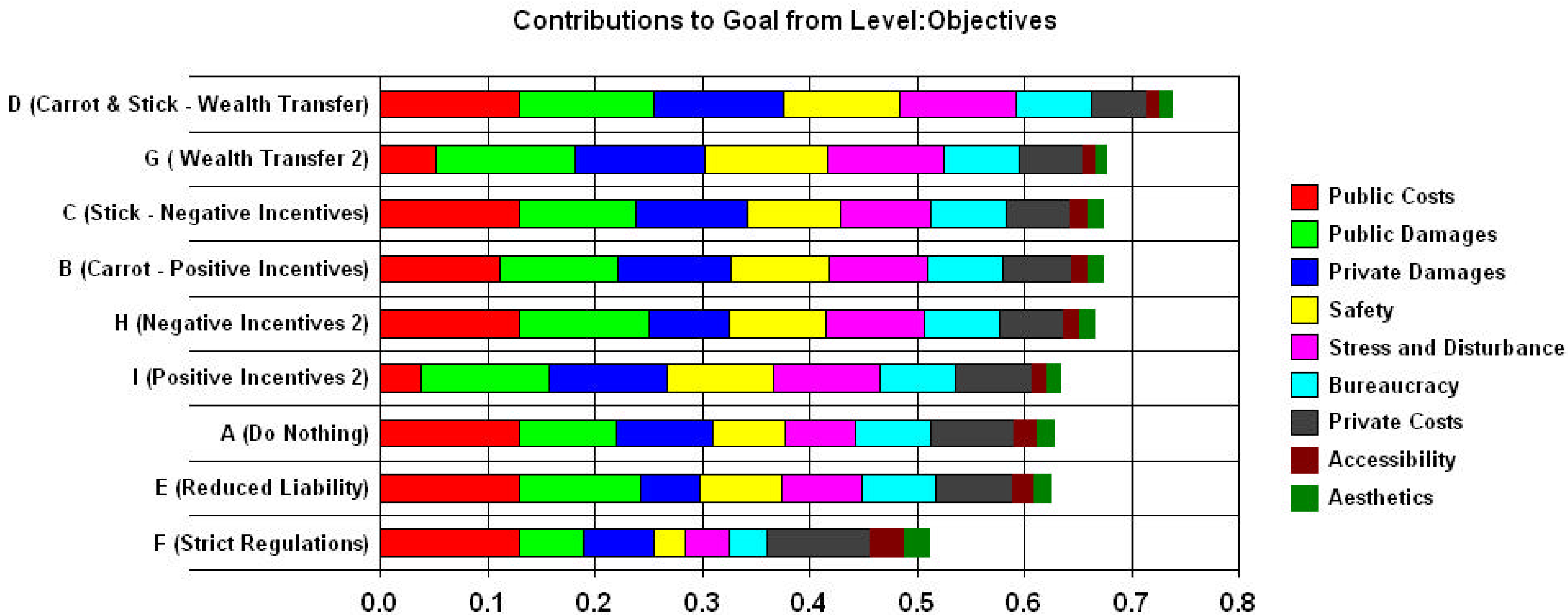

Figure 31 Decision scores for the expert preference decision model.

Figure 32 Decision scores and uncertainty information for the expert preference decision model.

As shown in Figure 32, the highest scoring alternative (D) is a better choice than all of the other alternatives combined 69% of the time. Alternatives ranking second through fifth score higher than all other alternatives 7% of the time or less. As a result, in the expert preferences model, strategy D appears to be a strong favourite.

Table 36 Expert Preferences Decision Model - Sensitivity table for relative attribute weights.

Top Scoring Alternative: D (Wealth Transfer I)				
Attribute	**Relative Weight**	**Transition Point**	**% Change**	**Preferred Alternative After Transition**
Homeowner Costs	0.11	0.40	264 %	A (Do Nothing)
	0.11	0.47	327 %	F (Strict Regulations)
Public Damages	0.16	0.72	350 %	G (Wealth Transfer II)
Public Costs	0.13	0.04	-69 %	G (Wealth Transfer II)
Aesthetics	0.03	0.39	1200 %	F (Strict Regulations)
Accessibility	0.04	0.35	775 %	F (Strict Regulations)
Safety	0.16	0.70	338 %	G (Wealth Transfer II)

As in the previous decision models, strategy F (Strict Regulations) is often preferred after the transition point but only after large increases in relative attribute weight are observed. In addition strategy A (Do Nothing) is preferred after large increases in Homeowner Costs. Similarly to the public preferences 1 decision model, the alternative that ranked second overall - strategy G (Wealth Transfer II) - is preferred in half of the cases.

5.2.2.4 Comparison of the three decision models and further sensitivity analysis

The results of the three decision models will now be briefly compared. The overall scores and ranks for the nine alternatives are contrasted between the three models in Figure 33 and Table 37.

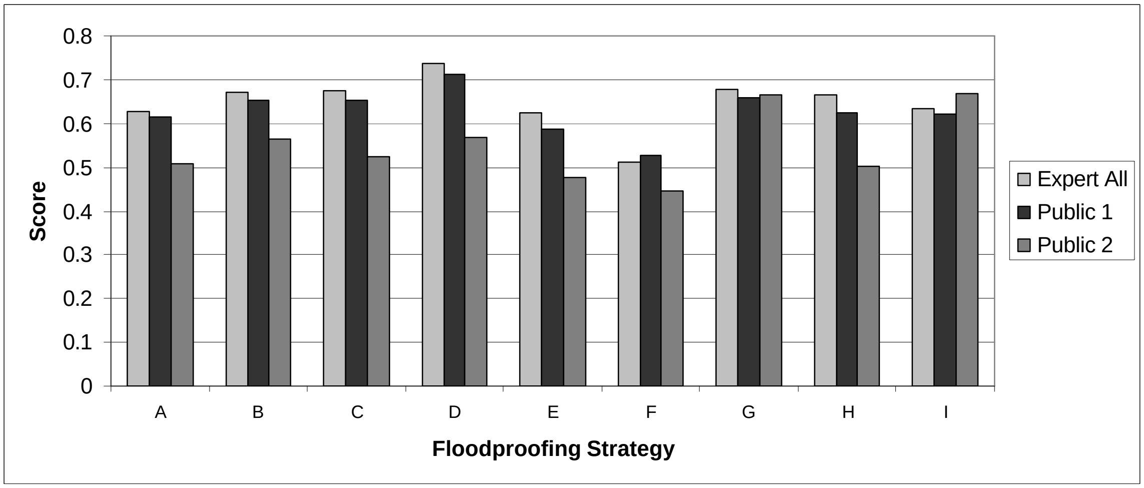

Figure 33 Overall scores for the nine floodproofing strategies categories by decision model (Expert, Public 1, and Public 2)

Table 37 Overall ranks compared for the nine alternatives between the three decision models.

	Decision Model		
Alternative	***Public 1***	***Public 2***	***Expert***
A (Do Nothing)	7	6	7
B (Carrot - Positive Incentives I)	3	4	4
C (Stick - Negative Incentives I)	4	5	3
D (Carrot & Stick – Wealth Trans I)	1	3	1
E (Reduced Liability)	8	8	8
F (Strict Regulations)	9	9	9
G (Wealth Transfer II)	2	2	2
H (Negative Incentives II)	5	7	5
I (Positive Incentives II)	6	1	6

The two wealth transfer alternatives rank in the top three for all decision models. In other words, the wealth transfer alternatives generally meet the objectives of both the public and experts despite differences in values (e.g. relative weights) and even differences in opinion regarding the direction of preference for some of the objectives (e.g. whether Public Sector Costs and Public Sector Damages should be maximized or minimized). The floodproofing strategies utilizing either positive or negative incentives tend to show average performances except for strategy I, which ranked first for public preference model 2, but sixth in both public preferences model 1 and the expert preferences model. For all three decision models, strategies E and F rank eighth and ninth respectively, while the "Do nothing" strategy also performs poorly, with two seventh place rankings and one sixth place ranking. As a result, "Doing Nothing," "Reducing Liability," or "Imposing strict regulations" as sole strategies seem to be the least successful at achieving the nine fundamental objectives used as evaluation criteria for this research project. Recall that strategy F is a non-voluntary floodproofing strategy. Consequently, these results must be considered in light of the caveat discussed earlier (section 5.1.2.5.1) regarding the potential overestimation of the rates of floodproofing adoption for the voluntary floodproofing strategies. As described in the following paragraphs, further sensitivity analyses were used to investigate the effects of the voluntary floodproofing rates on the rankings.

In order to investigate how the final ranking of alternatives could be influenced by inaccuracies in the floodproofing adoption rates, an attempt was made to correct for the overestimation bias. As mentioned previously, the percentage of homes floodproofed inside the urban exempt zone was calculated, using the results of the survey, to be approximately 3.7%. Given that the provincial regulations regarding floodproofing for new developments were implemented in 1973, it is reasonable to assume that, although not required, any floodproofing in the exempt zone was probably implemented since 1973 (perhaps on the individual initiative of informed or concerned residents). There is no completely accurate way to 'back-calculate' the yearly rate of floodproofing since 1973, since the yearly floodproofing rate will depend on such factors as the growth rate of the area in question, and the rate at which newly built homes are floodproofed in relation to pre-existing homes. A rough estimate of 0.20 % for the yearly rate of floodproofing over time was derived using a simple simulation model and a few simplifying assumptions (see Appendix J for a full account of how this estimate was derived). Subtracting this estimate from the "Do Nothing" floodproofing rate described in Table 31 gives a correction factor of 2.26%, which was then applied to each of the original voluntary floodproofing rates. The corrected voluntary floodproofing adoption rates were then used to recalculate the impact models and the three decision models within Criterium Decision Plus. The results of the reanalysis are shown in Figure 34, Figure 35, and Figure 36 for the Public Preferences 1, Public Preferences 2, and Expert Preferences decision models respectively.

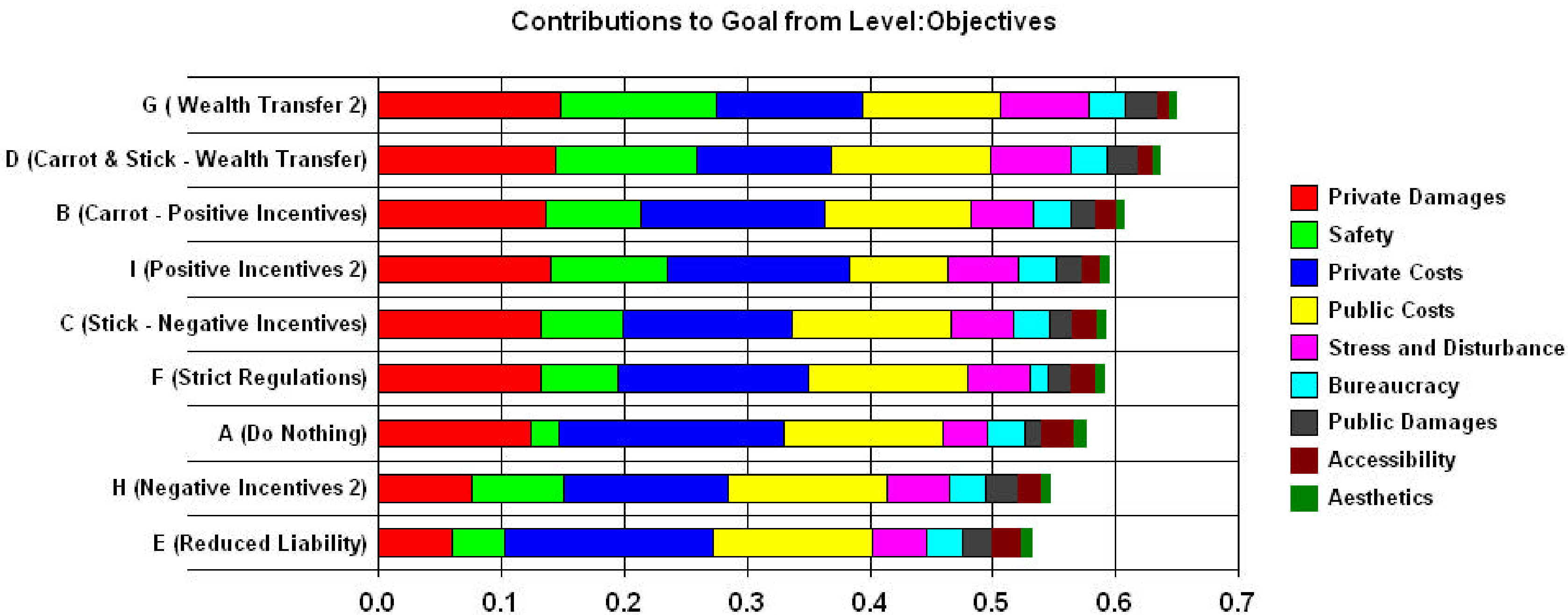

Figure 34 Decision scores for the public preference decision model 1 – Sensitivity analysis using corrected floodproofing rates for the voluntary floodproofing strategies.

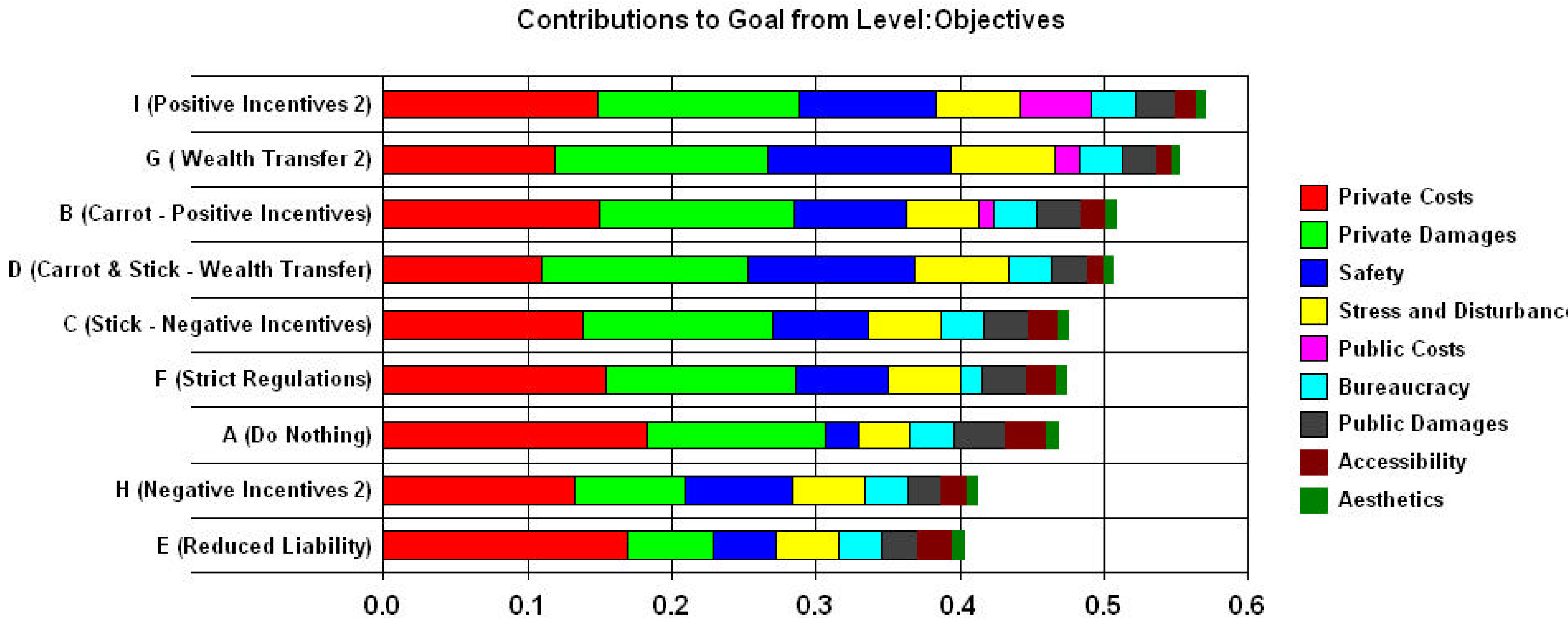

Figure 35 Decision scores for the public preference decision model 2 – Sensitivity analysis using corrected floodproofing rates for the voluntary floodproofing strategies.

