QUANTIFYING THE VALUE OF DATA OBTAINED FROM RIVER GAUGING STATIONS IN SCOTLAND: A USERS' PERSPECTIVE.

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy.

by:

Kush Thakar

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University of Liverpool

Department of Geography and Planning

School of Environmental Sciences

DEDICATION

To the memory of my four Grandparents,

my family, friends and the people of Scotland.

Abstract

The Scottish Environment Protection Agency (SEPA) monitors river water levels and flow at 392 gauging stations throughout Scotland. Data on river levels and flow are used by a diverse range of interest groups including industry, water authorities, wildlife and water managers, hydrologists, recreational and industrial fishers among others; but most importantly Category 1 Emergency Responders and local populations are reliant on the data produced by gauging stations to provide flood warnings. Data from gauging stations inform the management of water resources to help meet EU Water Framework Directive objectives, the design of new infrastructure on and across flood plains and have been increasingly used by scientists and policy practitioners to evaluate the impact of changes in land use and climate change. The data obtained from river gauging stations are thus a public good that accrue benefits well above their market value, but to date no evaluation of the economic benefit has been made. As agencies responsible for the collection, maintenance and dissemination of such data face a growing demand for their services, the rising costs of network infrastructure needs to be compared with the economic benefits of hydrometric data in order to recognise the societal value of providing such information. The aim of this thesis was to examine the value of the data provided by river gauging stations in Scotland. It did so by eliciting the preferences of two key cohorts in Scotland, namely households and professional data users, for a set of competing hydrometric attributes using stated choice methods; in particular, Choice Experiments. User valuations were analysed across several choice occasions using conditional logit, mixed logit and latent class models. Results demonstrated that both households and professionals derived significant levels of utility from hydrometric gauging activity. Moreover, specific socio-economic and demographic groups were willing to contribute high premiums in order to secure network upgrades, and the effects of cognitive indicators of individual preference were also important determinants of user valuations. Figures aggregated across the two different cohorts revealed non-market benefit-to-cost ratios of at least 15:1, rising to 44:1 when potential value-added services were accounted for. These findings are encouraging for Measuring Authorities facing public sector pressures to downscale their activities by quantifying the magnitude of societal benefits that such activities generate.

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TABLE OF CONTENTS

CHAPTER 1

The Economic Value of Collecting River Gauging Data in Scotland

1.1. Introduction

The Scottish Environment Protection Agency (SEPA) measures the level and flow of river water at 392 stations across Scotland. Data collected from hydrometric stations is used to inform a wide range of purposes from infrastructure planning on floodplains to water resource management, ecological protection and emergency response. This data is available free-of-charge to the public and it accrues a value well above the costs associated with data collection and provision. However, there is currently no quantified assessment of this value, in the absence of which the true social and economic worth of the data remains under-communicated and under-appreciated. As a result the value and role of river gauging stations is underestimated when comparing the benefits generated by the network with the costs of its operation and maintenance.

Gauging stations are riverside shelters containing equipment that continuously measure and record river levels (Shaw 2010). The levels are detected using specialised sensors that make repeated observations of changing water levels every 15 minutes. These figures are recorded electronically using a digital data logger. Trained hydrometry officers at SEPA then download this data remotely via the telephone network. All readings from stations are usually gathered and verified once daily or, sometimes, several times a day for purposes such as flood warning. Most river gauging stations are also designed and operated to produce a record of river flow. Flow is the volume of water moving downstream over a period of time and is also known as the 'discharge'. A continuous record of discharge is derived by relating a continuous measurement of river level with sample flow measurements (gaugings).

A river gauging network consists of several interacting systems and components. This includes the apparatus required to detect changes in river levels and to conduct flow gaugings; a telemetric communications system to automatically transmit data readings from all stations to a central server; an information management system to assemble and cleanse the data; a public dissemination system for both water levels and discharge figures and, finally, the management teams of trained hydrometric officers who are responsible for operating and maintaining the network. Water levels are usually updated in real-time on the SEPA water section pages. However, flow/discharge statistics are more intensive to compute and require a significantly higher input from hydrometry officers in terms detecting and correcting anomalies in readings, conducting spot flow gaugings and rating curve assessments, documenting changes and responding to user queries and requests for hydrometric data.

1.2. Valuation of Information

Microeconomic frameworks available for assessing the benefits of data focus on two main approaches. The first approach known as the Value of Information method examines changes in the beliefs and probability density of decisions made by individual data users when employing items of information for specific purposes. The magnitude of the readjustment in a firm's marginal costs and revenues arising from this changing set of beliefs are the main yardstick for assessing the value of information for that purpose (Hirshleifer and Riley 1992). The second approach comprises non-market valuation methods that are applied to estimate the satisfaction, wellbeing, or utility arising from consuming a public good or service (Bennett 2011). This approach makes it possible to estimate the wider, aggregate social benefits arising from the provision of public goods and services over a larger population.

Methods for estimating non-market benefits of public goods can be classified into Revealed Preference (RP) and Stated Preference (SP) methods (Champ, Boyle, Brown and Peterson, 2003). RP methods rely on data from existing commercial exchanges to infer the value of the public goods linked with the transaction. For example, the travel expenditure that a family is willing to undertake in order to spend a day at the beach might provide some indication of the value they place on the beach as a public amenity (Boyle 2003). Similarly, the higher price that a homebuyer might be willing to pay for a house close to a park could indicate the value s/he places on public green space. These approaches are known as the Travel Cost method (TCM) and Hedonic Pricing method (HPM) respectively. Other RP methods include the Averted Cost method and the Production Function approach (Boyle 2003).

In the absence of commercial transaction data, societal preferences for public goods cannot be deduced from actual decisions made by individual users. These users must then be polled to state what value they would place on a public asset under various constraining circumstances (Brown 2003). Contingent Valuation (CV) is a method which poses this question directly to users and potential users (Boyle 2003), while with choice experiments

(CE), a set of hypothetical consumption scenarios are designed in order to test user decisions under diverse, idealised conditions. In a choice experiment the public good/service of interest is deconstructed into a set of constituent attributes and users are then invited to make choices on alternative combinations of those attributes. The decisions taken by participants provide indirect valuations of the good's attributes. This method is particularly useful for evaluating competing options and formats for delivering public goods and services (Holmes and Adamowicz 2003).

1.3. Open Government Data

In recent years several governments have taken the initiative of opening up machine-readable data records gathered and held by public agencies. This data is usually free to access, use and exchange (Tong et al., 2013). The UK is considered to be a world leader in this movement (Shakespeare, 2013). Open government data, also termed public sector information, may consist of internal administrative records on the operations of a particular government department (for example, departmental expenditures above £10,000 by the Foreign and Commonwealth Office), or it may comprise the data collections of agencies invested with a specific mandate to monitor and regulate national activities/phenomena in the wider public interest (Shakespeare, 2013). River level and flow observations collected by SEPA are one such example.

In the UK many public data providers are constituted as trading funds. This is a special organisational structure allowing national information agencies to commercially develop and sell data products alongside long-term collection and archival responsibilities (Pollock 2009). Examples of trading funds include the British Geological Survey (BGS), Ordnance Survey (OS), Land Registry, Companies House, British Hydrographic Office and the Meteorological Office, among others. The socio-economic benefits generated by public data is a question central to the activities of both trading funds and regulators like SEPA. By estimating the magnitude of these benefits, funds that are spent on continued, long-term data collection and archival activities can be justified, and limited investment funds can be directed in a manner that best supports the diverse needs of individual data users (APPSI 2014).

Hydrometric data is a public good that is not depleted with repeated use. Any dataset containing readings of river levels and flows may be analysed and exchanged on innumerable occasions and for vastly different ends and purposes without eroding the quality of the originally observed data. River level readings are updated typically every 15 minutes on the SEPA water levels website and made available for viewing by the general public for no fee. As such any individual wishing to consult water gauge readings can do so using an internet-enabled electronic device such as a PC, smartphone or tablet. Hydrometric data is therefore non-diminishable and non-excludable, two key properties which define public goods and which are also held by other social amenities such as art galleries, beaches, public parks and transport networks.

Reviews of hydrometric networks and data in Scotland have previously been studied by Copestake et al. (2006) who conducted a review of SEPA's hydrometric network in relation to the monitoring requirements of the EU Water Framework Directive. This directive required member states to move towards water resource planning at the level of the catchment by employing holistic management measures and policies which transcend local political and economic geographies. An earlier review by Black et al. (1999) for the Environment Agency provided a framework for evaluating the benefits of hydrometric networks and identified the need for social, non-market values of the data to be quantified and included in economic calculations of hydrometric benefits. Although CNS Scientific and Engineering Services (1991) had already undertaken such an evaluation, non-market values were missing from their analysis.

1.4. Research Aims and Objectives

This study uses choice experiments to study the preferences of users for various attributes of hydrometric data and in so doing to quantify the wider public benefits generated by Scotland's river gauging network. Two main user groups are surveyed. The first of these comprises households who are mostly passive consumers or end-beneficiaries of hydrometric data-driven systems such as flood warning systems, water resource management policies and environmental protection/restoration programmes. The second group consists of professional data users such as academics, consultant engineers and planners who use hydrometric data series for a variety of purposes often defined by scientific research or commercial client requirements. The reason for surveying households was to understand their levels of prior awareness of the role of river hydrometry and to then measure their preferences as to the future of river gauging infrastructure in Scotland. Similarly, professionals were consulted in order to ascertain their consumption patterns and priorities for future hydrometric data collection. The societal value of the river gauging network was assessed in light of these considered preferences.

1.5. Structure of thesis

Chapter 2 describes the current hydrometric data collection system in Scotland and provides an overview of alternative approaches taken to hydrometric network evaluation. Chapter 3 provides a background of non-market valuation methods focusing on Stated Preference techniques, including their historical development and key issues to consider when seeking to design and analyse data from Contingent Valuation questionnaires and Choice Experiments. Chapter 4 presents an overview of the data, modelling theory and survey methodology. Chapters 5, 6 and 7 describe and discuss the results of the choice experiments taken by households and professional users of hydrometric data in Scotland. Chapter 8 concludes.

CHAPTER 2

The Scottish Hydrometric Network

2.1. INTRODUCTION

This project is undertaken in conjunction with the Scottish Environment Protection Agency (SEPA) and aims to quantify the benefits accruing from use of Scottish river hydrometric data. In so doing it intends to fill a major gap in demonstrating the value of such benefits that is beneficial to the priorities of economic and political decision makers as well as validating investment into the maintenance and operation of Scotland's gauging network. The study will illustrate some key economic characteristics of hydrometric data utility and produce a more rigorous analysis of the implications of network change in the context of changing user profiles and preferences. This chapter sets the application of proposed service valuation methods in context of SEPAs Hydrometric department and hydrometric services in general. It reports on the findings of key studies on hydrometric network reviews previously undertaken in Scotland and elsewhere. It also aims to highlight a path of progress for the study's methodology.

Section 2 will provide an outline of hydrometric data services in Scotland, while section 3 turns to reviews of hydrometric network studies. In section 4 a brief discussion will summarise the chapter and in section 5, the main objectives of the study will be stated.

An Introduction to Key Concepts and Issues in Stream Gauging

Stream flow is the velocity of a given quantity of water moving through a river channel and is measured by discharge or the volume of water measured at a specific cross section of the channel. It is the aggregation of all climate and geography-related factors operating in a drainage basin. A Drainage Basin refers to the area covered by a river and its tributaries in flowing from source to mouth. The terrain hosting this network of streams is also referred to as a Catchment Area as the rainfall intercepted in that region generates the observed flows of surface and ground waters and serves as a key stage in the operation of the hydrological cycle. Hydrology is the name given to the branch of science that deals with the form, features, processes, components, behaviour and patterns of freshwater on land and below the earth's surface. Hydrometry is the measurement of river level, velocity and discharge (Shaw, Beven, Chappell and Lamb 2010).

Purpose of Stream Gauging Programmes

The accuracy of field measurements determine the reliability of river flow data which, in turn, is required for the effective management of water resources as well as a scientific understanding of fluvial (river-related) processes. Stream gauging programmes aim mainly to monitor water resources in order to supply water to households and businesses and are also established for pollution control, irrigation, flood control, energy generation, industrial use, regulation and statutory reporting on these activities and the overall health of the country's water assets. Each of these objectives depend on the timely availability of accurate data describing stream behaviour at a specified location of interest in a catchment.

A range of methods are available for stream flow measurement and have been discussed in detail by Herschy (1995), of which the most common method tends to be the Velocity-Area method.

There are two sets of uses for deploying the information generated by stream flow data. Each comprises a range of further applications. The first set of uses can be categorised under Planning and Design. This consists of infrastructure development in a catchment landscape or channel (for example, civil engineering projects such as bridges, reservoirs, dams); flood frequency estimation and control structures; and monitoring long term trends in stream behaviour and environment. The second set of uses consists of Operation and Control related applications such as abstraction monitoring, water supply monitoring and pollution control (Herschy 1995).

Data required - particularly for planning and design purposes - tends to focus on the statistical characteristics of stream flow such as peak and low flows, mean daily and annual flows rather than on the flow sequences for a given historic period. Interest is usually in the probability that peak events (high or low flows) will occur over a span of years, for example highway bridges designed on the basis of the flood that will be exceeded, on average, once every fifty years, or water supply for purposes such as irrigation or waste dilution may be conveyed by mean flow figures or probability of peak flow magnitudes over a specified period. In order to reach dependable estimates of these figures, a record flow of at least 30 years is advised (WMO 2006).

International Standards in Stream Gauging

Streams often flow across the borders of more than one country. Data collection standards and hence estimates generated on the strength of these standards need to be consistent and comparable in order to be credible. Accordingly the International Standards Organisation (ISO) has been developing hydrometric standards in consultation with its member countries since 1956. A range of protocols have been released since then for adoption by member states along with additional technical guidance from the World Meteorological Organisation. These standards go some way towards defining a minimum acceptable quality of data for authorities which are required to adopt them. In the UK, the policy is to publish the ISO standard and to then produce an identical British Standard (WMO 2006).

In the context of hydrometric networks, the consumption of stream gauge data for operational, forecasting and design objectives is a key indicator of network purpose. This demand also constitutes the main grounds for justifying capital investment into network intensification, technological improvements or for averting the closure of stations with distinctive roles within the network. In order to provide a comprehensive user perspective that is also consistent with economic theory it is necessary to seek further insights in to the economic structure of demand for hydrometric data.

2.2 HYDROMETRIC DATA COLLECTION SCOTLAND

Physical Setting

Scotland is a mainly mountainous country covering 77,900km^2 which constitutes approximately one-third of the total area of the United Kingdom. It is bordered by England to the south and surrounded on the remaining three sides by the Atlantic Ocean; the Irish Sea to its South-West and the North Sea to its East. It consists of 790 islands in addition to the mainland (ONS 2012).

Scotland's terrain contains vast areas of natural beauty of high conservation value with approximately 13% of the land surface classified as National Scenic Areas by Scottish Natural Heritage (SNH, 2012). It also one of wettest countries of Europe receiving an average 1431 mm of rain per year (Gilvear, Heal and Stephenson, 2002).

Recent experience in the context of a changing climate has meant that the seasonal and spatial distribution of precipitation is leading to marked changes to historic climate patterns, with drier summers and wetter winters (Macdonald, 2006). Moreover, while the west coast has witnessed rising levels of rainfall and hence been in the national spotlight for flooding events, the east coast has been vulnerable to drought at the same time in light of declining precipitation rates (Werritty, 2002).

In comparison to other European countries of a similar size (for example, Austria, Ireland), Scotland is considered to demonstrate a high level of variation in both its hydrology and geomorphology (ibid.). Its geological composition is also particularly diverse which in turn is a key determinant of the soil structure and hence the land surface characterising the terrain. Highland areas to the north and west feature mountains exceeding 1300m. These act as shields to rain-bearing clouds from the Atlantic Ocean and thus experience markedly higher rates of precipitation relative to the national average. Rainfall maximum of over 4000mm has commonly been reported in the highlands in recent years (Met Office, accessed April 2014). Highlands are also prone to snowpack formation during the winter which can generate large quantities of run-off during the spring. Mountains have been subject to significant glacial action in the past as manifest in the topography of these areas today. The highlands feature steep slopes and deep valleys and are covered by only thin soils with limited water retention capacity. This results in the quick transmission of water to onward ground and surface water following precipitation events. Flooding in these areas is a key risk. In contrast, easterly areas feature gently undulating landscapes supporting arable land and pastoral agriculture. Mean annual precipitation in these areas is less than 600mm per year (Marsh and Lees 1998). The greater perviousness of local geology drift combines with the relatively lower levels of rainfall and results in low stream volumes making the measurement and modelling of low flows in these regions a notable challenge (Werritty, 2002).

Scotland has over 6000 rivers and a total stream length exceeding 100,000 km. Flow per unit area varies from 0.019m^3/s per km^2 in the Forth and Tweed catchments to 0.062 m^3/s per km^2 in the highlands. Furthermore, available water resources per person stood at 16,000m^3 compared with 2090m^3 for the rest of the U.K. The natural water quality of much Scottish water is high with low concentrations of nutrients and a neutral pH of between 5 and 6 (Soulsby et. al 2002).

These factors posit a unique and complex challenge to undertake the monitoring and research necessary to the sustainable management of freshwater resources.

The Scottish Hydrometric Network

The Scottish Hydrometric Network was initiated with the pioneering activities of Captain W.N. McLean who established the first gauging station in 1912 to measure river levels on the

River Garry in order to assess the site's suitability for hydroelectric power generation (Werritty 1985). Prior to that time water flow and levels were monitored arbitrarily on the basis of specific local requirements (SEPA, accessed April 2014). McLean was a keen hydrometrist and thanks in part to his efforts in raising awareness about the need for a centralised hydrometric network, an Inland Water Survey was established in 1932 following the passage of the Land Drainage and Reservoirs (Safety Provisions) Acts in 1930 (Werritty 1985). Subsequently the Water (Scotland) Act 1946 was the first piece of legislation to comprehensively define the water supply and water resource management powers and duties falling to local authorities (Cranston 1995). This remit was later expanded by the Rivers (Prevention of Pollution) (Scotland) Act of 1951 which appointed River Purification Authorities charged with the prevention of pollution and ensuring the cleanliness of Scottish rivers. Nine River Purification Boards (RPBs) and two island councils were set up in the wake of this legislation during the next few years. A further major review aimed at standardising the activities of the boards and assessing network effectiveness along with areas of poor provision and performance was conducted in in 1963. Twelve years later, local government in Scotland was re-organised, resulting in the consolidation of hydrometric activity conducted separately by individual RPBs and the Scottish Development Department. A more streamlined set of seven RPBs were the main consequence of this process. They covered the Highlands, North East, Tay, Forth, Tweed, Solway and Clyde and endured until the establishment of the Scottish Environment Protection Agency (SEPA) in 1996. Cranston (1995), Cranston and Black (1995), Poodle (1987) and Werritty (1985) provide a more comprehensive insight into the origins and institutional evolution of river gauging prior to 1996.

The current Hydrometric Network in Scotland is owned, operated and maintained by the Scottish Environment Protection Agency (SEPA). At its inception in 1996 SEPA inherited 330 gauging stations from the RPBs. During the course of the next decade 113 more sites were added to the network, so that by the time of a network review conducted in 2010 the agency was operating a collection of 443 stations. The two key drivers for this expansion were the Water Framework Directive (WFD) (2000) and the Flood Risk Management (Scotland) Act (FRMSA) (2009). The former called for a new, integrated and comprehensive approach to water management. These included the licensing of water abstraction, control of diffuse pollution and the consideration of river flow regimes in setting and meeting environmental standards and targets. The FRMSA built on the existing flood management duties that has already been a primary driver for station expansion over the last two decades. Following the review in 2010, 53 lower priority stations were mothballed. Since then the network has continued to grow back to pre-mothball numbers and there are now approximately 392 operational gauging stations across Scotland.

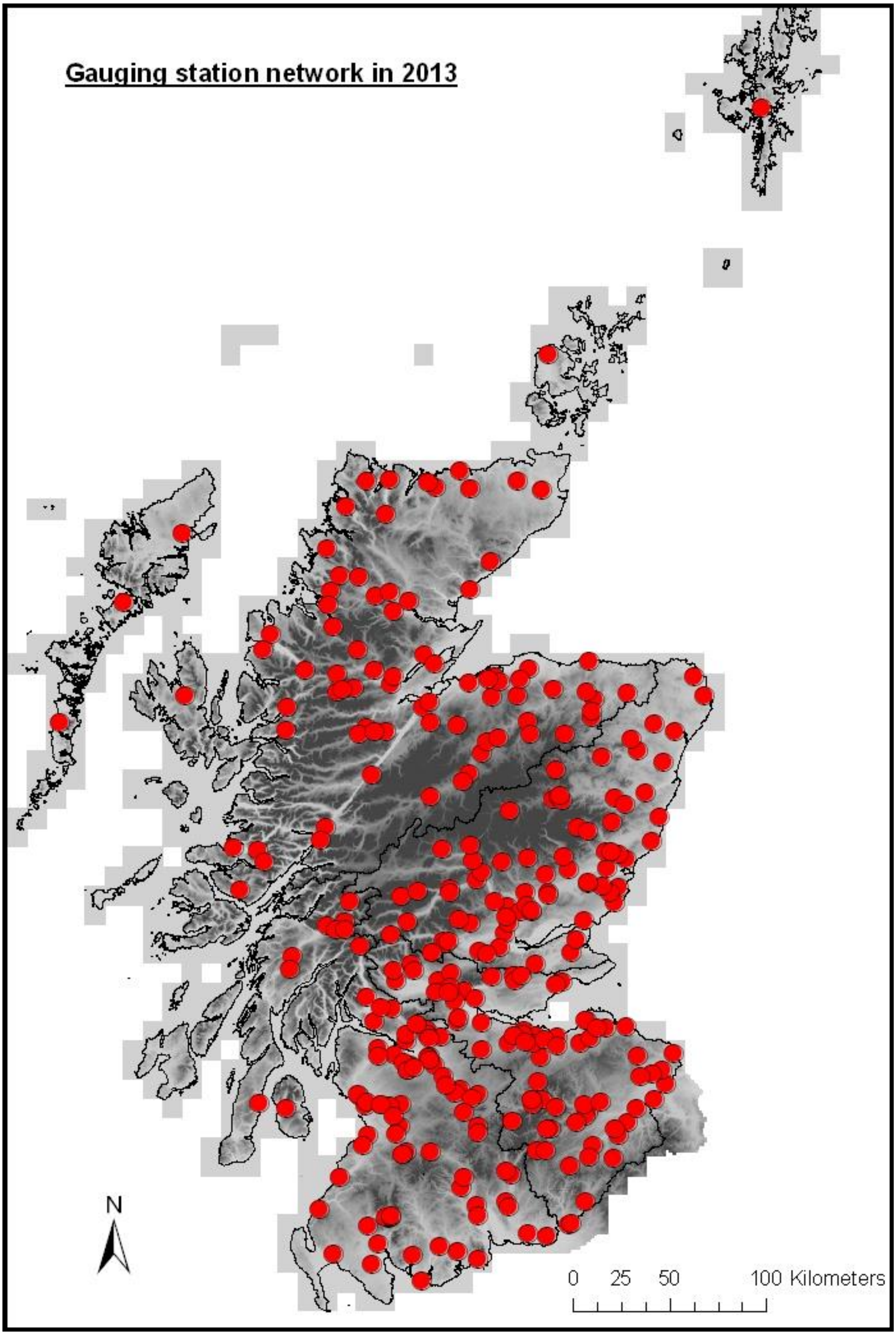

Figure 3.1: Distribution of River Gauging Stations in Scotland in 2013 (Courtesy of SEPA).

Utilisation of Hydrometric Data

The utilisation of hydrometric data may be considered from the viewpoints of internal and external clients. Internal users consist of government departments and agencies which may have a requirement for stream gauge data for monitoring, operational, safety, legal, planning or design purposes. External users are individuals and organisations in the private, residential or knowledge sectors outside of government whose data requirements may be for industrial, leisure or research purposes.

SEPA (2005) surveyed the economic use of water in Scotland and highlighted the contribution made by these areas to the country's economy. These demonstrate varied and changing fortunes across different sectors in particular with the waning significance of manufacturing industries relative to service sector industries. Table 3.1 provides an overview of these key sectors.

Table 2.1 : Major Sectors driving Water Use in Scotland (SEPA 2005).

Economic Sectors
Agriculture and Forestry; Aquaculture; Mining and Quarrying; Oil and Gas; Manufacture of Petroleum and Petroleum- Based Products; Oil Refining; Food Processing; Production of Alcoholic Beverages; Production of Mineral Water and Soft Drinks; Manufacture of Textile and Leather Products; Manufacture of Wood, Pulp and Paper Products; Chemicals; Other Manufacturing; Electricity Hydro; Electricity Non-Hydro.
Amenity and Recreation
Tourism and Water-dependent Visitor Attractions; Water Dependent Recreation; Angling; Navigation; Waterside Amenity; Ecosystem Services.

While the use specific use of hydrometric data use across each sector is not presently clear, MacLeod et al. (2012) report 250,000 data downloads from SEPA's river data website per month which indicates a wide range of external users probably spread across the commercial, household and recreational sectors.

A classification of internal clients for hydrometric data is presented in Table 3.2 presents a taxonomy following Cranston (1995).

The next section turns to the specific work carried out in order to evaluate the performance and fitness-for-purpose of hydrometric in the Scottish and wider UK context.

Table 2.2: Internal Hydrometric Network Purpose and Data Applications (Cranston 1995).