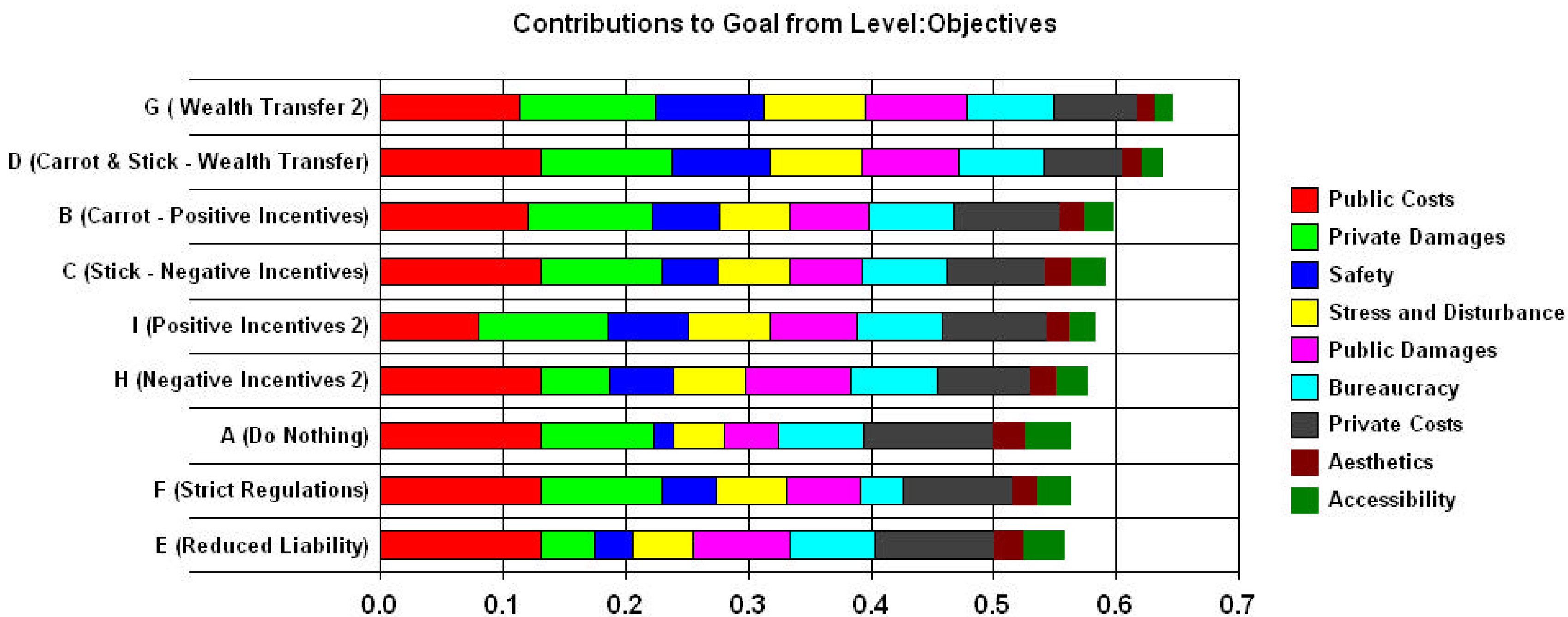

Figure 36 Decision scores for the expert preferences decision model – Sensitivity analysis using corrected floodproofing rates for the voluntary floodproofing strategies.

By comparing Figure 34 with Figure 27, it is clear that the rank ordering of the floodproofing strategies is somewhat sensitive to the rates of floodproofing adoption used in the impact assessment model. In particular, strategy (F) moved up in rank from ninth to sixth. In addition, strategy (I) improved from sixth place to fourth place, while strategy (H) moved down three places to eighth. Furthermore, a rank reversal is evident between the first and second place alternatives; strategy (G) is now the preferred alternative over strategy (D). Despite the adjustments observed in the rankings for a number of alternatives, it must be stressed that in both models the same three strategies (G, D, and B) outperform the remaining alternatives.

As with the sensitivity analysis for public preferences decision model 1, contrasting the sensitivity results with the original results for the public preferences decision model 2 (Figure 35 and Figure 29) reveals a reordering of alternatives in some cases. Again, strategy (F) increases in rank from ninth to sixth. In addition, a rank reversal is observed between the third and forth place alternatives; alternative D is replaced by alterative B as the third ranked alternative. The rank of the number one and two alternatives (I and G) remain unchanged.

Although there are a number of changes in rank order observed between Figure 31 and Figure 36 for the expert preferences decision model, the most significant involves the two rank reversals of the first and second place alternatives and the third and fourth placed alternatives. Consequently, strategy (G) is now the preferred alternative over (D), although not by a significant margin in actual score. In addition, a negative incentives strategy (C) has been replaced in third position by a positive incentives strategy (B).

<u>Conclusion</u>

The preceding section compared and contrasted the scores and associated rank orders of the nine alternatives from three different preference perspectives. Various sensitivity and uncertainty analyses were performed to test the robustness of the recommendations made by each model. Incorporating information about uncertainty into the calculation of the decision scores revealed that the top scoring floodproofing strategies for each decision model were fairly robust to the effects of uncertainty in the impact model parameters. In other words, generally alternatives that ranked lower than third were rarely found to be a better choice than all of the other alternatives more than 5% of the time. In addition, an analysis of the effect that changes in attribute weight could have on the results indicated that normally the relative weights of individual attributes would need to change significantly to replace the top ranked alternative and that the preferred alternative after the transition point was often the strategy that had originally ranked second. When the effect of overestimation of voluntary floodproofing adoption rates was investigated, it was revealed that the ordering of alternatives did change, but no major reordering of the top three ranked alternatives occurred. Furthermore, although there was some concern that overestimation of the floodproofing adoption rates for the voluntary floodproofing strategies could significantly affect the ranking of strategy (F), a mandatory strategy, the sensitivity analysis on the voluntary floodproofing rates showed that strategy (F) did not outperform any of the top ranked alternatives and never ranked higher that sixth.

In all of the analyses completed, the top three alternatives consistently included three strategies: D – a wealth transfer alternative involving tax breaks and levies, G - a wealth transfer alternative involving grants and levies, and B – a positive incentives alternative focused on tax breaks. Other alternatives occasionally ranked in top three, including (I), a positive incentive strategy of homeowner grants, and (C), a negative incentives strategy involving levies. As a result, it may be concluded with some confidence that based on the decision analysis results, floodproofing strategies involving creative systems of wealth transfer or approaches utilising positive incentives are the most likely to result in outcomes for the community that are in the interests of both floodplain managers and homeowners and are likely to adequately address concerns associated with the nine fundamental floodproofing objectives. Furthermore, the analysis proved that, given the assumptions and constraint of the study, the "Do Nothing" strategy is not a preferred option.

5.2.3 Evaluation using the Community Outcomes Discrete Choice Model

A second comparison of the nine alternatives was undertaken using a DSS built with the results of the Community Outcomes discrete choice experiment. The results of the best-fit linear model to the data from the 'Choice plus Base' analysis (e.g. Table 22) were used as parameters in the DSS. As with the Personal Floodproofing DSS, the alternatives of interest were compared by entering their appropriate attribute values (e.g. the impacts described in Table 32) into the DSS.[106] The percent support or 'market share' for each alternative was then calculated using the MNL equation.[107] The results of the Community Outcomes DSS analysis on the nine alternatives are described in Table 38. The percentage value listed in column 2 (labelled 'Alternative') is the proportion of respondents who would be expected to prefer the alternative floodproofing strategy listed in the first column, while the value in the 'Base Option' column (column 3) is the proportion who would prefer the base option over the floodproofing strategy.

Table 38 Community Outcomes Choice Model DSS output – Comparison of the nine floodproofing strategies using percentage market shares and rank.

Floodproofing Strategy	Market Shares (% who would choose…)		Rank
	Alternative	*Base Option*	
G (Wealth Transfer II)	72.9	27.1	1
I (Positive Incentives II)	70.2	29.8	2
D (Carrot & Stick – Wealth transfer)	65.1	34.9	3
B (Carrot - pos. Incentives)	61.5	38.5	4
C (Stick - neg. incentives)	55.6	44.4	5
A (Do Nothing – Current)[108]	51.1	48.9	6
H (Negative Incentives II)	49.8	50.2	7
E (Reduced Liability)	43.9	56.1	8
F (Strict Regulations Only)	35.3	64.7	9

The Community Outcomes DSS output can be compared to the results provided by the decision analysis on the same nine alternatives. The appropriate model for comparison in this case is public preference decision model 2, because the DSS uses the public

[106] The DSS settings are described in Appendix H.

[107] The DSS replicated the structure of the 'Choice plus Base' which asked for a choice between Outcome A or Outcome B vs. the 'Base Alternative'. In other words, the DSS calculations compared an alternative floodproofing option (generic Outcome A or B) to the base or 'Do Nothing' option.

[108] Since the base option was equivalent to the "Do Nothing" option, the market shares of alternative floodproofing strategy A (Do Nothing) and the Base Option should theoretically be split 50%:50%. The fact that this result is approximately true in the actual DSS output serves as an internal validity check.

preference survey results and public preference model 2 incorporates the same direction of preference for the public costs and public damages value functions. The comparison between the two model outputs is described in Table 39.

Table 39 Comparison of the nine floodproofing strategies using the Community Outcomes DSS and the Decision Analysis public preferences model 2.

	Community Outcomes DSS		Decision Analysis - PPM2	
Floodproofing Strategy	Market Shares (%)*	Rank	Score (%)*	Rank
G (Wealth Transfer II)	14.42%	1	13.52 %	2
I (Positive Incentives II)	13.89%	2	13.57 %	1
D (Carrot & Stick – Wealth transfer)	12.88%	3	11.52 %	3
B (Carrot - pos. Incentives)	12.17%	4	11.44 %	4
C (Stick - neg. incentives)	11.00%	5	10.66 %	5
A (Do Nothing – Current)	10.11%	6	10.29 %	6
H (Negative Incentives II)	9.85%	7	10.22 %	7
E (Reduced Liability)	8.69%	8	9.71 %	8
F (Strict Regulations Only)	6.98%	9	9.07 %	9

*For comparison, the decision analysis scores and the original market shares have been reformatted to % of total.

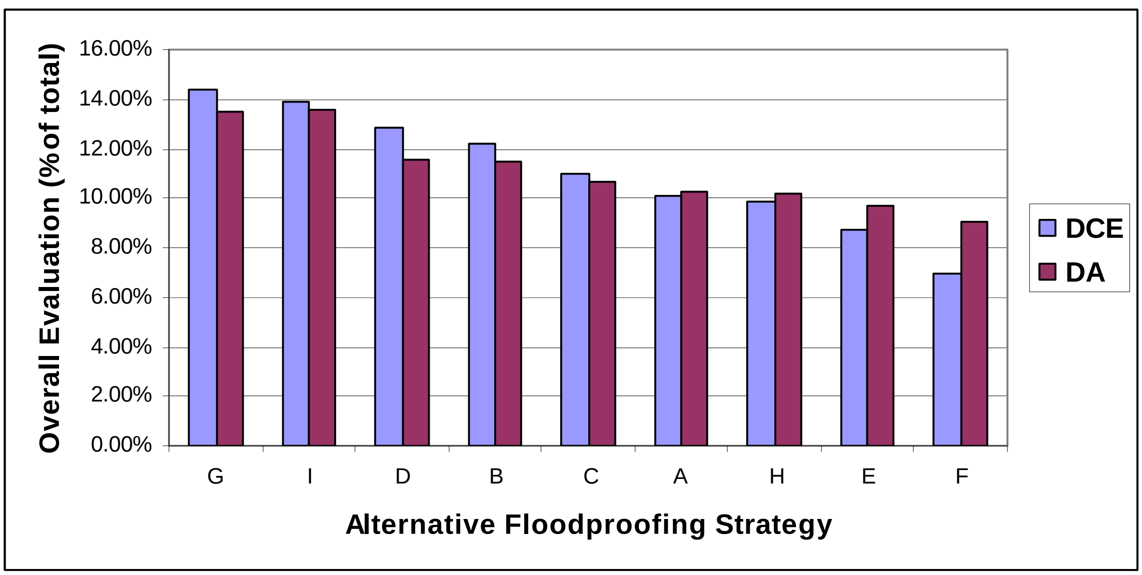

Figure 37 Comparison of the evaluations for the nine floodproofing strategies using decision analysis (DA) and the community outcomes discrete choice experiment (DCE).

The outputs of the two decision-making models are very similar. The alternatives are ranked in the same order in both models with the exception of a reversal between alternatives G and I. In both models, the top three alternatives include strategies (D), (G) and (I). As found with most of the decision analysis models, the analysis using the discrete choice data gives the highest scores to wealth transfer and positive incentives strategies. As a result, the recommended strategies based on the discrete choice results coincide with similar recommendations based on the results of the decision analysis.

The degree of similarity between the model outputs is surprising, given that the results of the community outcomes discrete choice experiment were not used in any way in the decision analysis. Except for the model inputs (e.g. the impact assessment information), the models were specified independently. The attribute preference information for the decision analysis was derived from the results of the MDC task, while the preference information for the discrete choice analysis was embedded in the coefficients derived from the choice data. In addition to a similar rankings for the alternative set, when reformatted in a similar measurement scale, the overall market shares based on the discrete choice analysis are very similar to scores derived using decision analysis methods.

The last section of this chapter will present a discussion and conclusions regarding the compatibility of Multiple Attribute Decision Making techniques and Stated Preference Choice methods. Final discussions and conclusions regarding the flood management implications of this research will be provided in Chapter 6 .

5.3 Conclusion – Compatibility of Multi Attribute Decision Making and Stated Preference Choice approaches for decision support.

Research objective 2 (Chapter 1) stated that one of the aims of this research project was to investigate the compatibility of decision analysis and stated preference techniques for analysing multiple objective decision problems of public interest. This research project endeavoured to achieve this purpose by analysing complementarities from a theoretical and an applied perspective. Chapter 3 compared the theoretical similarities and differences between the two approaches and concluded that, in general, the two methods are based on a number of very similar theoretical concepts (refer to Table 2, section 3.3).

Although a demonstration of the natural theoretical compatibility of the two methods was important for supporting the validity of a joint application, it is just as important to prove that the techniques are truly complementary from an applied perspective. This was accomplished by applying specific decision analysis and stated preference tools and techniques to the analysis of a multiple objective floodplain management problem of public interest. In particular, two stated choice methods (MDC and the DCE) were used in combination with a simple multiple attribute decision making process. The following sections will review the success of the combined approach, present suggestions for expansion of the method, and detail some limitations and potential drawbacks.

The evaluation of the compatibility of MADM methods and stated preference choice methods will focus on two aspects: 1) integration of methods, and 2) comparison of methods.

5.3.1 Integrating the Methods

Integration of decision analysis and stated preference methods was pursued on two levels: <u>general</u> and <u>specific</u>. First, integration was achieved generally by borrowing the essential concepts and ideas from both approaches to create a combined method. Specifically, the problem structuring methods of decision analysis were used to define the problem, and to develop objectives, attributes and alternatives. In addition, several key ideas in decision analysis influenced the development of the survey. Theories about the constructive nature of preference formation led in part to the use of a combination of warm-up exercises (e.g. the introductory survey questions and the objective rating questions), and simplified practice questions (e.g. the two common choice sets in the community outcomes section of the survey) for the purposes of helping respondents begin exploring and constructing their ideas and values regarding flooding and floodproofing in their community. In addition, the survey utilized more than one method for preference elicitation (e.g. objective rating, MDC, and discrete choice) to help ensure that the preference information obtained was widely valid and not just dependent on the specific method used. The <u>general</u> integration of theories and ideas during the problem structuring and survey development phases warranted the use of preference information derived from the survey in a decision analysis process. The direct use of stated preference information in a multiple attribute decision analysis process constituted the <u>specific</u> level of integration for the research project.