Purpose of Hydrometric Monitoring	**Data Applications**
Management and Control of Water Resources.	Yield Assessment Reservoir Safety Assessment Operational Resource Monitoring Compensation Flow Monitoring Other Abstraction Monitoring
Water Quality Monitoring.	Water Quality/Assimilative Capacity Studies Pollution Control/Consent Standard Monitoring PARCOM Harmonised Monitoring
Flood Risk Adaptation, Mitigation and Response.	Infrastructure Design Studies Flood Warning Systems.
Provision of Recreational Information	Bathing Boating/Navigation Angling
Urban and Landscape Planning	Land Drainage
Research and Evaluation	Basic Network/Baseline Monitoring Academic/Policy/Commissioned Research
Ecological Stewardship	Fisheries and Biodiversity Management
	Biodiversity Monitoring
Flood Insurance Programming	Premium Level and Claims Assessment

2.3 EXISTING REVIEWS OF HYDROMETRIC DATA VALUE

Where hydrometric networks are publicly funded, questions about whether the network is adequately meeting its stated objectives in a cost-effective manner are a key consideration for decision makers. In other words, fitness for purpose, along with any additional benefits relative to costs of network operation need to be considered, particularly if value for money is to be demonstrated for public accountability in a world where alternative uses exist for such investment. One approach used widely across the public sector is to quantify total costs (staff and capital) of network operation and to compare these with similarly quantified benefits aggregated across the diverse range of uses. However, the complete range of applications and associated benefits that can be accurately ascribed to the data are often not registered and methods to do have varied from study-to-study. One approach has been to consider the main quantifiable costs of water-related schemes and facilities that utilise hydrometric data, for example reservoir design, bridge construction and abstraction, and to determine a suitable percentage of these costs as an estimate of the benefits conferred by the underlying data. This method aims to quantify the role played by gauging data in the wider success story of the scheme as a way of calculating hydrometric benefits from several different activities. For example, an exercise to evaluate the Canadian Hydrometric network using this approach yielded costs of $13M against benefits of $119M giving a Benefit-Cost ratio of 9:1 (CNS Engineering Services, 1991). However this approach fails to provide a complete estimate of benefits due to instances where details of project operating costs, scheme design costs, or averted disaster costs are unavailable, or have occurred at a relatively distant point in history or whose rewards might be enjoyed by several generations from now. It also fails to include benefits which do not have an overt market value, but which nevertheless offer wellbeing returns to society, for example, as manifest in the peace of mind that citizens may enjoy with the knowledge that freshwater resource quantities are being properly and scientifically monitored. In addition, decisions that concern investment or disinvestment into the actual river gauging infrastructure (rather than water schemes reliant on hydrometric data) require specific and relevant economic valuations of how society might be made better or worse-off by any impending changes to monitoring facilities. The subjectivity of such valuations pose further difficulties for the quantification of benefits. Thus while the incremental costs of a programme to expand a river gauging network are relatively easy to quantify, the marginal benefits resulting from such changes are much more difficult to estimate and monetise, these being greater than simply the sum of parts constituting network operation. Making a case for additional investment in hydrometric networks on the basis of societal welfare returns can therefore prove challenging.

Early reviews of the Scottish hydrometric network consisted predominantly of commentaries on the strategic role, prospects and challenges facing the Scottish river gauging community. MacDonald and Agnew (1977) and Poodle (1987) are two notable studies of river gauging in Scotland. Werritty (1985) provides a helpful insight into the early origins of Scottish hydrometry, and specifically acknowledges the pioneering efforts of WN McLean in setting-up the first gauging station on the River Garry, and subsequently a small network operated by his company dedicated to hydrometry during the first four decades of the twentieth century. Lees (1987) similarly provides a brief history of Inland Water Surveying in the U.K., but makes only minor reference to the Scottish context. Poodle (1987) concludes that the Scottish hydrometric network is keenly sensitive to the political climate, which affects public expenditure and hence the resource forthcoming for gauging maintenance, station reconfiguration and data analysis. The requirements for data from small catchments, consistent observations over the long term and quality assurance of data quality through standardised procedures, improved analytical methods and equipment were urgently highlighted priorities.

The first systematic evaluation in Scotland of station purpose relative to individual uses of data was conducted by Cranston (1995). Given the rapid and piecemeal development of gauging stations over the preceding three decades, Cranston's review strategy was to compare the original data objectives underpinning the establishment of each station against the actual current purposes which the installations were serving. In so doing, the change in data use of flow records could be traced over time for each station. This information could then be used to assess the fitness-for-purpose of each station.

Cranston categorises data uses into a headline set of four major purposes. These are then subdivided into further specific uses, which gives a total of 15 uses as detailed in Table 3.2. For each use, respondents are asked to identify the original purpose of the station; to specify whether it is still being used for that purpose, and, if so, whether the latter data use was seen as essential (high priority) or simply desirable (lower priority). Questionnaires were sent out to all seven River Purification Boards (RPB) as well as to a number of local authorities and Scottish Hydroelectric (SHE). In his analysis Cranston provides a detailed configuration of the changing uses of data across the areas of the individual RPBs and successfully links the headline purpose and sub-categorised data uses with provision across the network.

As a result, what emerges is an insight into the physical utility of individual stations as items of public infrastructure. The statistics describing their functional purposes across uses will undoubtedly prove helpful for decision makers. However, the question of how truly valuable the data is, as a final product, to its ultimate client/s remains unanswered. What this research demonstrates is the state and suitability of the hydrometric network and its functional capability to deliver the data requirements for a pre-determined menu of applications. In economic terms it may be considered as a 'supply-side' study - that is, focused on the architecture and efficacy of data supply and rather than the structures and characteristics of data demand per se.

This is an important distinction to make since the advantages that hydrometric data confers upon its users is likely to translate into savings from say, averted disasters, or to form the basis of the creation of entirely new goods or services, both of which preserve or generate national wealth. Cranston (1995) does not account for this positive data effect as a determinant of hydrometric network worth. Yet on the basis of Cranston's (1995) findings, Cranston and Black (1995) identified that RPB stations, constructed originally for basic or baseline monitoring of river levels, now provided data for an additional 2.4 uses on average. This provided at least some indication of the cost utility of the network over time.

Black and Tavendale (2004) assess the effectiveness of the Scottish flow gauging network for the needs of flood data users, for example those conducting flood risk assessments using either single-set or pooling approaches. The study proceeded by comparing the physical characteristics of catchments draining to SEPA-operated river gauges against catchments for which SEPA had been asked to provide flood risk information. Comparator variables included: area of the upstream catchment, annual precipitation, runoff rates, baseflow rates, levels of flood mitigation due to reservoirs and lakes, and urbanisation. Identifying significant discrepancies in these variables between data-request and flow gauge sites would highlight areas of under or over provision and hence the network's fitness-for-purpose in providing adequately representative flow data for flood estimation.

The authors of this study implicitly acknowledge the limitations of evaluating user benefits from a provider's perspective. They recommend that SEPA devote some resource to understanding the interests of web-based data users of real-time data through an online questionnaire and improved web usage statistics as one way of increasing user perspectives for continually (re)defining the network's purpose (Black and Tavendale, 2004).

The last review of the Scottish stream gauge network took place in 2010. This consisted of an internal review undertaken by SEPA and adopted a two-pronged approach to network evaluation. Firstly a complete list of available gauging stations across the Scottish network was scored and ranked according to operational and surveillance effectiveness. This was undertaken with the explicit aim of identifying an 11% cut in network stations. The second part comprised an extensive survey of data user needs along with a customer feedback exercise. Through the consultation process the study identified the need for more small upland catchments; an improved understanding of urban hydrology (particularly in response to rainfall events); the provision of better station-related metadata (for example catchment description, data limitations and quality flags, and artificial influences on flow measurements); improved advertising and awareness of the full span of SEPA's hydrometric services; development of an analogue network for long-term trend analysis; near real-time feeds and fast-stream data provision; better data for fishing and canoeing as key economic and leisure activities, and diffuse pollution monitoring. These recommendations illustrate significant and enduring data requirements, highlighting the potential (or lost) value of the network, but failing all the same to quantify the benefits of the data in itself as an indicator of network value.

Studies examining the benefits of a national hydrometric network encompassing all of a country's regions are few – most tend to focus on provincial, sub-national or regional networks. In these cases it is equally difficult to locate investigations into the benefits delivered to more than one or a small number of data applications. CNS Scientific and Engineering Services (1991) were commissioned by the UK Department of the Environment to undertake a Cost-Benefit analysis of the UK stream gauge network in 1989. A Cost-Benefit Analysis aims to compare the relative advantages and disadvantages of two or more alternative options with a view to determining which option is the most beneficial for society. One of the options consists of the status quo which is the outcome if no action were taken – it also known therefore as the 'Do Nothing' option. Further actions or interventions are then compared to this as the baseline, or standard in order to assess the impacts of the change or programme on the status quo. The costs and benefits are reduced to monetary values as a common denominator in order to permit a comparison between the two. One problem for this study (and indeed any studies seeking to evaluate long established stream gauge networks using this methodology) was that a UK stream gauge network already existed, and the specific intervention needed to be defined not as the provision of a brand new network and data service, but rather in a context where a discontinuation of the network and data archive was assumed. In this case the benefit would result from continuing the use of the data archive and network which can then be compared with the costs of not doing so. It should also be noted that benefits were singularly evaluated in the context of the water supply industry to the exclusion of additional uses for which stream gauge could be deployed. CNS (1991) found that the spectrum of quantifiable benefits of data that were amenable to monetary expression ranged from a lower bound of £11M to an upper bound of £60M, with a best estimate of £21M. Comparing these numbers to the aggregate annual capital and revenue costs of stream gauging of £9M, Benefit-Cost Ratios of between 1.2 to 1 and 7 to 1 were established for the lower and upper bounds respectively with the best estimate yielding 2.3 to 1.

A key question to therefore consider are the relative merits of investigating data benefits in the context of single versus multiple uses, and the degree to which any one choice of application permits a scaling-up of findings for the network as a whole. What seems clear however is that even a single or small number of major uses of network data are capable of generating benefits well in excess of annual operating costs. In an evaluation of the Northern Ireland hydrometric network, Black et al. (1995) find that the use of hydrometric data for reservoir design yields a benefit-cost ratio of 15:1. In addition, Ian Cordery and Peter Cloke have conducted a number of studies in Australian settings to determine the value of stream flow data for the design of catchment infrastructure, such as flood protection and minor waterway crossings. They find Benefit-Cost ratios to the order of 80:1 and 92:1 for these schemes respectively (Cordery and Cloke, 1990; 1994). In a similar study for the design of storage reservoirs they assess the sensitivity of reservoir capital costs to length of available stream gauge record, identifying savings from avoiding under-design and over-design as data benefits. Further, they demonstrated that if data from all 500 stations located in New South Wales were dedicated solely for the purpose of storage design, then the benefits from data collection would remain higher than costs, until record lengths reached approximately 80 years before breaking-even (Cordery and Cloke 1993).

Perhaps the most comprehensive attempt at a quantified approach to hydrometric network benefit assessment is contained in Black et al (1999). This study aims to construct a framework within which both quantifiable and non-quantifiable benefits of hydrometric data can be taken into account by decision makers during an evaluation process. They draw on methods and approaches taken within other contexts, but generalise further to provide a template for future evaluations where needed. The paper presents a suite of methods for quantification and also provides a series of worked examples to value the role of data in reducing uncertainty for the design and planning of new infrastructure in the Bollin, Foyle and Tay catchments. These individual schemes and valuations are considered as components of the wider economic benefits arising from data collection, which could then be summed to calculate the total economic value of data. No actual aggregations of such benefits are undertaken, the objective being to simply illustrate an approach to total data benefit calculation and equally to consolidate methods hitherto adopted in the literature.

The recognition, opportunities and challenges of non-market valuation (NMV) methods of assessing user preferences for stream gauge data seem to have received scant if any attention in the literature. Goody and Kennedy (2009) note the availability of such methods but consider any further deployment to lie outside the scope of their current study. Similarly Black et al (1999) refer to an investigation conducted by the Environment Agency into the willingness-to-pay (WTP) for the maintenance and improvement of flow regime for the rivers of south-west England. However the link between WTP for improved stream flow and improvements in data describing that flow is tenuous at best.

The next chapter turns to discussing Choice Modelling as a specific class of non-market valuation techniques which we propose to employ for the purposes of understanding user preferences for stream gauge data. Furthermore, within the groups of available valuation methods, choice experiments emerge as the strongest candidate for conducting the investigation. This is because choice experiments allow researchers to deconstruct the hydrometric system at a conceptual level in terms of various competing attributes and to elicit user preferences for these attributes in light of well-developed economic frameworks. In so doing, choice experiments can be used to re-project thinking behind hydrometric system optimisation away from a traditional focus on the role played by data for specific applications or projects to a broader, choice-based paradigm which translates questions on ‘data usefulness’ (or utility) into a format whereby the preferences of individuals making decisions at the household or professional level can be incorporated and assessed. Hydrometric data has a number of discernible attributes. These include (but are not restricted to):

- Accuracy of aggregated flow parameters.
- Timeliness of supply from hydrometric information service providers such SEPA and the CEH National River Flow Archive.
- Representativeness of the data in terms of indicating wider catchment behaviour across both time and space.

- Frequency of flow measurements – for example daily versus monthly flows.
- Length of Record – the number of station-years of data available. Generally longer time series of flow data are more desirable as statistical inferences discussed in section one become more robust with length of record.
- Community Significance – extent to which data is effective in mobilising local community against flooding risk, say as proxied by distance from the river.

User preferences for these attributes can be usefully tested through a choice experimental procedure which would ultimately disclose a range of metrics, illustrating not only the relative trade-offs between competing scenarios and individual data attributes, but also permit further marginal analysis of network change effects.

2.4. DISCUSSION

Hydrometric data clients are spatially distributed and where electronic data is now downloaded directly from the SEPA or CEH websites, chances of securing sufficient input from respondents to the study may prove challenging. A more immediate concern will be to convene focus groups in order to determine relevant data attributes and level combinations, and also a plausible baseline from which to measure the impact of alternative choice sets.

A substantial literature exists on many aspects hydrometric network effectiveness and various attempts have been made to quantify the benefits arising from the use of hydrometric data. Some benefit evaluations have taken place in the context of specific applications such as reservoir design or water supply management while others attempt a more ambitious mission to evaluate the global benefits of national or regional hydrometric networks. The latter have proven less successful at quantifying the benefits into monetary terms but have nevertheless yielded useful metrics for internal management purposes. The Choice Experiment (CE) methodology may offer a more rewarding technique for the quantification exercise. Further details on how a CE is conducted and a discussion of its potential and limitations will be provided in Chapters 2 and 3.

2.5. AIMS AND OBJECTIVES OF RESEARCH

1. AIM: To quantify the value to society of collecting water level and flow data from river gauging stations in Scotland.

2. Objective 1: To determine household preferences and willingness-to-pay (WTP) for hydrometric data using Choice Experiments.

3. Objective 2: To determine business preferences and willingness-to-pay (WTP) for hydrometric data using Choice Experiments.

CHAPTER 3

Non-Market Valuation Methods and a Literature Review of Stated Preference Techniques: Contingent Valuation and Choice Experiments

3.1. Introduction

Chapter 2 provided an overview of hydrometric systems. The data provided by these systems represent a non-market good, in that consumers of the information do not pay an economic price for consuming the data. However, as data providers, it is important for the Scottish Environment Protection Agency to understand the economic utility of the data to the Scottish population. Using a non-market valuation technique, Choice Experiments, this thesis aims to elicit the value of hydrometric data to both households and businesses across Scotland. Within this context, this chapter will discuss the various valuation methodologies for measuring the welfare effects of improvements in the hydrometric service in Scotland, and provide the theoretical framework behind each valuation methodology.

3.2. Conceptual Framework for Non-Market Valuation

The term ‘Value’ in an economic sense refers to the specific contribution of an action or object to a pre-defined set of goals, objectives or conditions determined by the individual (Costanza, 2000). Valuation is the process of expressing a value for a particular object or action. Such a valuation can take place within the context of a market where buyers and sellers interact, bargain and finally establish a price for a good/service where the price provides an indication as to the value of providing an additional unit of that good/service (rather than the total value of the object to society). However, there are goods and services which are not available for sale through a bargaining process in an open market, but which may still be viewed and defined in economic terms as commodities or objects in their own right. These are referred to as Non-Market Goods. If access to such goods or service is not restricted, and where consumption by one person does not diminish either the quantity or quality of the good available to another person, then such commodities may be further classified as Public Goods. Examples of public goods include street lighting, air, features within the natural environment such as forests, wilderness and water bodies, national defence, and civil infrastructure such as bridges and flood defences (Samuelson 1967).

There are at least four reasons why the valuation of nonmarket public goods is important (Pascual et al., 2010).

The first is the problem of missing markets. Missing markets refer to the absence of defined exchange mechanisms for the production (supply), consumption (usage or demand) and distribution of public goods. Environmental systems underpin a wide range of ecosystem goods and services - however because their productive processes are often tied to naturally-occurring phenomena which are not property of any single company or individual then their existence is taken for granted; in the absence of a price they are over consumed and under supplied. This means that there is no way of holding responsible individuals to account for polluting the environment – a case of a negative spill over effect (Bingham et al 1995). Thus, there is no basis on which the people who suffer from the adverse consequences of the spillover effect to be compensated by those causing the pollution (Costanza et al., 1997). Moreover, an information failure arises from the difficulty of quantifying most ecosystem services in terms that are comparable with human-produced goods and services (Stiglitz 2002). The aim of valuation is thus to unpick the complexities of socio-environmental relationships and to make explicit how human decisions would affect ecosystem service values, and moreover to express these value changes in monetary units which allow for their integration with other public policy decisions (Carpenter 2010).

Second, for some public goods and services, it is necessary to understand the alternatives and alternative uses to which the good/service might be put. This is in order to verify that the proposed use is in fact the best possible deployment for the resources at hand, such that they are not being wasted by diverting their creative capacities from an alternative, more productive end. Thus valuation studies are aimed at determining the opportunity cost of proposed policy actions where indicative prices are not available to provide this information (Turner et. al., 2003).

A third reason for conducting nonmarket valuation is the uncertainty inherent in the future demand and supply of many natural resources.

Finally, governments may wish to use economic valuation rather than restricted, administered or operating market prices for designing new environmental programmes, or to inform reporting requirements under new Climate Change legislation (Hanley and Barbier 2009).

Since the 1960s, non-Market valuation studies have been used to inform both policy interventions and commercial applications across a large number of domains covering marketing, employment and human resources, the natural environment, transportation, urban planning and design, health and culture. While these are too numerous to provide a complete listing here, Appendix 1 provides an insight into the kinds of problems and issues which have been approached from a nonmarket perspective in several diverse domains.

Theoretical Model of Non-Market Goods

According to neo-classical economic theory, each individual will have well-defined goals and objectives which they wish to satisfy. In light of existing resources and endowments, they form preferences over alternative goods and services, which will help them achieve those goals by prioritising, in some ranked order, the bundles of goods and services which they deem to be optimally effective in meeting their targets. All social and economic choices are assumed to rest on the basis of this definitive practice. Human desires expressed through preference ordering can be represented by a Utility function defined over goods.

Let X = [x1, x2,…xn] denote a list or vector of all the levels for the n market goods chosen by the individual. The k nonmarket goods are similarly listed as Q=[q1, q2,…qk]. The utility function assigns a single number, U(X,Q), for each bundle of goods (X,Q). For any two bundles, (XA, QA) and (XB, QB), the respective numbers assigned by the utility function are such that U(XA, XB) > U(XB, QB) if, and only if, the individual prefers (XA, QA) over (XB, QB). The Utility Function is thus a complete representation of a person's preferences.

The role of money is observed as a feature of scarcity - that is, the scarcity of money available to spend on desired commodities. For market goods, individuals select the amount of each good to buy based on their preferences, the relative prices of goods, P = [p1, p2,…pn) and income. However, levels of nonmarket goods are pre-allocated and their provision is not amenable to individual influence. In this scenario, the basic choice problem is how to obtain the highest possible utility when spending income, y, on the purchase of market goods subject to the rationed level of nonmarket goods.

$$Max\ U(X,Q) s.t. P.X \leq Y, Q = Q_0 \qquad [1]$$

People face two constraints in Equation 1. First, the total expenditure on market goods cannot exceed income, y, and second, the levels of nonmarket goods are fixed. The X (i.e. level of market goods) that resolves this problem then depends on the level of income (y), the prices of all market goods (P), and the level of the fixed quantity nonmarket goods (Q). For each market good, we have an optimal demand function that depends on these three elements, x* = xi(P, Q, y); the vector of optimal demands can be written similarly, X* = X (P, Q, y) where the vector now lists the demand function for each market good. Substituting the set of optimal demands into the utility function, we obtain the indirect utility function, U(X*

Q) = v(P, Q, y). Since the demand depend on prices, the levels of the nonmarket goods, and income, the highest obtainable level of utility also depends on these elements. Demand functions thus provide the quantity of goods demanded at a given price vector and income level (Champ et. al., 2003). Demand functions thus also can be interpreted as marginal value curves since consumption of goods occurs up to the point where marginal benefits equal marginal costs. In this sense, demand is said to have social significance in the context of earlier discussion above.

3.4. Measures of Welfare: Compensating and Equivalent Variations

Utility is the 'usefulness' or satisfaction derived from the consumption of a good or service. It is a key concept underpinning the economic understanding of value: something has value if people derive utility from its consumption. Conversely, in order to consider whether a proposed product, programme, service or project is likely to deliver any benefits, then the question is distilled to a consideration of how much utility it delivers relative to costs. For example, consider a policy designed to improve the measurement of stream flow data in the Scottish highlands. This policy would require the installation of a range of new river gauging stations at key locations in local river catchments. Local residents care about acquiring more accurate data since this would provide improved flood warnings for the area, thereby allowing them to take demonstrable flood security measures, which could also translate into lower insurance premiums for their residential property. However, assume that the improvements are costly and that government has only two options available in order to finance the upgrade programme. The first is to raise funding through general taxation (for example, by increasing Income or taxes across the entire country), or secondly, to request local residents who will directly benefit from the programme to make a one-off, lump-sum payment towards the scheme. From the current state of utility, a citizen experiences a short-term fall in satisfaction upon having to pay for the proposed programme, while the long-term outcomes of successfully expanding the river gauging network are uncertain – they may result in a higher or lower level of utility than the status quo, since the advertised improvement in quality of hydrometric data and associated accuracy of flood warning systems may or may not take place to the citizen's desired level of satisfaction. Given that the effects of policy implementation are uncertain, in utility terms there are two concepts which can effectively be used to assess the value of an expanded hydrometric network.

The *Compensating Variation* describes the amount of income that the individual would be prepared to forgo, in order to bring his/her utility back to the status quo level after the programme has been delivered. More formally, let C denote the Compensating Variation measure with superscript 0 denoting the initial status quo conditions and the superscript 1 denoting the new state of utility provided by the policy. Define C using the indirect utility function:

$$V(P_0 Q_0 Y_0 = V(P_0 Q_0 Y_1 - C) \qquad [2]$$

The interpretation of C (Equation 2) is as follows: If a citizen gives up C after the policy changes have been implemented then he/she will be reinstated to their original utility position. C could be positive or negative depending on the impact of the policy on prices or the size of any lump sum tax which have been paid. If costs are less than C and the policy is implemented then the citizen is better off than before the policy. On the other hand if costs exceed C, the citizen is worse-off.

The second basic measure is the amount of additional income a citizen would need in the initial (pre-policy) state in order to obtain the same utility as after the policy change. This is referred to as the *Equivalent Variation*, E, defined:

$$V(P_0 Q_0 Y_0 + E = V(P_1 Q_1 Y_1) \qquad [3]$$

The two measures differ on the implicit assignment property rights. Using the Compensating measure assumes that the original, pre-intervention level of utility defined citizens' entitlement and therefore any programme costs should be evaluated using this measure as a yardstick. In contrast, the Equivalent measure supposes that the post-intervention utility is the basis for comparison of programme costs. Which measure ought to be selected depends on the circumstances of the policy valuation. For example, considering a programme to invest further in an existing, well-functioning hydrometric infrastructure would suggest that the status quo is the legal property right; citizens have, at the very least, a right to current standards of data provision as a minimal consequence of the stream-gauge expansion programme (i.e. it should be no worse). The Compensating variation in this situation is the more suitable measure. Conversely, suppose a piece of legislation defines a minimum data quality standard, but that the status quo provision from existing stream-gauges falls short of meeting it. Under these circumstances, citizens have a right to improved information from river gauge stations and any programme aiming to improve the service should be evaluated on the basis of the Equivalent measure.

3.5 Willingness to Pay and Willingness to Accept

Alternative terms for the Compensating and Equivalent Measures are Willingness-to-Pay and Willingness-to-Accept (WTA) compensation. WTP is usually employed in order to assess the likely benefits of a positive/desirable change while WTA is used in order to test the value of disbenefits from a negative/undesirable change. Table 3.2 illustrates further.

Table: 3.2: Welfare measured in terms of Compensating and Equivalent Variations

Welfare Measure	**Price Increase in Market Goods** (Detrimental Policy Effect).	**Price Decrease in Market Goods** (Beneficial Policy Effect).
Compensating Variation (CV): Property right lies in status quo.	Willingness to Accept Compensation (WTAC) for enduring outcomes of the change.	Willingness to Pay (WTP) for enjoying outcomes of the change.
Equivalent Variation (EV): Property right lies in outcome of the change.	Willingness-to-Pay (WTP) to avoid the outcomes of the change.	Willingness-to-Accept Compensation (WTAC) to forgo benefits of change.

Source: Freeman III (1993).

Clear-cut cases where impacts of policies are unambiguous make it relatively straightforward to select a suitable measure of welfare in order to gauge losses or gains in utility from a monetary perspective. For instance if a policy intervention is entirely detrimental (U0>U1), then the appropriate compensating measure is to consider how willing affected people are to accept compensation in order to live with the change. Equally, the equivalent measure would seek to assess how much people are willing to pay in order to avoid the adverse outcomes of the intervention. Similarly, if a policy intervention is considered to be strictly beneficial (U0<U1), then the compensating measure is used to understand how much people are willing to pay in order to realise the benefits of the change, while the equivalent measure would be more useful for assessing how much compensation an individual would require in order to relinquish the promised benefits of the change. However the consequences of policy interventions are not always as clearly discernible as this analysis suggests. The costs and benefits of an intervention vary across time, groups of individuals and space. For example gains and losses may be mixed for people in their competing roles as data users and local residents: new river gauging stations may provide improved stream flow data, but could

simultaneously detract from local amenity value if located within an area of outstanding natural beauty. Choosing a single measure which takes account of aggregate social preferences in this situation would be complicated by the conflicting desires of recreationalists and data users.