Multiple attribute decision analysis utilizes two forms of preference information: 1) relative weights, and 2) value functions (see section 3.1.2). Consequently, to ensure compatibility with decision analysis, the preference elicitation tasks in the public preference survey had to be suitable for providing relative weights and value functions for each fundamental objective. The utilities estimates derived from either a DCE or a MDC provide information on the shape of the value function for each objective (e.g. linear, quadratic). Furthermore, the relative differences in utilities between the best and the worst levels of an attribute can be manipulated to provide relative weights for the management objectives. As a result, the DCE and the MDC tasks can both provide preference information from a public perspective that can be <u>directly integrated</u> into a multiple attribute decision analysis.

As described in section 5.1.2.2.3, the MDC and the DCE results were successfully analysed to provide relative weights for each of the nine objectives from a public perspective. Furthermore, comparison of the results with those of the objective-rating question showed a similar preference order, which supports the validity of the results.

The public values weight set based on the MDC results was subsequently utilized in a simple MADM process, along with impact assessment information, to arrive at an overall ranking of the nine floodproofing strategies. A ranking of the nine alternatives from the perspective of floodplain managers was similarly derived and compared to that obtained for the public. As a result, it was shown that it is possible to fully integrate public preference information obtained from a stated preference survey instrument into a decision analysis process.

The success of the integrated approach is important because traditionally weights and value functions used in decision analysis processes have been limited to a select few expert decision makers and/or representatives of stakeholder groups, since the elicitation techniques were too intensive for inclusion of a wider group of participants. The approach used in this research project allows direct and full inclusion of public preference information in a decision analysis process, which can be contrasted to the indirect and often reactionary type of public preference information obtained through means such as public comments, open houses, and focus groups. In effect, the integrated approach allows the public a virtual "seat at the table" by providing preference information that is of the same form and calibre as that obtained for other decision makers and stakeholder representatives.

Benefits of the integrated approach

The primary benefit of the integrated approach is that the weights sets and value functions associated with public preferences can be directly compared with those derived for decision makers or stakeholder representatives using decision analysis methods. As a result, it is possible to pinpoint differences in value structures between various perspectives (e.g. the interests of floodplain managers vs. homeowners) that give rise to different overall evaluations of alternative options. In other words, the integrated approach allows one to determine the factors that contribute to agreements and disagreements between parties. This information can be used in many ways. First, it can be used to help solve conflicts by demonstrating how differences in values can give rise to different worldviews and by focusing the debate on the appropriate issues.

Second, information on value differences can be used proactively to design new alternatives that are compatible with the value structures of all interests.

The second benefit of the integrated approach is that the attribute values within the profiles and the sets of different profiles that participants see are carefully constructed using experimental designs to ensure that the required preference information can be elicited with a minimal number of questions. In this way, stated preference tasks may be more efficient for the survey environment than some traditional preference elicitation methods used in decision analysis (e.g. paired comparison), which may require the participant to respond to substantial numbers of questions.[109] Furthermore, the task environment of an MDC may be more realistic or meaningful than that provided by traditional decision analysis methods, such as paired comparison, since respondents make trade-offs between attributes by considering multivariate profiles, which are more descriptive of the actual decision context than a paired comparison approach in which only a subset of the data is considered in each question.[110]

5.3.2 Using the Methods Comparatively

In addition to provided preference information that may be directly integrated into a decision analysis, DCEs also provide an alternative means for evaluating competing alternatives by offering surrogate methods for completing step 3 (preference elicitation) and step 4 (evaluation of alternatives) of the decision analysis process.[111] Consequently,

[109] The value of the simplicity associated with certain preference elicitation methods, such as paired comparison, can be substantially offset by the overall number of comparisons required, which can make these types of traditional preference elicitation tasks practically infeasible for a large-scale public preference survey.

[110] Of course, this advantage will only be realized if the number of attributes included in each profile is not too large. If too many attributes are included, information overload could prevent respondents from considering all the information contained in a profile (e.g. they might resort to some simple decision rule), which would effectively negate any benefit of including the extra information in the first place.

[111] In a DCE, alternative options can be compared by calculating market shares using the appropriate choice model equation such as the MNL (usually performed in a DSS). Two pieces of information are required for the calculation: 1) the impact assessment information, which describes the attributes levels associated with each alternative, and 2) preference information in the form of part-worth utilities for each attribute level as derived from the DCE, which contain information on the relative desirability of different attribute levels.

the results of a DCE can be used in a comparative manner with the results of a decision analysis process, to provide a parallel process for evaluating alternatives.

In this project, the ranking of alternatives based on a DCE market-share calculation was compared to a similar ranking for the same alternatives using decision analysis methods. The purpose of this comparative approach was to investigate whether or not DCEs could provide a parallel process to a multi attribute decision analysis for evaluating alternatives from the perspective of the public. In other words, assuming the existence of a multiple stakeholder planning process, could a DCE provide a ranking of alternatives based on public preferences that could legitimately be compared to rankings based on a decision analysis evaluation that incorporates the preference information of individual experts and/or representatives of stakeholder groups?

For this research project, the results indicated that evaluation of alternatives within a discrete choice framework were very similar to evaluations within a decision analysis framework. Of course, for this problem the survey instrument was designed with careful consideration of the principles of decision analysis. In addition, the weights used in the decision analysis were based on a MDC preference task, which was completed on the same profiles as the discrete choice experiment. As described in section 5.1.2.2, the preference results of these two tasks were very similar, which probably played a significant role in producing the very similar rankings observed between the two approaches. Consequently, it could be possible that another preference elicitation method would have yielded different objective weights and, in turn, a different ranking within a decision analysis framework. This potential criticism can be countered by considering that even the simple objective rating exercise (a completely separate elicitation task) produced a preference ordering of the nine fundamental objectives that was very similar to that derived from the MDC results.

Benefits of a comparative approach – DCE as a parallel process to DA

There are numerous benefits of using a DCE approach in parallel to a decision analysis for public evaluation of potential alternatives. The part-worth utilities do not have to be further analysed to segregate weights and value functions but can be directly used in a decision support system to calculate the overall utility associated with various alternative options. Furthermore, the ability to build decision support systems is a key advantage, as such computerized tools can also help to identify or create new alternatives. In other words, alternatives are not limited to a predefined set as in MADM, since a decision support system based on DCE results can be used help identify alternatives that may have particularly high utility, but which were not developed as part of the original alternative set.[112,113] As a result, DCEs could play important roles as part of iterative or adaptive planning processes, in which the original alternative set is modified or expanded based on analysis completed using a DSS, which could help to identify alternatives that are more preferable from the public perspective.

5.3.3 Benefits of using Stated Preference Modelling with Decision Analysis

In addition to the specific benefits associated with either an integrated or a comparative approach, there are several decisive general benefits to a research method that combines decision analysis and stated preference choice modelling in a complementary manner.

Benefit 1 - Decision analysis can be used to structure the problem and to develop the stated preference survey.

Using decision analysis to inform the development of a public preference survey is beneficial for two reasons. First, although pre-testing and focus groups are often an essential part of survey development, the structure and extent of this aspect of the research are typically left to the discretion of the researcher (Louviere *et al.* 2000). In contrast, the problem structuring tools of decision analysis are well developed and are standard practice for most applications (see Clemen 1996, Keeney 1992).

[112] This advantage is due to the fact that the hypothetical profiles evaluated by respondents in the survey environment are based on experimental design plans, which permits extrapolation to the entire experimental domain.

[113] Since any conceivable combination of attribute values could be evaluated in a DSS, some alternatives (or alternative outcomes) identified as highly desirable may not be realistic or technically feasible.

The problem structuring and impact assessment tools of decision analysis provided a number of benefits for the stated preference survey.

1. Ensured that the decision problem was well defined and of suitable scope.
2. Allowed preference elicitation to be based on an appropriate structured set of fundamental objectives and associated attributes.
3. Assured that the attribute levels and ranges used in the stated preference survey were realistic and relevant to decision makers.
4. Provided a number of potential alternatives for in-depth evaluation that were of interest to decision makers.

In turn, the survey development process (e.g. through various pre-testing sessions) provided guidance for restructuring the objectives and redefining the attributes in ways that were coherent and understandable for laypersons. In other words, the survey development process encouraged the decision analysis based problem structure to become more accessible from a lay perspective.

The survey was also improved through the incorporation of recommendations based on several key concepts within decision analysis. Multiple elicitation tools, warm-up tasks and reminders of previous responses were utilized in an attempt to address the proposed "constructive nature of preference formation" (Payne *et al.* 1999).[114] The issue of range sensitivity was dealt with by ensuring that respondents were familiar with the attributes and ranges used in the survey before completing the primary elicitation task. Finally, three different preference elicitation tasks were incorporated into the survey in an attempt to heed the recommendation that different preference elicitation procedures be used to ensure validity of weights and value functions (Weber and Borcherding 1993, Hobbs *et al.* 1992).

[114] The constructed view of preference formulation postulates that a) individuals often do not have well-defined preferences when evaluation questions are asked; and b) constructed preferences are the result of the interaction between the human information processing system and the attributes of the decision task (Payne, Bettman, and Schkade 1999).

<u>Benefit 2</u> – One preference tool for eliciting both weights and value functions.

As described in section 5.1.2.2, preference information from MDC and DCE tasks is provided in the form of utility estimates for each attribute level, which contain information on both relative attribute weights and the shape of the value function. In contrast, decision analysis derived weights and value functions are normally obtained using two separate preference elicitation procedures (e.g. Keeney and Raiffa 1976). Using two separate elicitation tasks may be undesirable for a number of reasons. First, using separate tasks complicates the preference elicitation process by requiring respondents to differentiate between two types of value. Second, using two tasks puts additional burden on respondents, which may decrease their ability to provide the type and quality of responses desired by the researcher. Finally, the length of the response task is increased. All of the preceding disadvantages are especially relevant in the survey environment where time is limited and the respondents are laypersons.

Consequently, there are obvious benefits to using a single preference elicitation procedure, such as provided by DCE or MDC analysis that can provide information on both attribute weights and value functions.

<u>Benefit 3</u> – The appropriate functional forms for the attributes can be derived from the survey.

As mentioned previously, although decision analysis techniques exist for deriving the shape of the value function associated with each attribute or objective, it is very common in practice to make strong prior assumptions about appropriate functional forms. Often, value functions are assumed to be linear and consequently are not derived. Although linear value functions perform well for many decision problems (von Winterfeldt and Edwards 1986), there is no obvious way to retroactively test their validity. In contrast, stated preference choice methods do not make assumptions about the functional forms of the attributes. Instead the appropriate shape of the value function can normally be surmised by identifying a form that best fits the individual utility estimates calculated for each attribute level. In this particular project, the results of the MDC and DCE tasks indicated that the attribute value functions were primarily linear, which justified the use of linear value functions in the decision analysis. Although linear forms were generally found to be appropriate in this particular study, it is not unusual for a choice experiment to determine that quadratic or even polynomial curves are suitable.

<u>Benefit 4</u> – Preference information is based on a large-scale representative survey.

Preference elicitation tools designed for large-scale survey administration have two key benefits. First, participation is not limited to those individuals who have large amounts of time to devote to a planning process. Instead, many individuals can participate. As a result, the efficiency obtained from a survey instrument allows the views of a broader range of individuals to be directly used in a planning process, although the participation of a survey respondent is obviously limited in comparison to an individual, such as a stakeholder representative, who is actually physically present during a planning session. As more individuals are involved, it is more likely that the resulting decision will be generally acceptable to a wide range of people. The second key benefit of the large-scale survey is that it can be based on a truly random, large-scale sample, which encourages statistically significant model estimates and representative results. Such results are likely to be more defensible in the long term, since detractors are less likely to claim that special interests or other factors biased the decision making process in favour of a certain outcome. Of course, it cannot be argued that participatory decision processes are not legitimate without the use of public preference surveys or that surveys can be seen as a replacement for stakeholder participation. However, surveys, of the type utilized in this research project, should be seen as an important complementary tool to the participatory planning process, for ensuring fair and effective representation of the wide range of values that exist in society.

<u>Benefit 5</u> - Inclusion of the public interest and indirect participation of lay people.

It is difficult to ensure that the general public can be meaningfully involved in any planning process. Although significant efforts are often made to provide opportunities for public participation, such opportunities do not necessarily translate into representative results. Usually, the onus is still on the individual citizen to become informed and subsequently to take the time to become involved. As a result, public participation is generally limited to those with a high interest in the problem, or those with sufficient free time. The benefit of the stated preference survey is that it allows a representative sample of the public interest to be obtained. Instead of passively creating avenues for involvement and hoping the public will take an interest in the issue, the stated preference survey actively samples the existing population. Furthermore, unlike traditional survey instruments, the results of the stated preference survey are directly compatible with decision and planning processes based on structured or rational decision making techniques. As a result, instead of merely informing the process, the use of stated preference surveys allows public preferences to be directly incorporated in the decision making process alongside the views of stakeholder representatives and decision makers.

Benefit 6 - Reduced opportunity for the analyst to influence the results.

As opposed to the one-on-one interactive preference elicitation process often used in decision analysis, stated preference surveys are completed independently by each individual. Consequently, there is less opportunity for the personal views and values of the analyst to inadvertently influence the responses given by the participant. Of course, no instrument can ever be free of potential bias but using elicitation procedures that minimize this potential are clearly beneficial and help to ensure that ultimately the decisions made are defensible and valid.

The preceding paragraphs have reviewed the general benefits of combining stated preference modelling and decision analysis. The next section will present some potential limitations of such an approach and review some suggestions for further research.

5.3.4 General Limitations and Suggestions for Further Research

Limitations

For this project, the attributes defined to measure the achievement of the fundamental objectives were suitable for both expert and non-expert audiences. This was achieved by measuring impacts at a suitable level in the objectives hierarchy. In other words, the objectives used were higher-level fundamental objectives as opposed to lower level technical or means objectives. For some projects, especially those concerned with less strategic decision problems, it may not be possible to find attributes that can be used in both a decision analysis and in a stated preference survey. In such a situation, the link between the stated preference survey and decision analysis would be weaker and it might be impossible to use the results of the stated preference survey in the decision analysis or to make a direct comparison of the ranking of alternatives.

A further limitation, or perhaps a drawback, of using stated preference choice tools relates to how the alternative profiles used to elicit preferences in stated preference surveys are derived. The experimental design process systematically varies the attribute levels to produce profiles of attribute levels but there is no a-priori way to ensure that the profiles so developed are realistic representations of potential alternatives.[115] In other words, levels could be combined in such a way as to produce an alternative that is counter-intuitive or realistically impossible. For example, minimal government spending on flood protection combined with a maximum safety rating. Researchers can attempt to manually correct any obvious inconsistencies but this activity usually increases the standard error associated with the part-worth estimates. Participants in a stated preference survey may be confused or annoyed by counterintuitive profiles, which could result in less consistent or lower quality responses.

Finally, a third limitation or caveat, is that the multiple attribute decision analysis application used in this research project was relatively simple and was shown to rely on similar assumptions and theoretical constructs as stated preference choice modelling.

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[115] This is a concern only with purely orthogonal survey designs.

As a result, if a more complicated or different decision analysis approach were implemented, it is not clear that the same compatibility between the stated preference and decision analysis methods would be realized. For instance, a MADM method that incorporates a concept of thresholds into the evaluation of alternatives (e.g. ELECTRE), might give different evaluations of an alternative set than methods relying on compensatory decision making rules, which are inherent in discrete choice modelling and MAVT.