3.6. Techniques for Non-Market Valuation

Early Development of Non-Market Valuation Studies

In the 1950s, a think-tank called Resources for the Future (RFF) was founded in Washington in order to support the work of the presidential Paley Commission. The commission's remit was to examine the future supply of natural resources available to the US economy following the Second World War, not least given the high consumption of minerals, energy and agricultural resources expended to fuel the allied war effort (Pearce, 2002). A number of landmark studies were published by scholars at the think-tank including a historical analysis of resource price trends (Christy and Potter, 1962); Scarcity and Growth which proposed a conceptualisation of resource scarcity and tested a series of hypotheses to examine whether the US was in fact facing a situation of resource scarcity (Barnett and Morse, 1963); and Davis (1963) which investigated the value of outdoor recreation in the state of Maine. Another influential book – Silent Spring – was published by author Rachel Carson in 1962 which highlighted the effects of agrochemical use in the environment. The book was topical given both the successes and costs of agrochemical development – on the one hand, raising short term agricultural output and life expectancy associated with the DDT compound, but on the other, adverse long term soil and biodiversity impacts with accumulations in the natural environment. Silent Spring both emphasised and illustrated the notion of external costs associated with production processes developed earlier by Pigou (1920; 2013). In the context of the 1960s which saw the rise of large-scale peace, civil and environmental movements, the idea that intervention by the state to correct or internalise the externalities generated by industrial production and human consumption activity more generally, was justified. Designing policy interventions underpinning the role of the state on the basis of societal preferences as indicated by willingness-to-pay was first established by Dupuit (1844, 1853) and later developed by Pigou (1920), Hicks (1939, 1943) and Kaldor (1939). The first cost-benefit programme appraisal guidelines were drafted for use in the Water sector (Eckstein, 1958; cited in Pearce (1998), to assess government water departmental efficiency (Krutilla and Eckstein, 1958; 2013) and for military spending programmes (McKean, 1963). A key economic concept underlying these methods was that a policy outcome for which benefits exceeded costs would still have losers, but that the winners could, in principle, compensate the latter so that the losers were no worse off, and the winners were better off. In sum, there would overall social advancement in line with Pareto's criteria.

One key drawback of contemporary cost-benefit appraisal systems was that although Environmental Impact Assessments (EIA) were undertaken as part of a project, these rarely had an influence on project design or the decision to proceed. In the 1960s, Welfare Economics thinking had accepted that the correct measure for the value of a marginal change in the supply of a good, service or amenity was the market price struck through trade in an open market. But for non-marginal changes, producer and consumer surplus figures would need to be established for which the market demand and supply curves were necessary. Furthermore the magnitude of any changes in wellbeing (as indicated by changes in surplus figures) arising from a proposed project should be contained in cost-benefit appraisals if a more accurate, socially-sensitive impact of a programme/intervention was to be correctly represented. However in practice, market prices were considered but changes in public wellbeing as defined by consumer surplus were ignored because environmental changes were deemed to be intangible and hence not amenable to quantification within an appraisal framework. Environmental valuation methods helped to improve this situation by showing that: (i) appraisals omitting environmental change were incomplete and (ii) environmental change impacts could indeed be included in such appraisals.

Revealed Preference Methods

Travel Cost Method

In 1947, Hotelling had developed a method to proxy the value of US National Parks from the perspective of visitors by investigating the time, distance and money spent by visitors to the site (Hotelling 1947). Since the parks had no entry fee, the market value was unknown: this resembled the problem that Dupuit (1844, 1853) had encountered a century earlier – that is, that while roads and bridges were freely available to the exclusion of none, road and bridge users were still willing to pay for them. This report was deferred until about a decade later until Hotelling's next study into the recreational use of the Feather River, California undertaken for the Resources for the Future (RFF) organisation. Travel Cost methods (TCM) have been popular since the mid-60s particularly in response to US legislation requiring that benefits of sites be demonstrated.

Hedonic Pricing Method

The second revealed preference valuation method examines the change in land and property prices in order to acquire an indication of how valuable a linked asset is. These are read as capital values reflecting implicit rentals arising from the asset which in turn reflect the value of service flows from that asset (Carson and Louviere, 2011). If environmental characteristics are one among a number of features of these services then in principle the effect of each feature can be isolated and assessed relative to the property price. The first study examining the relationship between air quality and property values was set in St. Louis, Missouri (Ridker and Henning, 1967). This was estimated by a regression of property prices against various determining factors (including air pollution levels) with the coefficient on the latter providing the size and direction of the effect.

Stated Preference Methods

The idea that the willingness to pay for a good or service could be elicited via a questionnaire was first advanced by Ciriacy-Wantrup (1947). However a key concern about the use of questionnaires was whether the incentives of researchers and their subjects were effectively aligned. If not, then it was feared that members of the selected sample would be motivated to provide untruthful responses, or at least to conceal their true preferences/characteristics from the investigators. The design of questionnaires to avoid such incentives was therefore critical. For Maler (1974), while truth telling could not be guaranteed, sources and directions of bias could certainly be identified. Ciriacy-Wantrup's suggestion was not employed until more than a decade later by two independent research studies – one aiming to study recreation in the Maine woods (Davis, 1963) and another seeking to examine the value of water-based recreation in the Delaware River basin (Mack and Myers, 1965). After this time the number of Contingent Valuation studies has increased rapidly. Carson (2011) provides an overview and lists 7000 citations. In order to overcome the potentially adverse incentive posed by an explicit question structure focusing on willingness-to-pay (i.e. 'How much would you be willing to pay for commodity x, y, or z?'), alternative approaches were developed including Choice Experiments (CE), Contingent Ranking and Contingent Ratings (CR). However not all methods are compatible with consumer theory (Hanley, Mourato and Wright, 2000). In a contingent ranking for example respondents are presented with a single but sequential choice process, in which they first identify their most preferred choice and then, after the removal of that alternative from the choice set, identify their most desired choice out of the remaining set, and so on, until all available choices have been exhausted. This method is akin to a 'compressed' choice experiment, with each successive choice ranking being comparable to a 'forced-choice' format in which respondents are required to make compulsory selections of one of the alternatives, particularly if the status quo baseline option has already been chosen and thus eliminated from subsequent choice scenarios. This may result in welfare estimates of willingness to pay or accept that do not reflect the behavioural realism of a person's true preferences as once the choice for the status quo has been made, then subsequent choices are purely speculative. Chapman and Staelin (1982) and Hausman and Ruud (1987) also found that choices appeared to unreliable and inconsistent across ranks, yielding estimates that violated rationality principles insofar as transitivity and completeness axioms were concerned. In a contingent rating, respondents are given several scenarios and asked to rate them individually on a scale, for instance, by identifying 'most-to-least preferred' scores. However, this makes the strong assumptions that ratings are comparable across individuals, and that ratings can be reliably converted into utilities (Roe, Boyle and Teisl, 1996). On the other hand a feature that is particularly attractive about these methods is that passive or non-use values may be estimated – that is values of a good or service which may hold without directly consuming the product, amenity or service. In contrast, the alternatives, including Contingent Valuation and Choice Experiments, are likely to be the most economically rigorous and enduring. CEs are particularly advantageous in that they allow not just the WTP or WTA to be estimated but also a range of other parameters that shed light on the trade-offs between several individual attributes which characterise a good or programme within the natural format of the method. Compared with contingent valuation, respondents also get multiple opportunities to consider and express their preferences, hence incorporating learning effects associated with complex decisions or cognitively demanding valuations. By focusing more holistically on the characteristics of a series of alternative packages, CE also provides a potential solution to minimise the problems associated with explicitly asking respondents to state their willingness to pay or accept, as in CEs this is recovered indirectly from participants' choices where cost or price is but one important attribute among many. Some of these problems, such as 'ye-saying', strategic responses and protest bids are indeed enduring factors in CEs, however significant advances in their format and design have been made over the last decade that allow researchers to control for the impacts of such issues (Hoyos, 2010). A more detailed insight in to CEs is given later in this chapter.

A major review of Contingent Valuation was undertaken in 1989 with the grounding of an oil tanker the Exxon Valdez, in Alaska (Carson et. al., 1994). The US National Oceanic and Atmospheric Administration (NOAA) established a panel in 1992 in the wake of a challenge by the oil firm as to the veracity of CV as a methodology capable of computing a credible assessment of damages for both compensation purposes. It concluded that CV was indeed a credible method but value figures required greater sensitivity to scope – i.e. that values needed to reflect better the scale of the environmental effect at hand. Non-use values were first identified by Krutilla (1967). At the same, Weisbrod (1967) advanced the concept of Option value which described the willingness to pay at the present time for the option to make use of an asset at a future date, for example, access to water. The option exists regardless of whether it is exercised or not. The sum of existence and option values can be said to constitute non-use value. The main grounds for challenging the inclusion of non-use values in damage calculations was that they did not evince any verifiable behavioural footprint on which to estimate the impacts of the environmental damage. However, numerous studies have validated the concept.

Contingent Valuation (CV)

Contingent valuation seeks to establish the worth of a non-market commodity by obtaining relative values that are dependent or contingent on the features of the scenario posed in the survey. Respondents are asked to choose their preferred options within specific choice situations which are constructed by the investigator. Unique features of CV surveys are that compared with other behaviour-led surveys: (i) a great proportion of time is spent with the respondent to explain the proposed changes in the supply of a commodity to the subject: the idea being that they are fully aware of the context before electing a preference; (ii) the overall aim of the exercise from a statistical perspective is to obtain a measure for the Hicksian Consumer Surplus measure. This is the area under the demand and above the price equilibrium line and indicates the consumer's maximum willingness-to-pay (WTP) for a good/service, or alternatively, the minimum they would be willing-to-accept (WTA) in order to forgo the privilege of consuming the good. The organisation of the CV survey is as follows:

(1). Introduction: Overview of topic, investigator and sponsor.

(2). Questions about the respondent's prior level of knowledge about the good or service and their attitude towards it.

(3). Presentation of the CV scenario including what the proposed intervention, programme or change is designed to accomplish, how it would be implemented and paid for (that is, specifying the payment vehicle) and what would happen under the status quo if the intervention was not implemented.

(4). Questions asking the respondents' willingness to pay or willingness to accept compensation in order to continue to consume/forgo consumption respectively of the new level of the commodity.

(5). Debriefing questions to help understand how well the respondents understood the scenario.

(6). Demographic questions including age, sex, income, residence, ethnicity etc.

Early Empirical Development of Contingent Valuation

Contingent valuation was first applied in outdoor recreation contexts in the US (Carson 2011). The socio-economic drivers for its initial development as a method were (i) land-based and sponsored by the US parks and forest service agencies in the wake of rising numbers of Americans visiting government-owned land for recreational purposes after World War 2. The main objective of these studies was to find out visitors' economic behaviour relative to their leisure preferences in light of government funding pressures in the post-war era. The National Parks Service commissioned a marketing firm, Audience Research Inc. (ARI), to conduct the study. When undertaking the investigation, one set of respondents was asked about their willingness to pay a day-user fee as a trial – this was one founding stimulus to the development and deployment of the contingent valuation method in the field (Audience Research, 1958; cited in Carson, 2011). (ii) Water-based focused on major water projects undertaken by the US Army Corps of Engineers (USACE) in the 1950s and 60s. Key project outputs included water-based recreation, electricity and flood control. While the latter benefits were relatively amenable to quantified assessment, recreation as an intangible outcome was more difficult to conceptualise and monetise. Contingent Valuation helped to achieve a user-based perspective which was needed to ensure that recreation was also accounted for within cost-benefit evaluations underpinning civil infrastructure projects. Further information on the early empirical development of CV within land and water based settings is available from the report of the US Senate Committee on Public Works (1957), Eckstein (1958), and Krutilla and Eckstein (1958; 2013).

Davis (1963) is responsible for the first CV study into the recreational use of the Maine woods, drawing on concepts developed earlier by Ciriacy-Wantrup (1947) and Stouffer at Harvard. Davis' (1963) aim was to create a surrogate market for the woods' amenity value as a non-traded commodity. Knetsch and Davis (1966) later compared values obtained from a travel cost survey by Clawson and Knestch (1966) with the CV parameters and found them to be broadly similar. Hereafter a substantial rise in the use of CV for environment, health, transport, culture and recreation took place during the next four decades along with theoretical refinements.

Existence Values

Existence value refers to the worth of an amenity, good or service that is attributable to the degree of comfort people gain simply by knowing that the asset is available even if they do not actively engage in its direct consumption. The notion was first developed by Krutilla (1967). While these values were not reflected in market purchases there was qualitative evidence that existence values were indeed held by people and their inclusion within cost-benefit evaluations was thus justified as a valid means of procedure (Krutilla, 1967). This paper presented a framework for determining how large these values would need to be in order to tilt the decision about a proposed intervention towards the 'do-nothing', status quo option. Krutilla (1967) argued that not including existence values into public policy appraisals would lead to an overconsumption and the subsequent loss of existing environmental amenities as the benefits would be underestimated in both cases. Related concepts of value were subsequently developed including non-use value, stewardship value, bequest value and option value. The sum of these values was later classified as 'Passive Use Values' by a court decision in Ohio vs. Dept. of the Interior (DOI) (1999). The ruling required passive use values to be included in calculating damage claims. Carson et. al. (1999) provide a comprehensive review.

Mid-70s to early 90s - Developments

This period saw a continuation of valuation is areas developed earlier: recreation (McConnell, 1977; Cocheba and Langford, 1978); ski areas (Walsh et. al., 1984); offshore oil platforms (Roberts et. al., 1985); air quality (Brookshire et. al., 1976, Loehman and De, 1982, Tolley et al. 1986); water quality (Gramlich, 1977; Mitchell and Carson, 1986). Studies in Arts and Culture also became more popular (Throsby and Withers, 1984; Navrud and Ready, 2002; Noonan, 2003). A key concern from a methodological perspective during this time was to refine the method and test the internal and external validity of the theory – that is, examining in detail whether (i) CV modelling assumptions resulted in significant bias to parameter estimates and (ii) parameter estimates held true in the real world against more established methods such as the Travel Cost Method (TCM). Randall, Ives and Eastman (1974) was a key landmark study which demonstrated the external validity of CV estimates. CV also gained increasing acceptability as a valuation technique for policy and programme evaluation purposes in government during this time, with guidelines released by the US Water Resources Council (1979), US Army Corps of Engineers (Moser and Dunning, 1986), Department of the Interior (1986) and the US Environment Protection Agency (Smith, 1984). The use of CV also spread more widely outside of the US to other OECD and developing countries. Major innovations in study settings in developing countries was for the evaluation of environmental infrastructure projects, project evaluation (Whittington 1998), water supply (Whittington et. al., 1990) and sewage treatment (McConnell and Ducci, 1989). Walker and Mondello (2007) have provided an annotated bibliography canvassing much of this work. Cameron (1992) and Adamowicz, Louviere and Williams (1994) adapted for environmental applications an innovation in methods developed by Ben-Akiva and Morikawa (1990) on combining revealed and stated preference data. This allowed the calibration of stated choice data with observed revealed choice frequencies and also the augmenting of revealed preference datasets with stated choice responses that reflected new choice modes or notably different attributes for existing transport modes.

Key Issues in the Use of Contingent Valuation

The Exxon-Valdez case and ruling marked a watershed in the significance of contingent valuation as a credible technique for determining damage claims.

The second issue is that respondents may not take a hypothetical survey seriously, especially where money is not actually being paid.

Respondents may act strategically and conceal their true preferences for public goods – for example out of the fear that the payments expressed may actually be implemented. Carson et al. (1996) have provided a meta-analysis of this effect.

The manner in which a CV survey is carried out is shown to make a systematic difference to parameter estimates in ways not originally predicted welfare theory (Rosenburger and Loomis , 2000).

A divergence between WTP and WTA measures is frequently observed when, in the light of the consumer surplus concept, the two estimates should be identical for rational agents. Key studies examining the divergence effect include Willig (1976), Bishop and Heberlein (1979).

An appropriate elicitation format needs to be chosen in order to maximise the incentives for truthful and accurate responses from subjects by considering the trade-offs between the traditional bidding game (Davis 1963) versus open-ended, direct questioning structures. The bidding game format may be prone to starting point bias (Thayer, 1981). On the other hand, evidence that respondents experience difficulties in comprehending and responding to open ended questions is mixed.

Evolution of Contingent Valuation over Time and Place

The use of CV has increased substantially in the last four decades – not just in the UK but also across the wider developing and developed economies of the world (Carson, 2011). According to a cursory analysis by Carson (2011) a search for the term 'contingent valuation' on the ISI Web of Science database in 2006 resulted in 1045 studies using stated preference methods, 488 revealed preference and 282 papers based on actual cost analysis. In 1994 a global total of 440 studies employing CV methodology were available – over the next six years there were 400-500 papers authored annually using CV methods. This marks a nearly exponential rise in the use of the technique for non-market valuation. As at 2007, Carson (2011) reports over 10,000 papers containing the term 'contingent valuation'. This is likely to be a conservative estimate as the figure excludes a range of grey literature such as book chapters, consultant reports, conference proceedings, government reports, university theses and independent journal articles. Moreover, the literature pertaining to disciplines outside the social sciences - such as transport, health and culture, and which also deploy CV methodology - is catalogued in alternative databases which were not interrogated.

Alternative Approaches/Refinements to Contingent Valuation Methods

A variety of alternative approaches have been developed in order to address the limitations manifest in historic approaches to Contingent Valuation. These include:

1. Payment Card Approach (Mitchell and Carson, 1981).
2. Binary Discrete Choice Approach (Bishop and Heberlein, 1979).
3. Double-Bounded Discrete Choice (Hanemann 1991).
4. Multinomial Choice Experiments (Adamowicz, Louviere and Williams, 1994).

5. Asking respondents to rank and order programmes (Gilmour, Anderson and Rae, 1987).
6. Asking respondents to rate programmes (Johnson and Desvousges, 1997).
7. Avoided Cost Method (Brander et. al., 2012, in Kumar (ed.) (2012)).
8. Replacement Cost method (Sundberg, 2004).
9. Factor Income Method (Woodward and Wui, 2001)

Choice Experiments

One of the most popular methods designed to overcome the parameter inconsistencies arising from framing effects are multinomial Choice Experiments (Adamowicz, Boxall, Louviere, Swait and Williams, 1999; Louviere, Hensher and Swait, 2000). These are similar to the binary discrete choice formats but three or more choices are given to respondents in the form multinomial choice questions or choice sets. Respondents are then asked to select their most preferred option from a series of choice sets; two sequences of a binary choice set are often combined within this sequence. Choice experiments (CE) provide three main advantages over the traditional CV format:

(i) They permit the valuation not only of a single commodity but of multiple goods defined as bundles of attributes which are randomly varied in an experimental design that defines the alternatives of the choice set.
(ii) They allow the collection of large amounts of preference data relating to a single respondent. This reduces the need for a larger sample of respondents overall.
(iii) Participants of stated choice studies can include a diverse range of groups including corporate executives, advocacy groups, consultants, lawyers, policymakers, civil servants and other cohorts of interest. The distribution of WTP/WTA measures across these groups provides more detailed insights into group-based preferences. These estimates are useful to inform policy design in a manner that accounts for group-based inclinations and dynamics.

At the same time, some caveats should be kept in mind. As the number of attributes and their associated levels increase within a single experimental exercise, the need for lengthier and in-depth explanations beforehand also rises. Evidence that respondents experience significant cognitive burdens as a result of complex choice combinations is mixed. The multinomial format is tends to be more effective in health, transport and recreation where goods are quasi-public and respondents have some degree of real choices to consider – for example, the choice between alternative modes of transport, recreational sites/activities to engage or medical treatment options for addressing a health-related issue. It may be less effective for pure public goods where the provision of the product or amenity constitutes a natural monopoly such as street lighting, defence or the atmosphere.

Respondents may be insensitive to the scope of the good being valued – for example this was raised in the Exxon Valdez critique of CV. Scope effects are also discussed by Hausmann (1993; 2012).

The implications of neo-classical theory for what should be observed in CV surveys needs improved economic understanding – for example, the question over whether changes in WTP or WTA take place for price or quantity changes is not unambiguously established.

Quantity changes are very different from price changes because of the way the parameters of the preference function enter into the formulation. The basic predictions from neoclassical theory for non-market valuation are explored in Ebert (2003). Key elements to expect included predictions that: (i) sequence effects should exist; (ii) sequence effects are likely to be large; (iii) sequence effects operated in different directions for WTP and WTA; (iv) income elasticity of WTP is different from income elasticity of demand.

In the design of surveys and their administration, presentation of material should be adequately illustrated in order to more fully inform the participants of the choices they are being asked to make and the context in which these are choices are taking place. In some instances, pictures and visual aids may be appropriate. This requires training for economists and may be costly in terms of time and materials. Moreover while visual aids can be readily employed in face-to-face interviews, they may prove less convenient for use in postal questionnaires or telephone-based interviews. The choice of payment vehicle for the change under valuation has also been shown to have an effect - that is, participants have been shown to express differing WTP measures for the very same asset across alternative choice scenarios in which the funding mechanism is varied (Greenley, Walsh and Young, 1981). Thus respondents are not indifferent between competing public finance methods for achieving the same goal. Furthermore, there is little consistency as to how published best practice guidelines (for example, the NOAA guidelines) can be varied in accordance with the requirements of a given setting, particularly where the costs of adherence to these may be prohibitive. At the same time the process of developing the survey instrument is valuable in itself since it highlights which choice combinations are plausible, meaningful and economically relevant. A detailed account of the procedures for designing and conducting a Choice Experiment are discussed below. This is a general, non-mathematical overview of the relevant components and some important considerations of a Choice Experiment. A more detailed derivation of statistical methods used to calculate WTP using choice experimental data will be provided in Chapter 4.

Key Considerations for designing a Choice Experiment (CE):

[1]. Design Objectives

In designing a CE, Louviere, Hensher and Swait (2000) have identified four important objectives: identification; precision; cognitive complexity; and market realism.

Identification

The form of the utility function to be estimated needs to be identified. This can be an additive or multiplicative form of the effects of interest, which may include only the main effects or some of the interactions as well.

Precision

The size of the confidence interval of the parameters of the model to be estimated is decided subject to time and budget constraints. Designs with narrower confidence intervals and higher variance efficiency have more precise parameter estimates.

Cognitive Complexity

This involves, among other things, decisions on the number of alternatives in each choice set, and the number of choice sets presented to each individual.

Market Realism

This is the degree to which the decision environment provided by the CE matches the actual decision environment of the respondent in an actual market. Before moving on to the design of the experiment, the researcher needs first to specify the form of the utility function, determine the number of attributes and the levels for each attribute, and then identify the number of alternatives within each choice set and the number of choice sets to be presented to each individual. Once the number of attributes is determined and the number of levels for each attribute is selected, a set of attribute profiles can be generated, usually using a fractional factorial design. Next the choice sets are constructed using a design technique. Louviere, Hensher and Swait (2000) provide a detailed insight into alternative design techniques. The goal of this step is to allocate alternatives created in the factorial design into choice sets in such a way that a maximum amount of information is extracted from respondents. User manuals accompanying statistical computing programmes also provide helpful information how designs can be constructed and programmed by researchers. See for example the Ngene User manual 1.1.2. Aizaki (2015) provides programming guidance for designs in R.

[2]. Optimal Statistical Design of CE

The main objective of an 'optimal' statistical design in CE is the achievement of the highest precision possible for parameter estimates through maximum variance efficiency. The four properties of an efficient choice design (Huber and Zwerina, 1996) are: (i) level balance, (ii) orthogonality, (iii) minimal level overlap, and; (iv) utility balance. Level balance requires all attribute levels to occur with equal frequency in the design. Two main effects are orthogonal if the relative frequency of two levels of different attributes occurring jointly is equal to the product of their marginal relative frequencies. Orthogonal designs yield independent parameter estimates, and therefore minimize collinearity. Minimal overlap happens when the probability that an attribute level is repeated in a choice set is minimized. Finally, the utilities are balanced when the utilities from different alternatives in the choice set are as close to each other as possible. Huber and Zwerina (1996) showed that utility-balanced designs can be generated by adding prior parameter assumptions to designs that already possess the other three design principles. However, in practice these four design principles are generally in conflict with each other (Huber and Zwerina, 1996). Trade-offs exists between these four factors and emphasizing some of them at the expense of others may result in biased parameter estimates (Viney, Savage and Louviere, 2005). Carlsson and Martinsson (2003) described and compared some of the different design techniques used in creating the CE. One of the designs described is the traditional orthogonal design, where the levels for each attribute vary independently. Another criterion that increasingly popular is the D-optimal design which requires some prior knowledge about the true parameter estimates. Comparing the traditional orthogonal designs and the D-optimal designs with respect to their ability to correctly estimate marginal WTP, Carlsson and Martinsson (2003) found that D-optimal designs with priors result in smaller mean square errors and give parameter estimates with higher precision. However, if the pilot study does not allow for making good prior assumptions on the parameter values, there is uncertainty about the econometric model used in the estimation, and the sample size is not sufficiently large, then shifted designs based on orthogonal fractional factorial designs might be preferred (Ferrini and Scarpa, 2007).

When utility balance and D-efficiency criteria are applied together a CE design will have the most efficient parameter estimates possible. There is a strong positive correlation between utility balance and efficiency of a choice design (Huber and Zwerina, 1996; Golek, 2005). Maximizing utility balance in order to achieve maximum efficiency may, however, have negative consequences on the individual, such as fatigue effects, inconsistent choices, or disengaging from the task, which may lead to a loss of information due to non-response. Hence once the most efficient design is obtained, with the use of the software used in the analysis, and/or manually, the cumulative utility balance of the choice task can be manipulated, so that the cumulative utility balance is reduced without jeopardizing the efficiency significantly (Golek, 2005). The efficiency of a design also depends on the sample size available for a CE. More recently, emphasis has been placed on optimising sample size requirements for models estimated from choice data (Rose and Bliemer, 2013). Previously, researchers using a CE framework had to resort to simple rules of thumb or ignore the issue and collect samples of arbitrary size. However, using the expected asymptotic variance covariance (AVC) matrix generated for a CE, Bliemer and Rose (2005) showed that a relationship exists between the expected standard errors of a design and the sample size requirements for that design. They further demonstrated that this relationship can be manipulated to provide an indication as to what sample size will be required for each parameter estimate to be statistically significant. In doing so, Bliemer and Rose (2013) derived a statistical measure, the S-error, which they defined as the overall sample size that minimizes the required sample size for all parameters specified by focusing on the most difficult to estimate parameter (i.e., the parameter with the maximum required sample size). As with the D-error, the objective is to find a design that minimises the S-error value. More information on the relationship, programming and computation can be found in the Ngene software 1.1.2 User manual. Online discussions available at a dedicated forum for CE design using Ngene are also helpful.