Suggestions further research

One obvious research expansion would be to try using more complicated or different decision analysis models for comparison with stated preference modelling. Various MADM methods could be used such as multiplicative or multilinear models with MAVT (as opposed to additive), models that incorporate preference thresholds such as ELECTRE, or even a MODM optimization method such as compromise programming.

Another expansion would be to incorporate uncertainty into the derivation of preference information in a stated preference survey. For this research project, the alternative attribute profiles seen by participants were completely deterministic. In other words, there was no information provided regarding the uncertainty of any of the choices. As a result, the utility values describe respondents' values but impart no information on risk attitudes. If choices were made over risky alternatives (or the attribute profiles contained information regarding the probabilities of various outcomes), the utilities derived would be comparable to the Neumann-Morgenstern utilities (risky utilities) used by decision analysts (see Rasid, Haider, and Hunt (2000) for a simple attempt in this direction).

A final expansion that can be suggested involves further comparison and verification of the compatibility of the weights sets derived using stated preference modelling techniques with those derived using decision analysis elicitation methods. This research project utilized the decision analysis procedure of swing weighting to elicit preferences for objectives and attributes from the perspective of flood managers but no equivalent decision analysis method was used to derive public preferences (although a simple rating exercise was used). As a result, it would be useful to conduct further research aimed at exploring the relationship between weights derived using a popular decision analysis procedure such as swing weighting and those derived using a MDC task (or a DCE) for the same sample population.

Chapter 6 Flood Management Implications

Chapter 5 concluded with a discussion on the methodological suitability of combining multiple attribute decision analysis and stated preference choice methods for the analysis of decision problems of public interest that are characterized by multiple objectives. This concluding chapter will discuss the specific flood management implications of the applied research undertaken for this project.

6.1 Review – The Flood Management Context

The occurrence of a major flood on the Fraser at some time in the future is a certainty. However, it is uncertain when such an event will occur, and how severe it will be. Although humans have little control over the timing and nature of flood events, actions can be taken to minimize the effect, in terms of future damages, that flooding has on communities. In the lower Fraser Basin, historical settlement patterns, driven primarily by economic and transportation considerations, have led to the establishment of major population centres in the Fraser River floodplain. In 1998 it was estimated that 50% of the population of the lower Mainland lived behind dykes (Lyle 2001). This statistic is likely to increase as the region continues to experience high population growth rates, which puts increasing development pressure on the remaining floodplain lands (Smith 1991). The existing dyking system for the most part provides the sole means of flood protection for residents. Unfortunately, dykes do not eliminate the risk of flood damages; they only act to reduce it to an economically viable level.[116] In other words, dykes protect against floods only up to a certain design level and if the design level is exceeded, they offer no flood protection. Even at flood levels less than the design maximum, dyke failure is a serious possibility. In addition, dykes are subject to numerous other problems: they require continual maintenance to prevent deterioration over time; their protective ability can be compromised by slow changes in river

[116] The Fraser River dykes are built to protect to the level of the flood experienced in 1894 (approximately the 1 in 200 level) but construction beyond that level is not considered economically viable (Boeckh *et al.*1991).

hydrology caused by factors such as sedimentation and global warming; and they are vulnerable to damage caused by earthquakes.[117]

Aside from building structures such as dykes to protect people from flood waters after they have already taken up residence in the floodplain, there are several alternative measures, such as floodproofing, that form (or should form) part of any comprehensive integrated flood hazard management strategy. In BC, alternative flood hazard management strategies have been directed primarily at providing disaster financial assistance in the aftermath of a flood and using provincial regulations to require floodproofing in all new developments in the floodplain.[118] Although in place since 1973, the effectiveness of the floodproofing policy has been considerably hindered by several significant exemptions. In particular, many historically settled areas were granted a special exempt status. Since these areas have grown, in many cases, into the downtown or urban core areas of modern cities, large urban areas located in the floodplain are currently exempt from floodproofing requirements (e.g. most of urban and suburban Richmond).

6.2 General Implications for Floodplain Management

The research undertaken for this Master's project was aimed at investigating and evaluating floodproofing strategies to encourage floodproofing of existing residential homes in historic settlement areas. Nine representative floodproofing strategies were developed for this purpose. In addition, nine fundamental objectives and associated attributes were used to quantitatively measure the impact of various floodproofing strategies on the community over time. Preferences for the achievement of the objectives

[117] A major earthquake could seriously damage or destroy large portions of a dyking system, especially given the instability of the underlying delta soils (Clague 1998, Clague 2002). Studies have indicated that a serious earthquake would likely damage the dykes to such an extent that repair before the spring freshet may not be possible (Klohn Leonoff 1989).

[118] The combination of taxpayer funded flood protection works such as dykes and the provision of disaster financial assistance in the event of a flood creates perverse incentives. Continued growth in the floodplain is encouraged by providing dykes to protect an existing community (the flood protection development spiral), which results in more people being exposed to the flood hazard over time. In the event of a flood individuals are compensated for their losses and in most cases are permitted to rebuild in the same location, which further discourages personal responsibility for managing flood risk and enables future payouts to the same individual.

were derived from the perspective of both homeowners and floodplain managers. Furthermore, simple impact assessment models were built to estimate the effect that the nine floodproofing strategies would have on each of the nine objectives. Finally, the preference information and impact assessment data were combined to evaluate each of the nine alternative floodproofing strategies. The main outcomes of this research for floodplain management will be discussed in the upcoming sections.

6.2.1 Preferences for Objectives and Attributes

The surveys of homeowners and floodplain managers revealed that the nine fundamental objectives are not of equal importance. For homeowners, the key attributes are related to Safety (1), Homeowner Damages (2), Homeowner Costs (3), and Stress and Disturbance (4).[119] For floodplain managers, the key objectives include Safety (1), Public Sector Damages (1), Homeowner Damages (2), Stress and Disturbance (2), and Public Sector Costs (3).[120] It comes as no surprise that homeowners are more concerned with minimizing costs and damages to themselves, while floodplain managers place a higher priority on minimizing costs and damages to the public sector. It seems clear from these results that both homeowners and floodplain managers feel that minimizing the future negative effects of flooding should be a relatively more important consideration than minimizing current costs of providing protection or the potential social implications of floodproofing on communities (e.g. as measured by the attributes for Bureaucracy, Aesthetics, and Accessibility). The results are revealing given that concerns over costs and other social impacts are often those given as reasons that pursuing floodproofing in previously developed area may not be beneficial.[121]

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[119] Ranks in brackets are based on the results of the public community outcomes MDC assessment task.

[120] Ranks in brackets for floodplain managers are based on the results of the swing-weighting task.

[121] The results must be considered in light of the fact that for some of the weighting exercises (e.g. MDC, swing weighting) the weights given to the objectives are related to the attributes used to measure them. As a result, if the attributes were not properly specified (e.g. they didn't measure the right effect) the results could change. For example, the objective "Aesthetics" was measured by the attribute "percentage of homes greater than two stories tall in any given neighborhood." Perhaps an attribute that showed visual pictures of the floodproofing effects would have had more impact on responses. In defense of the current results, it must be noted that the objective rating exercise, which described the objectives generally with no associated attributes, gave a similar preference order for the objectives.

6.2.2 Policy Levers - Effectiveness for Encouraging Floodproofing

Each alternative floodproofing strategy was constructing using a number of different policy levers. For example, providing support for floodproofing with a homeowner grant and collecting levies to penalise owners of non-floodproofed homes were two policy levers considered in this project. The effectiveness of many of the individual policy levers for encouraging the voluntary adoption of floodproofing was investigated in a stated preference discrete choice task. By analysing the results of this choice task, a number of generalizations can be developed. First, the most successful strategies for encouraging floodproofing were those containing combinations of policy levers instead of a single tool. As a result, the two wealth transfer alternatives, which relied on a combination of positive incentives (homeowner grants or tax breaks) along with negative incentives (floodproofing levies), were the most successful. In addition, as single factors, positive incentives are more successful than negative incentives. In terms of specific positive incentives, grants are more effective and are preferred to tax breaks. For negative incentives, levies encourage more floodproofing than reducing damage payouts for disaster financial assistance.

<u>Summary Recommendations</u>

To maximize voluntary floodproofing –

- Create a portfolio of policy tools that utilizes various methods for encouraging people to floodproof.
- Focus on complementary tools such as levies and tax breaks (e.g. levies can offset the costs of the tax breaks).
- Include some sort of government support – preferably a grant.
- Do not rely only on negative incentives and especially disincentives with indirect or delayed costs for the homeowner (e.g. decreasing the percentage of damages covered by disaster financial assistance).

6.2.3 Evaluation of Floodproofing Strategies

The nine floodproofing strategies were evaluated by assessing their impacts in terms of the nine community outcomes objectives and combining this information with homeowner and expert preferences for the objectives. The result was a score for each alternative strategy that measured the ability of that strategy to jointly achieve the nine fundamental objectives.

The nine floodproofing strategies were evaluated from a number of different perspectives and using different analysis methods. In addition, several sensitivity analyses were performed that investigated the effect that uncertainty in the results could have on the recommendations. Based on the results of this extensive analysis, three floodproofing strategies were found to consistently rank in the top three (of the nine alternatives investigated). These strategies included both wealth transfer alternatives (a combination of tax breaks/grants and floodproofing levies), and a positive incentive strategy (tax breaks).[122] Other strategies sometimes found in the top three were a second positive incentives strategy (grants) and a negative incentives strategy (floodproofing levies). The current strategy, called "Do Nothing," was never a top performer except in extreme cases in which the weights on certain objectives (e.g. Aesthetics) increased by substantial margins.

The wealth transfer and positive incentives strategies generally performed the best, because they were successful in achieving the community objectives that homeowners and floodplain managers deemed important. In contrast, the outcomes of other competing strategies such as imposing strict floodproofing regulations, reducing government liability for flood damages, or 'doing nothing' are not consistent with the values expressed by homeowners and floodplain managers.

[122] Readers may note that the floodproofing strategies that ranked the highest in the overall analysis were those that were also found to be the most successful at encouraging voluntary floodproofing. This should not be surprising since the objectives that received the most weight in the analysis (were relatively more important) were those objectives whose measures improved with increases in the percentage of people who floodproofed (e.g. homeowner or public sector damages, and safety).

It is important to remember that only a limited number of alternatives were considered in this analysis and that most were based on a single policy lever. Consequently, the results tend to indicate which single policy levers are more or less successful at bringing about a future outcome in the community that is consistent with the objectives. The fact that the most beneficial floodproofing strategies were those that combined policy levers suggest that other more comprehensive floodproofing strategies could be designed using the available policy levers to create a floodproofing strategy that is more favourable. Just because an individual policy lever (e.g. reducing government liability for flood damages) is not successful in isolation, does not mean it could not be a useful or desirable component of a multi faceted floodproofing strategy.

6.3 Specific Observations and Results for the City of Richmond

The City of Richmond was an interesting case study area for many reasons. It is located on a low-lying island composed of soft delta soils. The flood threat in Richmond comes from all directions: from the Fraser River in the east and from the Pacific Ocean in the west. In addition to the flood threat, Richmond is also particularly vulnerable to earthquake damages due to its proximity to geologically active faults and its fragile soil composition. Furthermore, the City of Richmond is a significant urban area supporting a large and diverse population of more than 168,000 people.

As stated in Chapter 2, Richmond has experienced rapid growth in recent years. The large population of newcomers to the area is a concern from flood management perspective, since many new residents may not have any prior experience with living in a flood prone area and may not be fully aware of the flood risk. The survey found that only 6.3 % of respondents had ever experienced flooding caused by river water or wave action. In addition, only 15% of Richmond residents reported that the risk of natural disasters was an important consideration in the purchase of their current home.

In terms of risk perception, the survey respondents reported that they found major earthquakes to be a more significant threat to their current homes than major floods. Depending on how one classifies the word “major,” this result may or may not be a fair assessment of reality. A flood of magnitude equivalent to the largest flood of record on the Fraser (1894) is estimated to have a return frequency of approximately 1/200 years. Crustal earthquakes, with a magnitude of 6-7 on the Richter scale, have an estimated return frequency of 20-30 years, while the more damaging subduction zone earthquakes, with a magnitude of 8-9 on the Richter scale, have an estimated recurrence frequency of 1/500 years (Clague 2002).

The results of the personal floodproofing choice task revealed a high interest in floodproofing. For example in the first choice question, 89% of respondents stated that they would want to floodproof their home despite variations that occurred between respondents and survey versions with regards to impacts such as costs and damages, and in incentives and disincentives. This result must be tempered by a number of caveats, as discussed in Chapter 5, since even under the "Do Nothing" scenario, survey participants' stated willingness to floodproof far exceeds observations of actual floodproofing in the community. One explanation suggested for this enthusiastic response for floodproofing was the educational effect of the survey – an idea that is further supported by a number of observations made while administering the many survey sessions. First, during the introductory presentations in which information was presented to respondents regarding the risk of a major flood occurring sometime in the next twenty years (approximately 1 in 10 chance), it was often noted that respondents gave audible expressions of surprise and dismay. It appeared that many were unaware that dykes were only built to protect up to a certain level of flooding. In addition, various conversations with respondents revealed a troubling lack of understanding about the reality of the flood risk and their share of liability in the event of a flood. For example, in one survey session involving 11 homeowners, a casual conversation revealed that only one participant was aware that residential house insurance did not cover flood damages caused by river inundation (as opposed to sewer backup).[123] In

[123] Flood insurance is available for commercial and industrial developments but not residential developments (Shrubsole 2000). Although the provincial government has considered flood insurance programs, the initiatives have failed due to a lack of a willing insurer (Smith 1991). Flood insurance is available in the United States through the National Flood Insurance Program. Although the program has been in place since 1960, only ¼ of eligible property owners have purchased insurance (Blanchard-Boehm, Berry, and Showalter 2001).

another instance, a participant commented to the group that his/her family had lived in Richmond since the early 1900's and that except for annual high tides, floods do not occur in the area. Many of the comments written by participants further support the educational effect of the survey (Appendix G). This largely anecdotal evidence combined with the general willingness, once educated about flooding and floodproofing options, to choose floodproofing in favour of not floodproofing in the survey environment, suggests that more education about flooding is needed in the City of Richmond. Other studies have reached similar conclusions (Shanks 1972). In particular, residents need more factual information about the risks of flooding, the positive and negative aspects of different flood management options, current government responsibilities with respect to flood management and disaster assistance, and what their options are for decreasing their personal exposure to the flood hazard. Although some may argue that such flood information may be too technical or complicated to provide to ordinary citizens or, that once provided, such information will be misinterpreted and cause unnecessary panic, the ability of lay persons to understand and to respond rationally to such information was confirmed with the success of the floodproofing survey, since a significant amount of factual technical information about flooding was presented to respondents during the survey sessions. However, providing educational material and disseminating flood knowledge within the community will not be easy, and may be further complicated by the significant number of Richmond residents who do not have English as their first language, which may present communication barriers. Despite the challenge, the survey comments made by Richmond residents suggest that many are highly interested in learning more about flood management and would welcome such information.

6.4 Caveats

As highlighted in the following list, a number of caveats must be addressed with respect to this research project.

1. **<u>Sample Representation</u>** - Early in this document it was noted that the research was intended to be more exploratory than definitive, and as a result, a convenient sampling method was used over a random sampling method. Consequently, there was no guarantee that the results would be representative of Richmond's general population. Using responses to various demographic questions, the demographics of survey sample can be contrasted to those of Richmond's general population (Appendix G). The survey sample did not adequately represent the population in two key aspects. First, survey respondents were more likely to be women than men and, second, the survey under sampled persons belonging to visible minority groups.[124]

2. **<u>Model Complexity</u>** – The impact assessment and decision analysis models used were necessarily simple in order to facilitate the ambitious scope of the analysis within the confines of a Master's research project. For example, the decision analysis models relied on simple additive summation of weights and impact values to define the overall score of competing alternatives.