[3]. Prior Assumptions on the Parameter Values

Making assumptions about the parameter values is one of the recommendations in obtaining optimum designs (Sandor and Wedel, 2001; Ferrini and Scarpa, 2007; Scarpa and Rose, 2008). Misspecification of the parameter values has been shown not to have a significant effect on efficient designs (Huber and Zwerina, 1996; Carlsson and Martinsson, 2003).

Therefore, even though the exact parameter values may not be known, it is still recommended that prior assumptions on the direction of the parameter effects be made. Golek (2005) compared four different prior assumptions and analysed the effects in their misspecification on the utility balance and efficiency of the design.

The four different prior assumptions studied by Golek (2005) were the zero prior, the equal-spaced prior, the assumption that some attributes are more important than others, and the assumption that the attribute levels are not equally spaced. The zero prior specification assumes that the effect of the different attribute levels and the importance of different attributes are not known in advance. The equal-spaced prior specification assumes that the attribute levels can be ranked according to their relative utility. The levels are assumed to be equally spaced and the attributes to be equally important.

In the third prior specification, the assumption is that the rank ordering of the levels and the relative importance of the attributes are known. Finally the last prior assumption, is where in addition to knowing the relative importance of the attribute levels, we also know that they will not be equally spaced. Golek (2005) concludes that designs with the simpler prior assumptions like the equal-spaced prior specification, are more robust to misspecification of the prior.

[4]. Cognitive Complexity of the Design

In addition to the efficiency of a CE design, the design's complexity is another factor that may affect the results of the experiment (Swait and Adamowicz, 2001). Some of the criteria used to assess the complexity of a CE include (Swait and Adamowicz, 1996; Alpizar et al., 2001; Golek, 2005): Utility balance, number of tradeoffs, magnitude of tradeoffs, number of attributes, mean standard deviation of attribute levels within each alternative, dispersion of the standard deviation of attribute levels within each alternative, mean standard deviation of attribute levels within each attribute, and the dispersion of the standard deviation of attribute levels within each attribute. Caussade et al (2005) assessed the complexity of the design in terms of five design dimensions: the number of alternatives, the number of attributes in each alternative, the number of levels in each attribute, the range of each attribute level, and the number of choice sets presented to each respondent. All five design dimensions were found to affect the error variance; however the two with the highest negative impact were the number of attributes and the number of alternatives. The five design dimensions however were not found to have any systematic effect on the WTP estimates. Carlsson and Martinsson (2006) also investigated the effects of the number of choice sets and found that it did not have an important effect on the estimates.

Hensher, Shore and Train (2005) challenged the view that design complexity is aligned with the amount of information (number of attributes in each choice set) processed by the individual. They investigated the effect on WTP estimates of respondents ignoring specific attributes, and found significantly different WTP estimates in the models where specific attributes are ignored. Hensher (2006) looked at how the number of attributes that are ignored (or not attended to) in a CE varies with the dimensionality of the choice task (number of levels, attribute range, number of alternatives), the number of choice sets per individual, the deviation of the design attribute levels from the base (reference) alternative, the use of adding up attributes where this is feasible, and the socio-economic characteristics of the respondent. He found that the number of attributes ignored is likely to increase as the number of levels of each attribute increases, the range of each attribute narrows, and the number of alternatives decreases.

[5]. Impact of Choice Design on Preferences and WTP Estimates

As discussed above, the assumption in most choice models is that respondents behave rationally and always choose the utility maximizing alternative considering the trade-offs between the attributes (Louviere, Hensher and Swait, 2000). However, if individuals do not have predefined preferences and instead form their preferences during the CE or use some heuristic, then their “preferences” may be sensitive to the way in which information is presented to them (Louviere, Hensher and Swait, 2000; Kjaer, et al., 2006; Lancsar and Louviere, 2006). The recommendation of Golek (2005) is that we might be better off designing the choice tasks in a way that participants will not opt to simplifying strategies (heuristics) when answering the choice tasks. Ryan and Wordsworth (2000) examine the sensitivity of the WTP estimates to the level of attributes, and find that for five of the six attributes included in the experiments the coefficients were not significantly different. However, the mean WTP estimates were significantly different for the four of the five welfare estimates. Hanley et al. (2005) investigate whether preferences and WTP estimates are affected by the choice of which vector of prices to use in the experimental design. They find that individuals exhibit rational behaviour so that the probability of choosing an alternative over the status-quo is higher in the experiment with lower prices, however they do not observe any significant impact of the difference in prices on the WTP estimates.

Kjaer et al. (2006) study the effect the order of the price attribute has on the WTP estimate. They found that when the price attribute is presented to the respondents as the last attribute in the choice set, the WTP estimates are lower compared to the case where the price attribute is placed in the beginning. This implies that there is an ordering effect with respect to the price attribute. Carlsson and Martinsson (2006) in addition to the number of choice sets, also investigated the potential effects of the starting point (design of the first choice set), and the levels of the cost attribute on the precision of the marginal WTP estimates. While the design of the first choice set was found not to have an important effect on the estimates, the impact of the level of the cost attribute was significant. This is contrary to the theoretical expectation that in a utility function which is linear in the cost attribute, the difference in the levels of the two alternatives should have an effect, not the scale of the levels.

Lancsar and Louviere (2006) looked into studies that tested for respondents who behaved irrationally, and examined the effect of deleting those responses from the analysis of the CE. They concluded that deleting valid preferences may result in sample selection bias, and/or reduced statistical efficiency, and therefore unless backed by a very strong theory or empirical evidence, they should not be removed from the data set. The authors suggested considering ways of incorporating these data in the models instead. Johnson, Mathews and Bingham (2000) found that deleting inconsistent responses had a significant effect on the estimates.

[6]. Base or No-Choice Alternative

Including a base alternative or a no-choice alternative in the choice set makes the choice decision more realistic by giving the respondents an alternative choice when the other alternatives in the choice set are not attractive. It also ensures welfare consistent results (Hanley, Mourato and Wright, 2001). The respondents may opt for the no-choice alternative due to resistance to change (status-quo bias), fatigue, learning effect, or complexity of the choice task. Beenstock, Goldin and Haitovsky (1998) found that status quo bias is significant in their study and attribute it to the interviewees' characteristics. The probability of a participant choosing the no-option alternative increases when the task is long causing fatigue effects, or when the choice task is complex. Also a participant who is unfamiliar with the choice task or the good being valued may choose the no-choice option or a status quo option from the menu of alternatives in order to avoid full engagement with the choices provided (Johnson, Mathews and Bingham, 2000). With respect to the learning effect, Rose and Black

(2006) suggested including a couple of practice choice sets for respondents to familiarize themselves with the task, and then removing these from the estimation of the model. Alternatively they recommended measuring task response times, noting when it is stable and including only the responses after this point. Most choice models that incorporate the no-choice option assume that the reason behind selecting the no-choice option is mainly the unattractiveness of the other alternatives, and tend not to consider other reasons as to why this choice may in fact represent a person's true preferences. Including the no-choice alternative may make the task more realistic at the expense of information loss and decrease in efficiency of the experiment. Therefore it is important to determine the reasons for the no-choice selection, and minimize the ones that are not due to the unattractiveness of other alternatives. The complexity of the task and probability of choosing the no-choice alternative are related, hence it is recommended that the participants are not over burdened by choice sets that have high complexity (Dhar, 1997). Golek (2005) also showed that the choice set order within the choice task has an effect on the no-choice selection, and recommended that choice sets with high complexity are not placed late in the choice task. More recently Liebe et al. (2015; unpublished manuscript) have attempted to disentangle status quo and zero price effects associated with the baseline alternative by designing four separate treatments for the same experiment . They find that opt-out choices, if available, lower the frequency of choices directed towards alternatives with a positive price and less at status quo choices. This might hold a promising direction for both questionnaire design and tests for similar effects in other settings.

Steps for CE Design:

The steps involved in designing a CE include (Louviere, Hensher and Swait, (2000); Golek, 2005):

1. **An overview of the topic to be studied:** The researcher identifies the attributes of interest and their levels, starts developing the prior parameter assumptions (sign, influencing factors and potential sources of collinearity) and ranks the alternatives in order of importance to the study.

2. **Consider the target population:** The target population is considered with respect to their present knowledge of the study topic, expected degree of engagement in the project being evaluated, and homogeneity.

3. Select the number of attributes and the number of attribute levels: The attributes to be included in the experiment and their levels are decided.

4. Select the number of alternatives and the number of choice sets: Keeping the properties of the target population and the reward and delivery systems of the CE (mail, telephone, or in-person) in mind, the number of alternatives and the number of choice sets are selected. At this stage, the decision can be made on whether or not to include a constant alternative.

5. **Select the number of alternatives and the number of choice sets**: Keeping the properties of the target population and the reward and delivery systems of the CE (mail, telephone, or in-person) in mind, the number of alternatives and the number of choice sets are selected. At this stage, the decision can be made on whether or not to include a constant alternative.

6. Select the number of participants: A decision on the required sample size is made, among other factors, by the budget allocated to the study, desired degree of accuracy, delivery system of the experiment and number of no-choice responses expected**.**

7. Create several candidate master designs for evaluation: After deciding on the model that will be used in analyzing data and making the prior assumptions for the parameter estimates, with the use of the software several candidate designs are created.

8. Evaluate and examine the complexity measures for each of the candidate master designs: The complexity of each candidate design is examined by evaluating the utility balance, number of tradeoffs, and magnitude of tradeoffs.

9. Select the final master design: The final design is selected among the candidate designs based on performance with respect to the complexity measures calculated above.

10. Allocate choice sets to participants according to complexity measures: The choice sets are grouped and divided among the participants in such a way that each participant faces equal task complexity. The ordering of the choice sets within each task is also considered, so that the choice sets with more complexity are not placed at the beginning of the task. Minimum variability in the parameter estimates and decreased probability of selecting the no-choice alternative are two important considerations.

Steps in a CE Study

The steps in a CE study as stated by Louviere, Hensher and Swait (2000) are:

1. **Define study objectives:** The questions to be answered by the study are decided, and the objectives of the study are defined.

2. **Conduct supporting qualitative study:** Using focus groups and/or personal interviews, information about the way consumers think about a product or service is gathered. In conjunction with literature reviews, focus group interviews are an essential step in the identification of attributes to be included in the initial design of the CE. Focus groups in CE studies usually consist of 5-10 participants and a facilitator that are brought together to discuss their attitudes, beliefs, and experience on a topic of interest with the goal of revealing the significant attributes they are willing to pay for in a product or service. Consequently not only is the omission of important attributes minimised from the model, but the attributes are also described in a way that will be best understood by the respondents in the survey. Due to small sample sizes from focus groups, data collected from such interviews can only be used to identify plausible attributes to be included in the initial design of the CE and in ensuring that these attributes are phrased in a way that will be meaningful to participants.

3. **Develop and pilot the data collection instrument:** The CE is designed, and pilot tests of the survey are conducted.

4. **Define sample characteristics:** determine the relevant population from which respondents will be sampled, and minimum sample size required. See Bliemer and Rose (2005) and Ngene manual 1.1.2 (2014) for further information on how to determine a minimum sample size.

5. **Perform data collection:** The method by which the survey will be conducted is decided.

6. **Conduct model estimation:** The model is estimated using the choice model selected for the study.

7. **Conduct policy analysis:** The estimated model is used to answer the questions laid down in the first step.

3.7. Conclusion

This chapter aimed to provide a comprehensive overview of how non-market valuation studies have evolved since their conception in the 1920s. Two major groups of nonmarket methods, namely revealed and stated preference methods, were investigated. Key assumptions and theoretical frameworks underlying these methods were discussed. Within the Stated Preference paradigm two predominant techniques were examined in detail with information on how studies could be conducted using Contingent Valuation and Choice Experiments. Choice experiments are a popular technique as they allow the decomposition of economic goods and services into constituent attributes. Trade-offs between these attributes can then be investigated in a hypothetical market by recruiting subjects to participate in a choice-based exercise. Choices made by study participants can then be modelled and estimates of the willingness-to-pay, or implicit prices of individual attributes can be recovered. As such CEs provide a powerful and informative set of insights into the demand for non-market goods and services which can used to assess the impacts of policy changes on the wider population's welfare. In the next chapter, the methodology used to collect and analyse preference data for hydrometric systems in Scotland will be discussed.