3. **<u>Uncertainty in flood data (uncertain states of nature)</u>** – There are many sources of uncertainty to consider when doing research in floodplain management but perhaps the most important are related to the risks associated with a major flood event. There are two distinct aspects to flood uncertainty: the probability of occurrence for floods of a given magnitude and duration, and the probability that the dyking system will be successful at withstanding the floodwaters. The original intent was to directly incorporate information on flood uncertainty into the calculation of the

[124] Although extensive attempts were made to engage a sufficiently broad range of non-profit groups, recruiting was the most successful with groups containing a higher proportion of non-visible minority members. Regrettably language barriers and other challenges experienced while making contacts with various groups probably played a role in determining the groups that actually participated in the survey.

impact models. Instead of deriving a deterministic value for flood damage, the initial goal was to use measures (e.g. expected damages) that account for the probabilities of different potential flood levels and the probability of dyke failure at various flood heights.[125] Unfortunately, the critical information on flood levels for floods of various magnitudes in the event of a dyke breach in the Richmond area did not exist. In addition, the probability of dyke failure has not been quantified to the author's knowledge. The only information that was readily available was the exceedance probability for the flood of record and the flood level associated with such an event. As a result, the analysis was constrained to situations in which the dykes are overtopped by floodwater. The most important effect of this constraint on the results is that all the flood damage values will be underestimated. Consequently, the negative impacts associated with less aggressive floodproofing strategies (e.g. "Do Nothing") will be too low. As a result, these alternatives should realistically have lower overall scores than were calculated in this analysis.

4. **Limitations imposed by scope** – This analysis looked at floodproofing in historic settlement areas as one element of an integrated floodplain management strategy and the results and recommendations made must be considered within this limited scope. The study did not attempt to address the larger, more comprehensive flood management issue of what elements should be used as part of a flood mitigation plan for the City of Richmond. For example, should governments spend more money on increasing the design level of existing dykes, encourage floodproofing in existing developments, invest in emergency preparedness and response, or implement some sort of flood insurance program? What are the trade-offs that have to be made between different approaches? Is the issue really bigger, better dykes versus alternative flood protection and management efforts, or can a variety of flood hazard management measures be implemented in a complementary fashion? These questions and many others were not considered. As a result, it must be stressed that

[125] Damages occur in the event of a flood with a magnitude that is a result of the severity of the flood. For example, large floods that last for long periods are much more economically devastating but floods of this severity also occur less frequently (have a lower probability of occurrence). The term 'expected' is used to indicate that damages are uncertain and that the estimation of the impacts should be based on a probabilistic analysis of potential outcomes.

the intent of this project was not to suggest that floodproofing should be the only flood hazard management issue or that floodproofing should be pursued at the expense of investment in other flood management activities. The question that this project addressed was whether or not encouraging floodproofing in historic settlement areas, as part of an integrated flood hazard management strategy could be a beneficial or acceptable approach given a set of key flood management objectives.

6.5 Suggestions for Research Extensions and Further Analysis

As stated in the previous section, this research project was necessarily limited in scope and extent of analysis in order to form a reasonable task for a Master's research project. As a result, a number of suggestions for extensions and further analysis can be made and are presented below.

1. **Alternative floodproofing strategies** – A limited set of nine floodproofing strategies were analysed for this research project and many were focused on just one type of strategy for encouraging floodproofing (e.g. tax breaks). Before drawing any definitive conclusions regarding an optimal floodproofing strategy, a more comprehensive analysis should be performed involving many more strategies. Instead of relying on one type of policy lever, the expanded alternative set should include alternatives that use creative portfolios of policy levers. In addition, it must be stressed that the alternatives are not limited to those that include the policy levers described in this document; this research project used policy levers simply as convenient means for creating alternatives and for analysing the effects of alternatives. Managers and others may be interested in designing completely different floodproofing strategies that rely on different components. For example, the results of this project suggested that education could be an important factor in encouraging floodproofing, but none of the strategies directly included an educational program component.

2. **Extended sensitivity analysis** – Although a fairly extensive sensitivity analysis was undertaken, there are a number of additional analyses that could be completed. One such analysis would include an expanded set of values for the policy components, since the values used in the impact model were fixed and based on the average levels seen in the floodproofing survey. For example, in the survey, tax break levels of 5%, 10%, and 15% were used (in addition to the zero level), but the impact models used only the average value of 10%. It is possible that strategies defined with different levels could result in a different ordering of the alternatives.

3. **Reduced Flood Construction Levels** – This suggestion is particular to the City of Richmond. The Flood Construction Levels (FCL) used in the analysis were based on a scenario in which the proposed No. 8 road dyke did not exist (e.g. the current scenario) but the FCLs for many areas would be reduced if such a project were completed.[126]

4. **Model refinement and expansion** – As suggested earlier, the impact assessment models were, by necessity, relatively simple in design. A number of expansions and refinements could be implemented to make them more sophisticated. Some of these improvements could be realized just by undertaking research to improve the quality of data used to define many of the key parameters. Other improvements could include analysis of uncertain or probabilistic outcomes, adding the ability to deal with future discounted benefits, and utilising more complex functional forms for different variables (e.g. using a non-linear function to model change in floodproofing rates over time). Another interesting improvement would be to incorporate the personal floodproofing decision support system as a sub-model into the impact assessment models. Recall that the personal floodproofing DSS was based on the results of the second discrete choice model in the survey and was used to derive estimates of the percentage of homeowners that would voluntarily floodproof under different floodproofing strategies – a value that was used as a parameter in many of the models.

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[126] The No. 8 road or mid island dyke would act to compartmentalize Lulu island and in effect protect the developed west side of the island from a dyke breach in the east side of the island.

6.6 Conclusions

This research project investigated strategies that could be used to encourage floodproofing of existing residential development in historic settlement areas. The general finding was that floodproofing can be a beneficial strategy to employ for achieving key flood management objectives and that most floodproofing strategies are preferable to a "Do Nothing" strategy. In addition, it was revealed that, in general, homeowners are not unwilling to floodproof even if floodproofing requires significant personal investment but they would like to see an active and positive government role in funding and providing direction for such a program. In addition, from a community perspective, homeowners are supportive of seeing increased levels of floodproofing in the community over time, even if it means making some trade-offs with respect to aesthetic impacts, accessibility, and other concerns.

Floodproofing requires individuals to take an active role in managing their own flood risk instead of passively receiving the benefits of flood protection offered by dykes and other structural measures. Providing government direction for encouraging floodproofing in the community will likely create the added educational benefit of encouraging individuals to obtain a deeper and more realistic assessment of risks associated with living in a floodplain and the capabilities of existing dyking systems to provide the sole flood protection for the community.

Floodproofing is not the definitive solution to the risk associated with locating large human settlements in major floodplains; it should ideally be considered as one component of a suite of available options for mitigating flood damages. This research project has shown that encouraging floodproofing in existing developments of historic settlement areas can be a reasonable and publicly acceptable measure for reducing the exposure of previously developed urban areas to future flood damages.

List of References

For overviews of decision analysis, refer to Bunn (1984), Hwang and Yoon (1981), Clemen (1996), Keeney (1992), and von Winterfeldt and Edwards (1986). For overviews of Discrete Choice Experiments refer to Train (2003) and Louviere et al. (2000).

Adamowicz, V., J. Louviere, and J. Swaite. 1998. *Final Report: Introduction to Attribute-Based Stated Choice Methods.* Edmonton: Advanis.

Ahmad, S., and S. Simonovic. 2000. Systems Dynamics Modeling of Reservoir Operations for Flood Management. *Journal of Computing in Civil Engineering* 14(3): 190-198.

Ahmad, S., and S. Simonovic. 2001. Integration of Heuristic Knowledge with Analytical Tools for the Selection of Flood Damage Reduction Measures. *Canadian Journal of Civil Engineering* 28: 208-221.

Al-Kloub, B., T. Al-Shemmeri, and A. Pearman. 1997. The Role of Weights in Multi-Criteria Decision Aid, and the Ranking of Water Projects in Jordan. *European Journal of Operational Research* 99: 278-288.

Allenby, G., N. Arora, and J. Ginter. 1995. Incorporating Prior Knowledge in the Analysis of Conjoint Studies. *Journal of Marketing Research* 11: 152 -162.

Anand, R. 2001. Multicriteria Methods in River Basin Planning – A Case Study. *Water Science and Technology* 31(8): 261-272.

Arlington Group Planning and Architecture Inc. 2001. *Floodproofing Options for Historic Settlement Areas.* Report Prepared for the Fraser Basin Council. Vancouver, B.C.

BC Hydro.1995. *1995 Integrated Electricity Plan, Appendix F: Resource Trade-off Decision Analysis.* Vancouver: British Columbia Hydro and Power Authority.

Ben-Akiva, M., and S.R. Lerman. 1985. *Discrete Choice Analysis: Theory and Application to Travel Demand*. Cambridge: MIT Press.

Blanchard-Boehm, R.D., K.A. Berry, and P.S. Showalter. 2001. Should Flood Insurance be Mandatory? Insights in the Wake of the 1997 New Year's Day Flood in Reno-Sparks, Nevada. *Applied Geography* 21: 199-221.

Bocking, R.C. 1997. *Mighty River – A Portrait of the Fraser*. Vancouver: Douglas and McIntyre.

Boeckh, I., V.S. Christie, A.H.J. Dorcey, and H.I. Rueggeberg. 1991. Water Use in the Fraser River Basin. In *Water in Sustainable Development: Exploring our Common Future in the Fraser River Basin*, ed. Anthony H.J. Dorcey and Julian R. Griggs. Vancouver: Westwater Research Centre, University of British Columbia.

Boxall, P., W. Adamowicz, J. Swait, M. Williams, and J. Louviere. 1996. A Comparison of Stated Preference Methods for Environmental Valuation. *Ecological Economics* 18: 243-253.

Bragge, J. 2001. Premediation Analysis of the Energy Taxation Dispute in Finland. *European Journal of Operational Research*. 132: 1-16.

Bunn, D.W. 1984. *Applied Decision Analysis*. New York: McGraw-Hill.

Burton, I., R.W. Kates, and G.F. White. 1993. *The Environment as a Hazard*. New York: Oxford University Press.

Cassidy, J.F., and G.C. Rogers. 1998. Seismic Site Response in the Greater Vancouver, British Columbia, Area: Spectral Ratios from Moderate Earthquakes. *Canadian Geotechnical Journal*. 36: 195-209.

City of Richmond. 1989. *Floodplain Management Implementation Policy*. revised February 2003. Richmond: Development Applications Department. Accessed February 2, 2004 at <http://www.city.richmond.bc.ca/services/forms/dev_apps/da_24.pdf>.

City of Richmond. 2003a. *Discover Richmond: City History*. updated January 2, 2003. City of Richmond Official Web Site. Accessed October 15, 2003 at <http://www.city.richmond.bc.ca/discover/ history.htm>.

City of Richmond. 2003b. *Discover Richmond: City Profile*. updated January 6, 2004. City of Richmond Official Web Site. Accessed October 15, 2003 at <http://www.city.richmond.bc.ca/discover/discover_index.htm>.

City of Richmond. 2003c. *Hot Facts – Housing Characteristics*. revised December 3, 2003. City of Richmond Official Web Site. Accessed October 15, 2003 at <http://www.city.richmond.bc.ca/services/forms/policy/hotfacts/PP_HF_7.pdf>.

City of Richmond. 2003d. One Meter Elevations - Elevation Map. Unpublished Data. Richmond, B.C.: Policy and Planning Department, City of Richmond.

City of Richmond. 2003e. *Hot Facts – Education*. revised September 3, 2003. City of Richmond Official Web Site. Accessed October 15, 2003 at <http://www.city.richmond.bc.ca/ services/forms/policy/hotfacts/pp_hf_22.pdf>.

City of Richmond. 2003f. *Hot Facts – Income*. revised September 3, 2003. City of Richmond Official Web Site. Accessed October 15, 2003 at <http://www.city.richmond.bc.ca/ services/forms/policy/hotfacts/pp_hf_25.pdf>.

City of Richmond. 2003g. *Hot Facts – Ethnicity*. revised September 3, 2003. City of Richmond Official Web Site. Accessed October 15, 2003 at <http://www.city.richmond.bc.ca/ services/forms/policy/hotfacts/pp_hf_20.pdf>.

City of Richmond. 2003h. *Hot Facts – Population*. revised December 2, 2003. City of Richmond Official Web Site. Accessed February 2, 2004 at <http://www.city.richmond.bc.ca/ services/forms/policy/hotfacts/PP_HF_1.pdf>.

City of Richmond. 2003i. *Official Community Plan Hot Facts – The Population of Richmond in 2021*. revised April 11, 2003. City of Richmond Official Web Site. Accessed February 2, 2004 at < http://www.city.richmond.bc.ca/ocp/ocp202.htm>.

Clague, J.J. 1998. Introduction. In *Geology and Natural Hazards of the Fraser River Delta, British Columbia*, ed. J.J. Clague, J.C. Luternauer, and D.C. Mosher. *Geological Survey of Canada Bulletin* 525: 17-25.

Clague, J.J. 2002. The Earthquake Threat in South Western British Columbia: A Geologic Perspective. *Natural Hazards* 26(1): 7-34.

Clemen, R. 1996. *Making Hard Decisions: An Introduction to Decision Analysis.* 2nd edition. Belmont: Duxbury.

Cohen, S.H. 2003. *Maximum Difference Scaling: Improved Measures of Importance and Preference for Segmentation.* Sawtooth Software Research Paper Series. Sequim, WA: Sawtooth Software, Inc., www.sawtoothsoftware.com.

Cooksey, R.W. 1996. *Judgement Analysis: Theory, Methods and Applications*. Sydney: Sydney Academic Press.

Day, J.C. 1999. Planning for Floods in the Lower Fraser Basin, British Columbia: Towards an Integrated Approach? *Environments* 27(1): 49-65.

de Garis, Y., N. Lutt, and A. Tagg. 2003. Stakeholder Involvement in Water Resources Planning. *Journal of the Chartered Institution of Water and Environmental Management* 17(1): 54-58.

Dennis, D. 1998. Analyzing Public Inputs to Multiple Objective Decisions on National Forests using Conjoint Analysis. *Forest Science* 44(3): 421-428.

District of Pitt Meadows. 2002. *Tax Facts - Tax Survey (Greater Vancouver Regional District).* Accessed October 17th, 2002 at <http://www.pittmeadows.bc.ca/government/proptax/tfsurv.html>.

Dodgson, J., M. Spackman, A. Pearman, and L. Phillips. 2000. *DTLR Multi-Criteria Analysis Manual*. London: Department of Transport, Local Government and the Regions, Government of the United Kingdom.

Dorcey, A.H.J. 1991. Water in Sustainable Development: from Ideal to Reality. In *Perspectives of Sustainable Development in Water Management: Towards Agreement in the Fraser River Basin*, ed. Anthony H.J. Dorcey. Vancouver: Westwater Research Centre, University of British Columbia.

Duke, J., T. Ilvento, and R. Hyde. 2002. *Public Support for Land Preservation: Measuring Relative Preferences in Delaware*. Newark: Department of Food and Resource Economics, College of Agriculture and Natural Resources, University of Delaware. FREC RR02-01.

Duke, J.M., and R. Aull-Hyde. 2002. Identifying Public Preferences for Land Preservation using the Analytical Hierarchy Process. *Ecological Economics* 42: 131-145.

Dzurik, A.A. 2003. *Water Resources Planning.* 3rd edition. New York: Rowman & Littlefield.

Eschenback, E.A., T.H. Magee, E. Zagona, M. Goranflo, and R. Shane. 2001. Goal Programming Decision Support System for Multi Objective Operation of Reservoir Systems. *Journal of Water Resources Planning and Management* 127(2): 108-120.

FBMP (Fraser Basin Management Program). 1996. *Integrated Flood Hazard Management Strategy: A Task Force Report to the Fraser River Management Board.* Vancouver, B.C.

Fearon, R. 2003. Linking Stakeholder and Decision Makers with Science in Managing the Coastal Water Environment: Case Studies from Urban, Industrial, and Rural Subtropical Catchments in Australia. *Water Science and Technology* 47(6): 179-184.

FEMA (Federal Emergency Management Agency). 1998. *A Homeowners Guide to Retrofitting: Six Ways to Protect your House from Flooding.* Washington: Mitigation Directorate, FEMA.

Fischer, G.W. 1979. Utility Models for Multiple Objective Decisions: Do They Accurately Represent Human Preferences? *Decision Sciences* 10: 451-479.

Fischer, G.W. 1995. Range Sensitivity of Attribute Weights in Multiattribute Value Models. *Organizational Behaviour and Human Decision Processes* 62(3): 252-266.

Fordham, M. 1999. Participatory Planning for Flood Mitigation: Models and Approaches. *Australian Journal of Emergency Management* 13(4): 27-34.

Fraser Basin Council. 2002a. *Floodproofing in Historic Settlement Areas.* Brochure. Vancouver: Fraser Basin Council.

Fraser Basin Council. 2002b. *Flood Hazard Information: Lower Fraser River Floodplain.* Brochure. Vancouver: Fraser Basin Council.

Fraser Basin Council. 2003. *Annual Report 2002-2003.* Vancouver: Fraser Basin Council. Accessed February 20, 2004 at <http://www.fraserbasin.bc.ca/publications/ documents/02-03-FBCAnnualRpt.pdf>.

Fraser Basin Council. 2004. *Flood Management – Brief History of Fraser River Flooding*. Accessed February 12, 2004 at <http://www.fraserbasin.bc.ca/programs/flood.html>.

FREMP (Fraser River Estuary Management Program). 2003. *A Living Working River: An Estuary Management Plan for the Fraser River.* updated 2003. New Westminster, B.C.: Fraser River Estuary Management Program.

French, S. 1988. *Decision Theory: An Introduction to the Mathematics of Rationality.* Chichester: Ellis Horwood.

Goicoechea, A., D. Hansen, and L. Duckstein. 1982. *Multiobjective Decision Analysis with Engineering and Business Applications.* New York: John Wiley and Sons.

Grant, W., E. Pedersen, and S. Marin. 1997. *Ecology and Natural Resource Management: Systems Analysis and Simulation.* New York: John Wiley and Sons.

Green, P.E., and Y. Wind. 1975. New Way to Measure Consumer's Judgements. *Harvard Business Review* 53: 107-117.

Greene, W.H. 1998. *Limdep Version 7.0 – User's Manual*. New York: Econometric Software Inc.

Gregory, R. 2000. Valuing Environmental Policy Options: A Case Study Comparison of Multiattribute and Contingent Valuation Survey Methods. *Land Economics* 76(2): 151-173.

Gregory, R., and K. Wellman. 2001. Bringing Stakeholder Values into Environmental Policy Choices: A Community Based Estuary Case Study. Ecological Economics 39: 37-52.

Gregory, R., and R. Keeney. 2002. Making Smarter Environmental Management Decisions. *Journal of the American Water Resources Association* 38(6): 1601-1612.

Gregory, R., J. Flynn, S. Johnson, T. Satterfield, P. Slovic, and R. Wagner. 1997. Decision-Pathway Surveys: A Tool for Resource Managers. *Land Economics* 73(2): 240-254.

Gregory, R., S. Lichtenstein, and P. Slovic. 1993. Valuing Environmental Resources: A Constructive Approach. *Journal of Risk and Uncertainty* 7 (2): 177-197.

Grigg, N.S. 1996. *Water Resources Management: Principles, Regulations, and Cases*. New York: McGraw-Hill.

Gruntfest, E. 2000. Non-structural Mitigation of Flood Hazards. In *Inland Flood Hazards: Human, Riparian and Aquatic Communities*, ed. E. Wohl. New York: Cambridge University Press.

Haider, W., and H. Rasid. 1998. Assessing Lay Preferences for Water Level Management in a Regulated River System in Northwestern Ontario: Application of a Stated Preference Model. *Canadian Water Resources Journal* 23(3): 289-307.

Haider, W., and H. Rasid. 2002. Eliciting Public Preferences for Municipal Water Supply Options. *Environmental Impact Assessment Review* 22(4): 337-360.

Haimes, Y., W. Hall, and H.T. Freedman. 1975. *Multiobjective Optimization in Water Resource Systems: The Surrogate Worth Trade-off Method*. New York: Elsevier Scientific Publishing Company.

Hajkowicz, S., and T. Prato. 1998. *Multiple Objective Decision Analysis on Farming Systems in Goodwater Creek Watershed, Missouri*. Columbia, MO: Centre for Agricultural, Resource and Environmental Systems; College of Agriculture, Food and Natural Resources, University of Missouri-Columbia. Research Report No. 24. Accessed January 23, 2004 at <http://www.cares.missouri.edu/about/reports/report24.html>.

Hanley, N., R. Wright, and V. Adamowicz. 1998. Using Choice Experiments to Value the Environment: Design Issues, Current Experience, and Future Prospects. *Environmental and Resource Economics* 11(3-4): 414-428.

Hay and Company Consultants Inc. 1989. *Technical Report: Floodplain Management Study*. Richmond, B.C.: The Corporation of the Township of Richmond. Government Publication 282.

Hewitt, K. 1983. *Interpretations of Calamity*. Winchester, MA: Allen and Unwin.

Hobbs, B. 1980. A Comparison of Weighting Methods in Power Plant Siting. *Decision Sciences* 11: 725-737.

Hobbs, B., V. Changkong, W. Hamedeh, and E. Stakhiv. 1992. Does Choice of Multicriteria Method Matter? An Experiment in Water Resources Planning. *Water Resources Research* 28(7): 1767-1769.

Huber, J., and K. Train. 2000. On the Similarity of Classical and Bayesian Estimates of Individual Mean Part-worths. Accessed June 18, 2002 at <http://iber.berkeley.edu/wps/econ/E00-289.pdf>.

Hwang, C., and K. Yoon. 1981. *Multiple Attribute Decision Making Methods and Applications: A State of the Art Survey*. Survey Lecture Notes in Economics and Mathematical Systems 186. Berlin: Springer-Verlag.

Intergovernmental Panel on Climate Change. 1995. *Climate Change 1995 - The Science of Climate Change: Summary for Policy Makers and Technical Summary of the Working Group 1 Report*, ed. J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell. New York: Cambridge University Press.

Jia, J., G. Fischer, and J. Dyer. 1998. Attribute Weighting Methods and Decision Quality in the Presence of Response Error: A Simulation Study. *Journal of Behavioral Decision Making* 11: 85-105.

Jones, Stuart. 2003. Personal communication in his position, March 2003. Planner/Analyst. Urban Development Division. Policy and Planning Department. City of Richmond, B.C.

Jones, Stuart. 2003a. Major Renovations of Existing Homes (>$100,000 in value): 1986-2003. Richmond, B.C.: Policy and Planning Department, City of Richmond. Unpublished Data.

Jones, Stuart. 2003b. Number of New Housing Units Added Each Year: 1986-2003. Richmond, B.C.: Policy and Planning Department, City of Richmond. Unpublished Data.

Jones, Stuart. 2003c. Number of Demolitions of Residential Units each Year: 1986-2003. Richmond, B.C.: Policy and Planning Department, City of Richmond. Unpublished Data.

Jones, Stuart. 2003d. Number of Residential Units Inside and Outside of the Urban Exempt Area - 2003. Richmond, B.C.: Policy and Planning Department, City of Richmond. Unpublished Data.

Karamouz, M., B. Zahraie, R. Kerechian. 2003. Development of a Master Plan for Water Pollution Control using MCDM Techniques: A Case Study. *Water International* 28(4): 478-490.

Kates, R.W. 1962. *Hazard and Choice Perception in Flood Plain Management.* Chicago: University of Chicago Press. Department of Geography Research Paper No. 78.

Kates, R.W., and I. Burton. 1986. *Themes from the work of Gilbert F. White: Geography Resources and the Environment.* Volume 2. Chicago: University of Chicago Press.

Keeney, R. 1982. Decision Analysis: An Overview. *Operations Research* 30(5): 803-838.

Keeney, R. 1992. *Value Focused Thinking: A Path to Creative Decision Making.* Cambridge: Harvard University Press.

Keeney, R., and H. Raiffa. 1976. *Decisions with Multiple Objectives.* New York: John Wiley.

KGS Group (Kontzamanis-Graumann-Smith-MacMillan Inc.). 1999. *Flood Protection for Winnipeg, Part I–Vulnerabilities and Part II–Mitigation Measures.* Winnipeg, Manitoba.

Klohn Leonoff Ltd. 1989. *Floodplain Management Plan.* Engineering Studies. District of Abbottsford. Richmond, B.C.: Klohn Leonoff.

Laituri, M.J. 2000. Cultural Perspectives of Flooding. In *Inland Flood Hazards: Human, Riparian and Aquatic Communities,* ed. E. Wohl. New York: Cambridge Univ. Press.

Landcor (Landcor Data Corporation Inc.). 2003. Unpublished data. New Westminster, B.C.: Landcor Data Corporation Inc., www.landcor.com.

Loomis, J.B. 2000. Environmental Valuation Techniques in Water Resource Decision Making. *Journal of Water Resources Planning and Management* 126(6): 339-344.

Louviere, J.J. 2000. *Why Stated Preference Discrete Choice Modelling is not Conjoint Analysis (and what SPDCM is).* Memetrics White Paper No.1. Accessed May 28, 2002 at < http://www.memetrix.com/products/SPDCM_whitepaper.pdf >.

Louviere, J.J., and G. Woodworth. 1983. Design and Analysis of Simulated Consumer Choice or Allocation Experiments: An Approach Based on Aggregate Data. *Journal of Marketing Research* 20(4): 350-366.

Louviere, J.J., and J. Swait. 1996. *Searching for Regularities in Choice Processes, Or The Little Constant that Could.* Unpublished Working Paper. Sidney: Department of Marketing, Faculty of Economics, University of Sidney, Australia.

Louviere, J.J., D.A. Anderson, and D.L. Edwards. 1993. *Maximum Difference Conjoint Theory, Methods and Comparisons with Choice and Rating Based Conjoint.* Unpublished Working Paper. Salt Lake City: Department of Marketing, Eccles School of Business, University of Utah.

Louviere, J.J., D.A. Hensher, and J.D. Swaite. 2000. *Stated Choice Methods: Analysis and Applications.* New York: Cambridge University Press.

Lyle, T.S. 2001.*Non-Structural Flood Management Solutions for the Lower Fraser River Valley, British Columbia*. Master of Resource Management Research Project, School of Resource and Environmental Management, Simon Fraser University, Burnaby, B.C.

Lynch, J.G., Jr. 1985. Uniqueness Issues in the Decompositional Modeling of Multiattribute Overall Evaluations: An Information Integration Perspective. *Journal of Marketing Research* 22: 1-19.

Malczewski, J. 1999. *GIS and Multicriteria Decision Analysis*. New York: John Wiley and Sons.

Market Vision Research. 2002. *Conjoint Analysis: An Introduction*. Market Vision Research White Paper. Accessed March 2, 2004 at <http://www.mv-research.com/pdf/Intro%20to%20Conjoint%202002.pdf>.

McDaniels, T., and C. Roessler. 1998. Multi Attribute Elicitation of Wilderness Preservation Benefits: A Constructive Approach. *Ecological Economics* 27: 299-312.

McDaniels, T., R. Gregory, and D. Fields. 1999. Democratizing Risk Management: Successful Public Involvement in Local Water Management Decisions. *Risk Analysis* 19(3): 497-510.

McDaniels, T.L. 1996. The Structured Value Referendum: Eliciting Preferences for Environmental Policy Alternatives. *Journal of Policy Analysis and Management* 15(2): 227-251.

McFadden, D. 1974. Conditional Logit Analysis of Qualitative Choice Behavior. In *Frontiers in Economics*, ed. P. Zarembka. New York: Academic Press.

Merritts, D. 2000. The Effects of Variable River Flow on Human Communities. In *Inland flood Hazards: Human, Riparian and Aquatic Communities*, ed. E. Wohl. New York: Cambridge University Press.

Mitchell, J.K., N. Devine, and K. Jagger. 1989. A Contextual Model of Natural Hazard. *Geographical Review* 79: 391-409.

Mitchell, R.C., and R.T. Carson. 1989. *Using Surveys to Value Public Goods: the Contingent Valuation Method.* Baltimore: John Hopkins University Press.

Moorhouse, M., and S. Elliff. 2002. Planning Processes for Public Participation in Regional Water Resources Planning. *Journal of the American Water Resources Association* 38(2): 531-540.

Morgan, M.G., and M. Henrion. 1990. *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*. New York: Cambridge University Press.

Morrison, M.D., R.K. Blamey, J.W. Bennett, and J.J. Louviere. 1996. *A Comparison of Stated Preference Techniques for Estimating Environmental Values*. Choice Modeling Research Report No. 1. University of New South Wales, Australia.

NOAA (National Oceanic and Atmospheric Administration). 1994. *The Great Flood of 1993.* Washington, D.C.

Opaluch, J., S. Swallow, T. Weaver, C. Wessells, and D. Wichelns. 1993. Evaluating Impacts from Noxious Facilities: Including Public Preferences in Current Siting Mechanisms. *Journal of Environmental Economics and Management* 24(1): 41-59.

Parker, D.J. 1995. Floodplain Development Policy in England and Wales. *Applied Geography* 15(4): 341-363.

Pavlikakis, G.E., and V.A. Tsihrintzis. 2003. Integrating Humans in Ecosystem Management using Multi-Criteria Decision Making. *Journal of the American Water Resources Association* 39(2): 277-288.

Payne, J., J. Bettman, and D. Schkade. 1999. Measuring Constructed Preferences: Towards a Building Code. *Journal of Risk and Uncertainty* 19(1-3): 243-270.

Penning-Rowsell, E.C. 1996. Flood-Hazard Response in Argentina. *Geographical Review* 86(1): 72-90.

PEP (Provincial Emergency Program). 2001. *Disaster Financial Assistance: Homeowner and Residential Tenant Guidelines.* Victoria, B.C.: Province of British Columbia, Provincial Emergency Program. British Columbia Ministry of Public Safety and Solicitor General. Accessed October 20, 2002 at <http://www.pep.bc.ca/dfa_claims/ DFA_homeowner_and_residential.pdf>.

Peters, Neil. 2003. Personal communication in his position, March 2003. Section Head, Flood Hazard Management/Inspector of Dykes, Ministry of Water, Land, and Air Protection, Province of British Columbia.

Poyhonen, M., and R. Hamalainen. 2001. On the Convergence of Multiattribute Weighting Methods. *European Journal of Operational Research* 129: 569-585.

Prato, T, S., Hajkowicz. 2001. Comparison of Profit Maximization and Multiple Criteria Models for Selecting Farming Systems. *Journal of Soil and Water Conservation* 56 (1): 52-55.

Rajabi, S., K.W. Hipel, and D.M. Kilgour. 2001. Multiple Criteria Screening of a Large Water Policy Subset Selection Problem. *Journal of the American Water Resources Association* 37(3): 533-546.

Rajasekaram, V., S.P. Simonovic, and K.D.W. Nandalal. 2003. Computer Support for Implementation of a Systematic Approach to Water Conflict Resolution. *Water International* 28(4): 454-466.

Raktoe, B.L., A. Hadayat, and W.T. Federer. 1981. *Factorial Designs.* Wiley Series in Probability and Mathematical Statistics. New York: John Wiley and Sons.

Ramachandran, R., and S.C Thakur. 1974. India and the Ganga Floodplain. In *Natural Hazards: Local, National, Global*, ed. G.F. White. New York: Oxford University Press.

Rasid, H. 2000. Reducing Vulnerability to Flood Disasters in Bangladesh: Compatibility of Floodplain Residents' Preferences for Flood Alleviation Measures with Indigenous Adjustments to Floods. In *Floods: Volume II*, ed. D.J. Parker. Routledge Hazards and Data Series. London: Routledge.

Rasid, H., and W. Haider. 2002. Floodplain Residents' Preferences for Non-Structural Flood Alleviation Measures in the Red River Basin, Manitoba, Canada. *Water International* 27(1): 132-152.

Rasid, H., and W. Haider. 2003. Floodplain Residents' Preferences for Water Level Management Options in Flood Control Projects in Bangladesh. *Natural Hazards* 28: 101-129.

Rasid, H., W. Haider, and L. Hunt. 2000. Post-flood Assessment of Emergency Evacuation Policies in the Red River Basin, Southern Manitoba. *The Canadian Geographer* 44(4): 369-386.

Robert, G., and G. Casella. 1999. *Monte Carlo Statistical Methods*. New York: Springer-Verlag.

Rogers, G.C. 1998. Earthquakes and Earthquake Hazard in the Vancouver Area. In *Geology and Natural Hazards of the Fraser River Delta, British Columbia,* ed. J.J. Clague, J.C. Luternauer, and D.C. Mosher. *Geological Survey of Canada Bulletin* 525: 17–25.

Rogers, J.J.W., and P.G. Feiss. 1998. *People and the Earth: Basic Issues in the Sustainability of Resources and Environment.* Cambridge, U.K.: Cambridge University Press.

Roy, B. 1968. Classement et Choix en Presence de Criteres Multiples. *Rero. 2' Annee* 8: 57-75.

Roy, B. 1973. How Outranking Relation Helps Multiple Criteria Decision Making. In *Selected Proceedings of a Seminar on Multi-criteria Decision Making*, Chapel Hill, SC: University of South Carolina Press.

Rudwick, B.H. 1973. *Systems Analysis for Effective Planning.* New York: John Wiley and Sons.

Russell, C., V. Dale, J. Lee, M. Jensen, M. Kane, and R. Gregory. 2001. Experimenting with Multi Attribute Utility Survey Methods in a Multi Dimensional Valuation Problem. *Ecological Economics* 36: 87-108.

Saaty, T.L. 1992. *Multicriteria Decision Making - The Analytical Hierarchy Process*. Pittsburgh, RWS Publications.

Savage, L.J. 1954. *The Foundations of Statistics*. New York: John Wiley and Sons.

Schoemaker, P., and C. Waid. 1982. An Experimental Comparison of Different Approaches to Determining Weights in Additive Utility Models. *Management Science* 28(2): 182-195.

Sewell, W.R.D. 1965. *Water Management and Floods in the Fraser River Basin*. Chicago: University of Chicago Press.

Shanks, G.R. 1972. The Role of Perception in Floodplain Management. Master of Arts Thesis, University of British Columbia.

Shaw, J., R.B. Taylor, D.L. Forbes, and S. Solomon. 2001. Sea Level Rise in Canada. *Geological Survey of Canada Bulletin*. 548: 225-226.

Shrubsole, D. 2000. *Flood Management in Canada at the Crossroads*. Toronto: Institute for Catastrophic Loss Reduction. ICLR Research Paper Series No. 5.

Shrubsole, D., M. Green, and J. Scherer. 1997. The Actual and Perceived Effects of Floodplain Land-use Regulations on Residential Property Values in London, Ontario. *Canadian Geographer* 41(2): 166-178.

Simonovic, S.P. 1999. *Decision Support System for Flood Management in the Red River Basin.* Report to the International Joint Commission Red River Basin Task Force, Ottawa, Washington D.C.

Slaymaker, O. 1990. Climate Change and Erosion Processes in Mountain Regions of Western Canada. *Mountain Research and Development* 10: 171-182.

Slovic, P. 1995. The Construction of Preference. *American Psychologist* May 1995: 364-371.

Smith, K., and G.A. Tobin. 1979. *Human Adjustment to the Flood Hazard*. London: Longman.

Smith, K., and R.C. Ward. 1998. *Floods: Physical Processes and Human Impacts*. New York: John Wiley and Sons.

Smith, S.E. 1991. Floodplain Management in the Fraser Basin. In *Perspectives of Sustainable Development in Water Management: Towards Agreement in the Fraser River Basin,* ed. Anthony H.J. Dorcey. Volume I. Vancouver: Westwater Research Centre, University of British Columbia.

Smolko, B.A., R.R. Huberd, and N. Tam-Davis. 2002. Creating Meaningful Stakeholder Involvement in Watershed Planning in Pierce County, Washington. *Journal of the American Water Resources Association* 38(4): 981-994.

Solyody, L. 1997. Use of Optimization Models in River Basin Water Quality Planning. *Water Science and Technology* 36(5): 209-218.

Srininvasa Raju, K., and C.R.S. Pillai. 1999. Multicriterion Decision Making in River Basin Planning and Development. *European Journal of Operational Research* 112: 249-257.

Stedinger, J.R. 2000. Flood Frequency Analysis and Statistical Estimation of Flood Risk. In *Inland Flood Hazards: Human, Riparian and Aquatic Communities,* ed. E. Wohl. New York: Cambridge University Press.

Stewart, T., and L. Scott. 1995. A Scenario Based Framework for Multi Criteria Decision Analysis in Water Resources Planning. *Water Resources Research* 31(11): 2835-2943.

Thurstone, L.L. 1927. A Law of Comparative Judgement. *Psychological Review* 4: 273-286.

Timmermans, H. 1984. Decompositional Multi-attribute Preference Models in Spatial Choice Analysis: A Review of some Recent Developments. *Progress in Human Geography* 14: 311-334.

Train, K. 2003. *Discrete Choice Methods with Simulation*. New York: Cambridge University Press.

Ulegin, B., F. Ulegin, and U. Guvenc. 2001. A Multidimensional Approach to Urban Quality of Life: The Case of Istanbul. *European Journal of Operational Research* 130: 361-374.

USACE (United States Army Corps of Engineers). 1993. *Floodproofing – How to Evaluate your Options: Decision Trees.* National Floodproofing Committee. Washington, D.C.

von Winterfeldt, D., and W. Edwards. 1986. *Decision Analysis and Behavioral Research.* New York: Cambridge University Press.

Watson, C.C., and D.S. Biedenharn. 2000. Comparison of Flood Management Strategies. In *Inland Flood Hazards: Human, Riparian and Aquatic Communities*, ed. E. Wohl. New York: Cambridge University Press.

Watson, S.R., and D.M. Buede. 1987. *Decision Synthesis: The Principles and Practice of Decision Analysis.* Cambridge: Cambridge University Press.

Weber, M., and K. Borcherding. 1993. Behavioural Influences on Weight Judgements in Multiattribute Decision Making. *European Journal of Operational Research* 67: 1-12.

Wetmore, F., and G. Jamieson. 1999. Flood Mitigation Planning: The CRS Approach. *Natural Hazards Informer* 1. Boulder: Natural Hazards Research and Applications Information Center, University of Colorado. Accessed June 18, 2004 at <http://www.colorado.edu/hazards/informer/infrmr/infrmr1.pdf>.

White, G.F. 1945. *Human Adjustment to Floods: A Geographical Approach to the Flood Problem in the United States*. Department of Geography Research Paper No. 29. Chicago: University of Chicago Press.

White, G.F. 1964. *Choice of Adjustment to Floods*. Department of Geography Research Paper No. 93. Chicago: University of Chicago Press.

White, G.F. 1974. *Natural Hazards: Local, National, Global*, ed. G.F. White. London: Oxford University Press.

White, G.F., W.C. Calef, J.W. Hudson, H.M. Mayer, J.R. Sheaffer, and D.J. Volk. 1958. *Changes in Urban Occupance of Flood Plains in the United States.* Research Paper 57. Chicago: Department of Geography, University of Chicago.

Wohl, E.E. 2000. Inland Flood Hazards. In *Inland Flood Hazards: Human, Riparian and Aquatic Communities*, ed. E. Wohl. New York: Cambridge University Press.

Yin, YY. 2001. Flood Management and Sustainable Development of Water Resources: The case of the Great Lakes Basin. *Water International* 26(2): 197-205.

Yoe, C. 2002. *Trade-off Analysis Planning and Procedures Guidebook.* Alexandria, VA: Institute for Water Resources, United States Army Corps of Engineers. Report Number IWR 02-R-2. Accessed February 26, 2004 at <http://www.iwr.usace.army.mil/iwr/pdf/tradeoff.pdf>.

Yoon, K.P, and C.L. Hwang. 1995. *Multiple Attribute Decision Making: An Introduction.* Sage University Paper Series on Quantitative Applications in the Social Sciences, no. 07-104. Thousand Oaks, CA: Sage Publications.

Zahedi, F. 1986. The Analytical Hierarchy Process: A Survey of the Method and its Applications. *Interfaces* 16: 96-108.

APPENDIX A • ETHICAL APPROVALS

Ethical approval for research utilising human subjects was required for this research project. This appendix contains two letters from Simon Fraser University's Office of Research Ethics outlining ethical approval for the two preference surveys.

APPENDIX B • COMPONENTS OF INTEGRATED FLOODPLAIN MANAGEMENT

Classification	Type	Specific Tools/Techniques
MITIGATION	Prevention	• planning and zoning • open space preservation • land development regulations • building code development and enforcement • maintenance of existing structural protective measures • development incentives • storm water management
	Property Protection	• acquisition • relocation • rebuilding • flood proofing
	Natural Resources Protection	• wetlands protection • erosion and sediment control • best management practices
	Structural Projects	• reservoirs • levees, floodwalls • diversions • channel modification • storm sewer
	Public Information	• flood maps and data • library resources • outreach projects • technical assistance • real estate disclosure • education
	Emergency Services Planning	• setting up warning systems • dam condition monitoring • emergency response planning
RESPONSE	Emergency Services Provision	• warning • activating response plans • opening emergency operations centers • evacuation • opening shelters • organizing volunteer efforts
	Flood fighting	• temporary structures (e.g. earthen or sandbag dikes) • operation of gates, channels, and diversions
RECOVERY	Public Assistance	• government aid
	Private Assistance	• insurance plan • international aid/charity

List of measures available for use in integrated floodplain management (modified from Wetmore and Jamieson 1999).

APPENDIX C • WORKSHOP PARTICIPANTS

The following individuals participated in workshops during the problem-structuring phase of this research project.

- Carrie Baron, *City of Surrey*
- David Brownlee, *City of Richmond*
- Steve Litke, *Fraser Basin Council*
- Mitch Fumall, *Provincial Ministry of Community, Aboriginal, and Women's Services*
- Hugh Sloan, *Fraser Valley Regional District*
- Jim Hurst, *City of New Westminster*
- Neil Peters, *Provincial Ministry of Water, Land, and Air Protection*

APPENDIX D • FLOODPROOFING SURVEY, ORAL PRESENTATIONS, AND DSS

The contents of this appendix are provided on a CD located on the inside back cover of this document.

CD contents:

Filename	Description
Read me.txt	Text file containing information on how to use files on the CD.
IntroductoryPresentation.pps	Introductory powerpoint presentation.
ExamplePresentation.pps	Mid-survey powerpoint presentation.
Run Floodproofing Survey from CD	**Folder** containing the executable file that can be used to run a limited version of the floodproofing survey from the CD.
Install-Floodproofing Survey (limited)	**Folder** containing the installation files for the floodproofing survey.
FloodproofingDSS.exe	Executable file containing the floodproofing decision support systems (English version only).
Install-Floodproofing DSS	**Folder** containing the installation files for the floodproofing decision support system.

APPENDIX E• COMMUNITY GROUPS PARTICIPATING IN SURVEY

The names of the local non-profit groups who arranged participants for the floodproofing survey are provided below.

- Richmond Homeless Cats
- Richmond Baseball Association
- Islanders 88A (Baseball club)
- Richmond Minor Hockey
- Richmond Minor Football
- Richmond Youth Soccer
- Richmond Christmas Fund
- Batons West Twirling Club
- Richmond Business and Professional Women's Association
- Richmond Baptist Church
- Richmond Alliance Church

APPENDIX F• SURVEY INFORMATION HANDOUT

SIMON FRASER UNIVERSITY FLOODPROOFING SURVEY

Your Personal Survey Number is _______

Thank you for agreeing to share your views with us in this survey. Your participation will help to ensure that important public values are understood and documented so that they may be used to help create acceptable flood management policies in areas in which flooding is a concern.

Important Information (Please read carefully before we start the session.)

This survey is part of a graduate research project conducted by researchers from the School of Resource and Environmental Management at Simon Fraser University. Funding for this project has been provided by the Social Science and Humanities Research Council of Canada under the Community University Research Alliance program.

The ethics committee at Simon Fraser University has approved the content of this survey. Any information that is obtained during this study will be kept confidential to the full extent permitted by the law. Knowledge of your identity is not required. You will not be required to write your name or any other identifying information on research materials. Materials will be maintained in a secure location accessible only to the researchers involved.

Participation in this survey is completely voluntary and can be withdrawn at any time (every page in the survey has a 'quit' button for your convenience). Results will be published as summaries only, in which no individual answers can be identified.

If you have any questions or concerns about this survey or if you know of any other non-profit groups that might like to organize their members to take this survey, please contact us.

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APPENDIX G • ADDITIONAL SURVEY RESULTS

Gender	Number
Male	137
Female	78

Age Category	Number
18 – 29	7
30 – 39	33
40 – 49	103
50 – 59	46
60 – 69	16
70 or older	10

Employment Type	Number
Unemployed	5
Retired	25
Homemaker	24
Student	2
Full-time	129
Part-time	27
Seasonal	2

Participation in Floodplain Management Planning Process?	Number
Yes	5
No	210

Education	Percent of Sample	Percent City of Richmond*
Elementary	0.5	6
Some High School	3.7	14
High School	20.8	13
Technical Training or College	31.5	32
Some University	14.8	11
University	20.4	24
Post graduate study	8.3	Not available

*City of Richmond (2003e)

Annual Income Category	Number	Average Survey Income (Aug/Sept 2003)	Average Income, City of Richmond, in 2000*
Under $30,000	16	$65,000	$61,000
$30,000 to $49,000	39		
$50,000 to $69,000	48		
$70,000 to $89,000	38		
$90,000 or more	62		

*City of Richmond (2003f)

Ethnic Origins	Percentage of Survey Sample	Percentage, City of Richmond, 2001*
Non-visible minority groups	72.9	42
East/Southeast Asian	14.0	47
Southwest Asian or Arab	4.7	9
African	1.9	1
Latin American	0.9	0.1
Other	5.6	Not applicable

*City of Richmond (2003g)

Respondents' comments on the survey

The following list contains a selection of comments written by respondents. Comments have been edited to exclude general comments not directly related to flooding and floodproofing. Most spelling mistakes and grammatical errors have been corrected to improve readability. Comments are presented in no particular order.

- Would like to know that there is gas or diesel generator backup for the flood pumps, for all the flood pumps in Richmond
- I have no problem with higher residential buildings. I question why Richmond continues to allow new homes to be built without significantly raising the house site with fill. Our subdivision is @ 8 feet higher than the older homes near us. The cost of flood proofing homes should be up to the homeowner, not the taxpayer; we spent more for our home because of the fill, why should we pay for others?
- Survey was easy to do. I can't say that I know very much about floodproofing or have even thought about it very much, so I hope my information is useful to you.
- The survey was very good. I however think the government should be highly responsible for homeowner's safety. This means they need to make sure we are safe and have done everything to stop flooding.
- I am surprised that an undertaking of this nature has not been a major focus in this community. I have not lived here long, yet, people seem to take a "wait and see" approach to the ever-present dangers of flooding in Richmond ... (of all places!). Good Luck.
- Make the major roads higher to act as dykes.
- Dykes can be configured in such a way as to provide public recreational opportunities, thereby lessening the perceived expense of floodplain management.
- I'd rather improve dykes/pumps than individual homes. Concentrate on keeping water out of the whole rather than the individual lot
- I believe that if the individuals of Richmond are to buy into floodproofing strategies it would need to be proven and mandated by the municipal government, and perhaps all levels of government. I have found this study to be enlightening.
- I think Richmond has to get serious about floodproofing.
- Safety and get on it now thank you please
- Richmond is a risk factor and vulnerable to flooding in the near future. The government should have more grants to prevent such future disasters.
- Both the Provincial and Federal governments should require insurance companies to provide flood insurance for homeowners. Currently, they offer Earthquake coverage as an option but not flood!
- Insurance should be made available.
- Thank you for making me think about this situation. I don't consider the policies and outcomes truthfully. I know that flooding is a strong possibility. We actually chose our home thinking about distance from the dyke and structure of the home (it's a walk-up). You could consider the insurance factor - or is that homeowners cost?
- Very interesting. Answers are skewed if I think I will move out of the community within 5 yrs. Good luck. Where can we see the results of your thesis?
- Survey is OK. I think serious debate should revolve around the "first line of defence" (dykes, pumps, etc) before going too far down the road on changing the structure of individual homes. i.e.: if the dykes are crested, what is the best secondary disaster prevention devise... and maybe what is a tertiary disaster prevention devise. The key is to provide the highest SAFETY RATING for Richmond Citizens with the most functional and economical method.
- My vote is for higher dykes. Individual floodproofing is like trying to solve a big problem with hundreds of band-aids. Trying to floodproof a whole city one house at a time will be extremely disruptive. Also there is a good history of these kinds of government-induced programs being subject to rip-off and con artists. Just like the recent gun registry disaster, managing a

program of individual floodproofing will be difficult and will almost certainly lead to abuse. (Other examples of public policy disaster are the "urea formaldehyde" insulating disaster and the scientific research credit disaster.)

- I might be moving and my own house is somewhat old though still quite liveable so I would not due to priorities put a high priority on any of this and prefer to take my chances and any consequences that may ensue. However it might be a good idea for new homes and anyone wishing and able to upgrade or might be a consideration for schools, hospitals etc.
- Just spend the money on building and maintaining a highest-grade dyke system.
- I found survey interesting. With being an owner it gives some ideas to think about. Can give others some in put as to what to do to their homes and or complex. We have done some waterproofing already to Complex by replacing membrane all around and to crawl space which now allows no more water to enter. Membranes over time rupture and should be checked periodically. Check home and complex crawl space for any moisture and then act on your findings.
- Thank you for enlightening me in regards to flooding. It’s not something that I thought of before but see the importance of it. Good luck with the study.
- Excellent presentation & research - welcome the results
- I would like to see a strategy for people living in townhomes or condos, because most decisions are based on a strata management system.
- I have lived in Richmond since 1962 but never considered flooding a threat as I live just below Steveston Highway. However, in past years with the change in the global climate there could be a potential problem so we should possible be more aware of what could occur. My house is 2-1/2 ft. above sea level.
- Government should be willing to make it harder to build unsafe housing. As for what is already there it should not be the homeowner’s responsibility to cover costs for any maintenance, this should have been thought about before building in Richmond.
- It's certainly brought up some issues that I have previously not been concerned with.
- I am concerned that not enough attention may be paid to the building process even though this will not affect existing homes. If a serious flood should take place then the existing homes need to be considered in the percentage of homes that should be floodproofed. It's a good thing that you are looking into this because I, too, believe that there will be some natural disaster, which will cause flooding in the next couple of decades. Best of luck with this project!
- It is my opinion that floodproofing is a necessary precaution for homeowners (old/new) although it doesn't seem to effect my current residence as I live on the third floor of an apartment building.
- A timely research study. If the predictions of a major flood sometime soon (?) are accurate, I hope that the results of this research--if provided in some manner to Richmond's municipal government --will be a spur to their planning processes.
- I think initiatives should be offered to residents to begin flood proofing their homes, education is needed.

APPENDIX H • DSS SETTINGS

The settings used for the community outcomes DSS are described in the table below (note that the settings are the same as the values described in Table 32).

Attribute	A	B	C	D	E	F	G	H	I
Aesthetics (%)	27	34	33	38	30	15	40	34	36
Accessibility (% decrease)	37	48	46	55	42	17	57	48	51
Bureaucracy (steps)	0	0	0	0	0	2	0	0	0
Public Sector Costs ($)	0	1,513	0	0	0	0	6,070	0	7,100
Homeowner Costs ($)	18,400	24,486	26,970	31,627	21,199	7,477	26,729	28,107	21,299
Safety (%)	50	69	65	82	60	22	86	68	75
Stress and Disturbance (Months)	2.5	1.75	2	1.25	2.25	3.25	1.25	1.75	1.5
Public Sector Damages ($)	43,840	30,627	33,409	21,586	30,485	62,830	18,804	24,991	26,454
Homeowner Damages ($)	11,960	8,657	9,352	6,397	19,230	16,708	5,701	15,162	7,614

The settings used for the personal floodproofing DSS are described in the table below.

	Alternative								
Attribute	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Floodproofing Costs:									
- Elevation	Constant, set to average value seen by respondents in survey ($60,000)								
- Wet Floodproofing	Constant, set to average value seen by respondents in survey ($18,000)								
Flood Damages:									
- Elevation	Constant, set to average value seen by respondents in survey ($4,400)								
- Wet Floodproofing	Constant, set to average value seen by respondents in survey ($41,000)								
- No Floodproofing	Constant, set to average value seen by respondents in survey ($87,000)								
Disturbance:									
- Elevation	Constant, set to average value seen by respondents in survey (2 weeks)								
- Wet Floodproofing	Constant, set to average value seen by respondents in survey (2 months)								
Support Type (1 = Tax Break, 2 = Grant)	1	1	1	1	1	NA*	2	1	2
Support Value Tax Break (1 = None, 2 = Yes) Grant (0, 5, 10, 15 thousand $)	1	2	1	2	1	NA	10	1	10
Levies (1 = None, 2 = Yes)	1	1	2	2	1	NA	2	2	1
Compensation (50, 60, 70, 80 %)	80	80	80	80	60	NA	80	70	80

*Not applicable - Strategy F was a non-voluntary floodproofing strategy.

APPENDIX I • DETAILED DECISION ANALYSIS EVALUATION TABLES

Alternative Evaluation Tables

Comparison with detail for each attribute. Scores are derived from linear additive summation

Decision Maker:	***Public 1***	***A***		***B***		***C***		***D***		***E***		***F***		***G***		***H***		***I***	
Attributes	**Weights**	**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**	
Aesthetics	0.01	27.00	0.55	34.00	0.43	33.00	0.45	38.00	0.37	30.00	0.50	15.00	0.75	40.00	0.33	34.00	0.43	36.00	0.40
Accessibility	0.03	37.00	0.54	48.00	0.40	46.00	0.43	55.00	0.31	41.00	0.49	17.00	0.79	57.00	0.29	48.00	0.40	52.00	0.35
Bureaucracy	0.03	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	2.00	0.50	0.00	1.00	0.00	1.00	0.00	1.00
Public Costs	0.13	0.00	1.00	1500.00	0.85	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	6000.00	0.40	0.00	1.00	7100.00	0.29
Private Costs	0.19	18000.00	0.70	25000.00	0.58	27000.00	0.55	32000.00	0.47	21000.00	0.65	7500.00	0.88	27000.00	0.55	28000.00	0.53	21000.00	0.65
Safety	0.23	50.00	0.42	69.00	0.58	65.00	0.54	82.00	0.68	57.00	0.48	22.00	0.18	86.00	0.72	68.00	0.57	75.00	0.63
Stress and Disturbai	0.13	10.00	0.44	7.00	0.61	8.00	0.56	5.00	0.72	9.00	0.50	13.00	0.28	5.00	0.72	7.00	0.61	6.00	0.67
Public Damages	0.05	44000.00	0.56	31000.00	0.69	33000.00	0.67	22000.00	0.78	30000.00	0.70	63000.00	0.37	19000.00	0.81	25000.00	0.75	26000.00	0.74
Private Damages	0.20	12000.00	0.60	9000.00	0.70	9000.00	0.70	6000.00	0.80	19000.00	0.37	17000.00	0.43	6000.00	0.80	15000.00	0.50	8000.00	0.73
		Score:	**0.62**		**0.65**		**0.65**		**0.71**		**0.59**		**0.53**		**0.66**		**0.62**		**0.62**
		Rank:	**7**		**3**		**4**		**1**		**8**		**9**		**2**		**5**		**6**

Decision Maker:	***Public 2***	***A***		***B***		***C***		***D***		***E***		***F***		***G***		***H***		***I***	
Attributes	**Weights**	**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**	
Aesthetics	0.01	27.00	0.55	34.00	0.43	33.00	0.45	38.00	0.37	30.00	0.50	15.00	0.75	40.00	0.33	34.00	0.43	36.00	0.40
Accessibility	0.03	37.00	0.54	48.00	0.40	46.00	0.43	55.00	0.31	41.00	0.49	17.00	0.79	57.00	0.29	48.00	0.40	52.00	0.35
Bureaucracy	0.03	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	2.00	0.50	0.00	1.00	0.00	1.00	0.00	1.00
Public Costs	0.13	0.00	0.00	1500.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6000.00	0.60	0.00	0.00	7100.00	0.71
Private Costs	0.19	18000.00	0.70	25000.00	0.58	27000.00	0.55	32000.00	0.47	21000.00	0.65	7500.00	0.88	27000.00	0.55	28000.00	0.53	21000.00	0.65
Safety	0.23	50.00	0.42	69.00	0.58	65.00	0.54	82.00	0.68	57.00	0.48	22.00	0.18	86.00	0.72	68.00	0.57	75.00	0.63
Stress and Disturbai	0.13	10.00	0.44	7.00	0.61	8.00	0.56	5.00	0.72	9.00	0.50	13.00	0.28	5.00	0.72	7.00	0.61	6.00	0.67
Public Damages	0.05	44000.00	0.44	31000.00	0.31	33000.00	0.33	22000.00	0.22	30000.00	0.30	63000.00	0.63	19000.00	0.19	25000.00	0.25	26000.00	0.26
Private Damages	0.20	12000.00	0.73	9000.00	0.80	9000.00	0.80	6000.00	0.87	19000.00	0.58	17000.00	0.62	6000.00	0.87	15000.00	0.67	8000.00	0.82
		Score:	**0.51**		**0.56**		**0.53**		**0.57**		**0.48**		**0.45**		**0.67**		**0.50**		**0.67**
		Rank:	**6**		**4**		**5**		**3**		**8**		**9**		**2**		**7**		**1**

Decision Maker:	***Expert All***	***A***		***B***		***C***		***D***		***E***		***F***		***G***		***H***		***I***	
Attributes	**Weights**	**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**		**Impacts**	
Aesthetics	0.03	27.00	0.55	34.00	0.43	33.00	0.45	38.00	0.37	30.00	0.50	15.00	0.75	40.00	0.33	34.00	0.43	36.00	0.40
Accessibility	0.04	37.00	0.54	48.00	0.40	46.00	0.43	55.00	0.31	41.00	0.49	17.00	0.79	57.00	0.29	48.00	0.40	52.00	0.35
Bureaucracy	0.07	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	2.00	0.50	0.00	1.00	0.00	1.00	0.00	1.00
Public Costs	0.13	0.00	1.00	1500.00	0.85	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	6000.00	0.40	0.00	1.00	7100.00	0.29
Private Costs	0.11	18000.00	0.70	25000.00	0.58	27000.00	0.55	32000.00	0.47	21000.00	0.65	7500.00	0.88	27000.00	0.55	28000.00	0.53	21000.00	0.65
Safety	0.16	50.00	0.42	69.00	0.58	65.00	0.54	82.00	0.68	57.00	0.48	22.00	0.18	86.00	0.72	68.00	0.57	75.00	0.63
Stress and Disturbai	0.15	10.00	0.44	7.00	0.61	8.00	0.56	5.00	0.72	9.00	0.50	13.00	0.28	5.00	0.72	7.00	0.61	6.00	0.67
Public Damages	0.16	44000.00	0.56	31000.00	0.69	33000.00	0.67	22000.00	0.78	30000.00	0.70	63000.00	0.37	19000.00	0.81	25000.00	0.75	26000.00	0.74
Private Damages	0.15	12000.00	0.60	9000.00	0.70	9000.00	0.70	6000.00	0.80	19000.00	0.37	17000.00	0.43	6000.00	0.80	15000.00	0.50	8000.00	0.73
		Score:	**0.63**		**0.67**		**0.67**		**0.74**		**0.62**		**0.51**		**0.68**		**0.66**		**0.63**
		Rank:	**7**		**4**		**3**		**1**		**8**		**9**		**2**		**5**		**6**

APPENDIX J • DERIVATION OF YEARLY FLOODPROOFING RATE

The purpose of this simulation model was to derive the average rate of floodproofing in the urban exempt area between the years 1973 to 2003 that would yield a final percentage floodproofed of 3.7%.

This was accomplished by developing a simple simulation model that kept track of the total number of homes in the exempt zone, the total number of non-floodproofed homes in the exempt zone, and the total number of floodproofed homes in the exempt zone. The models were built in Microsoft Excel and used difference equations and a time step of 1 year.

Assumptions:

- Residential growth rate is approximately equal to the average population growth rate over the same time period (1973 – 2003).
- Floodproofing occurs at an equal rate in new developments (e.g. new growth) and existing developments (e.g. previously non-floodproofed).
- The population growth rate (and consequently the residential growth rate) is constant.
- The rate of floodproofing is constant
- There are no floodproofed homes at time = 0 (e.g. 1973).

Equations:

The total number of homes in the exempt zone was assumed to be described by the following equation:

Equation 34 $T_t = T_{t-1} + g*T_{t-1} ? t = (1+g)*T_{t-1}$,

where T is the total number of homes in the exempt area, and g is the growth rate.

The total number of floodproofed homes in the exempt zone was assumed to be modelled by the following equation:

Equation 35 $FP_t = FP_{t-1} + fp*NFP_{t-1} + fp*g*T_{t-1}$,

where FP is the number of homes that are floodproofed, fp is the rate of floodproofing for both existing and new developments, and g is the growth rate.

The total number of non-floodproofed homes in the exempt zone was assumed to be modelled by the following equation:

Equation 36 $NFP_t = T_t – FP_t = (1+ g – fp*g)*T_{t-1} – FP_{t-1} – fp*NFP_{t-1}$,

where NFP is the number of homes that are not floodproofed, T is the total number of homes, FP is the number of floodproofed homes, fp is the rate of floodproofing for both existing and new developments, and g is the growth rate.

Parameters:

Parameter	Description	Value	Source/Comments
g	The growth rate (%/yr) for homes inside the exempt zone.	3	Estimated from City of Richmond (2003h, 2003i)
fp	The floodproofing rate (%/yr) for homes inside the exempt zone.	?	Initially unknown, derived from analysis.
FP_0	The initial number of floodproofed homes inside exempt zone.	0	Assumption
T_0	The initial number of homes (total) inside the exempt zone.	21000	Estimated from City of Richmond (2003c, 2003h).
NFP_0	The initial number of non-floodproofed homes inside the exempt zone.	21000	Assumption

Analysis:
The above equations can be used to simulate, for each year, the total number of homes, the number floodproofed homes, and the number non- floodproofed homes over the thirty-year time span between 1973 and 2003. The ultimate goal was to determine the value of fp such that the percentage of people floodproofed in the exempt zone at the end of thirty years is equal to 3.7% (the number of estimated from the survey responses). In other words, solve for fp such that $(FP_{30}/T_{30})*(100) = 3.7\%$. This was easily accomplished using Excel's Solver add-in.

Result:
fp ˜ 0.20 %/year.