Chapter 4

Data and Methodology

4.1 Introduction

The first river gauging station in Scotland was established in 1913 in order to assess the potential for hydroelectric development in the highlands (Werritty, 1985). Since this early foray into the scientific measurement of freshwater quantity the number of stations has expanded into a network of 392 stations all established at different periods during the last century. These network expansions were undertaken in response to competing scientific and societal requirements including the need to provide flood warnings, manage freshwater abstractions for commercial and domestic consumption purposes, and for the large-scale impoundment of river courses in the form of dams constructed mainly for hydroelectric power development and municipal water supply. Geographically, most stations were sited close to the main population centres in Scotland focused on the central vertical belt of the country (SEPA, 2014). Over time the data from individual, special-purpose stations have come to be used and consulted for a wider range of applications than originally intended when the station site was first selected for continuous gauging. As a result the utility of a station may have increased, decreased or adapted into a new set of useful purposes (Whitfield et al., 2012).

The augmented availability of hydrometric data over the last century has taken place in the context of an increasing demand for fresh water resources, improved access to the river environment, and for more water-sensitive management practices and development (Poodle, 1987). In 2012 the Scottish Government launched a prospectus for developing Scotland as the world's first 'Hydro Nation' (SDI, 2014). This is defined as 'a nation that recognises the importance and value of water within its national and international identity and manages its water environment to the best advantage, employing its knowledge and expertise effectively at home and internationally in ways which contribute to a flourishing low-carbon economy' (SDI, 2014). The Hydro Nation agenda aims to secure a place for Scotland as a world leader in water resource governance; water industrial performance and its conversion to low-carbon sustainable approaches; international water research, and; adding economic value to its water resources (SDI, 2014). Each of these aims underlines the importance of evidence-based policies, procedures and practices across the water sector.

An emphasis on evidence-based decision-making means that both regulation policies and commercial/domestic water use should be managed in manner consistent with the best available understandings of hydrological science (Marsh and Anderson, 2002). The physical impacts of human-driven development in catchments and their effects on river flows and biotic systems reliant on these flows can only be assessed by modelling changes in flow regimes arising from a proposed development/intervention/policy. Moreover, it is becoming increasingly important to understand the localised effects of such developments in upstream or downstream areas which may lie in municipal districts governed by a councils different from the authority of the area where the development is taking place (USEPA, 2005). As the *prima materia* of environmental information, hydrometric data is therefore a critical input for realising the Government's sectoral aspirations for water from the most localised to the most global level (Croke and McIntyre, 2013).

In Scotland riverine environments are used by a wide range of citizens. Major users include recreational fishermen (anglers), boatmen (canoeists, kayakers, rafters and yachters), birdwatchers, swimmers, walkers, runners, farmers and waterfront property owners. Several riverfront properties and estates have been converted into commercial dwellings for tourism purposes in recent years. The level of the river is important information for these users who wish to establish whether flow conditions are safe and adequate in order to access the river environment and whether any hazards are foreseen for their rivers of choice during the next 24-48 hours. Information on current levels and flow conditions are freely available from the website of the Scottish Environment Protection Agency where river level charts are updated every 15 minutes. Some private enterprises have also developed new software applications which provide real-time camera views of the river channel (Farson Digital Watercams), station level data enabled for mobile electronic platforms such as smart phones and tablets (Shoothill Gaugemap) and gauge data on subsets of stations for specific user groups such as fishers (Fishpal).

Hydrometric data is also used by a wide range of professionals. Within SEPA the operations of several departments rely on gaugings of river flow in order to assess compliance with water abstraction licenses, create maps of flood risk, understand the chemistry of water courses, trigger flood warnings, examine planning applications for flood safety, check elevation conditions for access to a river, and to model scenarios for potential impacts of point and diffuse pollution sources. Outside SEPA, hydrometric data is requested by water and energy utilities; road, rail and shipping operators; engineering consultancies; university departments; local authority departments; agriculture, aquaculture, distilling and mining organisations for environmental assessments related to specific projects, processes and activities. Data from a subset of SEPA gauges is also supplied regularly to the National River Flow Archive (NRFA) at the Centre for Ecology and Hydrology (CEH) in Wallingford, Oxford, where hydrometric data from the UK's four collecting authorities is compiled into a unified set of official hydrological records for the British Isles.

At a very high level the use of hydrometric data is an exercise in marrying the geography of existing stations with the geography of new development. In other words the impacts and optimisation of new schemes within catchments require an accurate scientific insight of river flow characteristics for specific locations/areas in order to make informed, intelligent and insightful decisions about proposed schemes.[1] However continuous flow gauging data may not be available for the particular location/area in question. In some instances, short-term flow gauging apparatus may be installed in order to establish a scientific baseline however there is no substitute for long-term data which reflects seasonal variations in river flow regime over many years (Cordery and Cloke, 1994). Further levels of complexity are added by the large-scale alteration of natural flow regimes driven by human modifications of river channels which makes it difficult to define what 'natural' conditions may have looked like and against which scheme impacts are now being assessed (Dixon, 2011). In such cases hydrological professionals are required to construct and calibrate statistical models which test the impacts of proposed schemes by using available hydrometric data from similar or nearby catchments (Hannaford et. al., 2013).

There are five main problems arising from the preceding discussion. First, hydrometric data is not always available in catchments for which hydrological information is increasingly required for development purposes such as renewable energy (hydropower) projects or water resource monitoring (McColl and Aggett, 2007). Second, several ungauged catchments are now experiencing unprecedented and unforeseen climate events (Kennedy 2010a; Kennedy, 2010b). Larger, more population-intensive areas were historically prioritised for river gauging activity (Poodle, 1987) however smaller catchments in more remote areas across the highlands and islands are now becoming candidates for the establishment of

[1] For example the developer of a hydroelectric power scheme may wish to estimate the annual maximum power yield from a river in order to plan the size of investment required for the project. Mean annual flow information is required for this assessment. Similarly, a distiller may wish to evaluate the incidence of low flow conditions in a watercourse in order to match water abstraction limits with production schedules for the next two years. Equally, a local authority may wish to evaluate the environmental merits of a new forestry or housing programme by examining the likely impacts of these large-scale developments on catchment-level river flow regimes. Long-term hydrometric data identifying minimum, maximum and seasonal flow variations for the affected river or catchment is critical for such decisions.

continuous river gauging stations in order to track climate change impacts and improve weather preparedness in these areas (SEPA, 2011). Third, there is a variable limit to the utility of some existing stations in that the data may not be fit for purpose for the main uses to which the station was originally established.[2] (SEPA, 2011). Fourth, the range of users and applications of hydrometric data has expanded considerably in the last thirty years. Households are seeking improved information on river level conditions for both safety and recreational purposes such as fishing, canoeing and flood preparedness, while professionals are seeking higher quality flow data in order to inform commercial decisions that may carry significant levels of risk (Banjacic et.al., 2015). Fifth, there is a limit to the costs and resource that SEPA as a collecting authority can devote to river gauging activity (SEPA, 2011).

Several research areas are available for addressing the issues discussed in 4.6. Hydrometric network optimisation might be approached from the perspective of business information systems which focus on data product design, production, sales, delivery and service (Alter, 2002). Engineering approaches have sought to rationalise the use of hydrometric data with statistical techniques for specific purposes such as hydropower development, dam construction and fish-pass installations (Rood and Hamilton, 1995; Mishra and Coulibaly, 2009). Information theory approaches have been used to assess the siting and number of stations in a network with a view to optimising the total information efficiency of the network (Alfonso et al., 2010). Literatures on public sector information (PSI) and Big and Open Data have also grown in recent years. These have focused on a wide range of questions from the development of large-scale, linked, open government data resources to data interrogation algorithms, the Internet of Things (IOT) and unlocking the value of innovation from data-based applications (Manyika et al., 2013).

Societal preferences are important indicators of both the direct and passive use values delivered by public services (Flores, 2003). Although many studies have attempted to explore the uses and applications of hydrometric data resources, non to the author's knowledge have sought to assess society's preferences for hydrometric data or to determine the benefits of increasing the level of river gauging activity in Scotland. Insufficient river gauging activity leads to inadequate hydrometric data which, in turn, risks providing inaccurate hydrological information (R. Halliday & Associates, 2011). This lowers data use values as well as the passive benefits to society arising from potentially improved decisions and outcomes which could have resulted from improved information availability. In the

[2] However the station may still be maintained for different (equally sound) reasons such as the availability of a long and uninterrupted time series of flow data at that location.

absence of societal preference metrics for river level and flow data, the total economic value of gauging activity is underestimated, and any service level or policy changes made without these considerations will remain both incomplete and misleading (Dupont and Adamowicz, 2016, in Renzetti and Dupont eds. 2016).

This study aims to examine the preferences of society for publicly-funded river gauging services in Scotland. Two choice experiments were administered to households and professionals in order to elicit and compare the willingness-to-pay of both users and non-users for several elements of hydrometric data provision in Scotland.

4.2. Research Design

User Engagement

Choice experiments aim to elicit societal values for public goods and services. The technique's ability to reflect true consumer preferences is heavily dependent upon existing levels of community awareness, usage patterns, attitudes, beliefs and contextual factors within which the good's consumption takes place (Louviere et. al., 2000). User input in to the design process of a choice experiment is required for two main purposes: first, to understand which attributes of the good/service are relevant to users and to identify the appropriate range of levels that the attributes take in practice (or levels that they might take in hypothetical, but plausible, settings) (Klojgaard et. al., 2012). The second role is to test the plausibility of the design through critical sense-making of the assumptions, choice scenarios and overall realism of the choice experimental questionnaire/instrument (Bekker-Grob et. al., 2012). A qualitative process consisting of focus groups, interviews, literature reviews and general engagement with the user community has been recommended for this purpose (Hensher et. al., 2005; Coast and Horrocks, 2007).

Hydrometric data holds different types of value for diverse segments of society. Professional groups and individuals might attach direct forms of value to the data as it enables them to fulfil work-related responsibilities which may not have been possible in the absence of publicly-funded river gauging activity. In contrast, the wider citizenry benefits indirectly from data-driven public decisions which result in sound water resource management, agricultural yields, flood warnings and infrastructure design. These benefits accrue to all members of the public who may have little or no prior awareness of gauging station networks (Hester et al., 2006). In order to elicit valuations from both direct users and indirect beneficiaries of hydrometric data a series of interviews, focus groups, meetings and presentations were organised with the respective user segments so as to understand their key avenues of hydrometric data consumption and main attributes of interest. This information was used to design two choice experiments; one for households and another for professionals.

Professional users of hydrometric data in Scotland can be divided into two main groups. The first division comprises internal users or people employed at the Scottish Environment Protection Agency (SEPA). These professionals make use of river gauge data collected by the SEPA Hydrometry Unit for a range of tasks and functions such as abstraction licensing, flood risk mapping, providing flood warnings, water quality assessments, ecology protection and water chemistry. Internal user applications of hydrometric data are aimed at three of SEPA's overarching functions: to protect the environment and human health; to ensure sustainable resource use and to support economic growth (SEPA, 2017). The second professional group consists of external data users who were based in organisations outside of SEPA. These users were further categorised into private sector users (e.g. engineering consultants, small-scale hydropower developers, agri-businesses); public sector users (e.g. local authority departments); utilities (water, energy, transport), and; universities and research institutes. External user applications were aimed mainly at fulfilling client, compliance, education, research and operations-related responsibilities.

In order to engage professional data users, a total of 50 interviews were conducted in-person or by telephone with users both within SEPA and in the external professional community. In addition, a presentation and focus group was convened with approximately 20 members of the Scottish Hydrological group at their annual general meeting in 2015. Members of the National River Flow Archive based at the Centre for Ecology and Hydrology (CEH) in Wallingford, Oxford were also interviewed. Finally, field visits were undertaken to the Harlaw Hydro green energy scheme; the Eddleston Water natural flood management project, and; the Seafield wastewater treatment works during the World Water Congress 2015. The reason for attending field trips was in order to understand the freshwater processing lifecycle in a greater level of depth and to thereby situate the professional consumption of gauging data in a range of applied, practical settings. Informal interviews were conducted during the congress and at all visits.

Household users of hydrometric data can also be grouped into two broad categories. The first group comprises positive and negative river users. Positive river users are defined as households in which at least one individual regularly visits the river for recreational purposes such as boating, kayaking, swimming, walking or fishing. Such users actively seek engagement with a river for personal satisfaction and are likely to consult river level data made available on the website pages of the Scottish Environment Protection Agency in order to assess two key issues: safety of access to the river bank and water flow conditions for river use. A similar type of river user, perhaps an example of a 'negative' river user, are residents living in a flood zone, several of whom might regularly consult SEPA water level charts in order to check for bank-topping conditions during periods of high flood risk following severe rainfall or snowmelt events. Negative users do not seek active engagement with the river as a source of personal wellbeing but are mainly concerned with the ability of hydrometric data readings to avert threats posed by the river to their lives, families and property from timely warnings indicated by online hydrographs and SEPA flood warning services. The second household user group consists of residents who are not regular river users and who have never consulted river gauging data. However, they still benefit indirectly from modern environmental management procedures made possible by data-driven public decisions.

In order to engage household users, presentations and focus groups were convened with the Moffatt Flood Action Group (MFAG) and the Inverness Community Council Forum. The MFAG is a group of local resident volunteers in the Dumfries and Galloway region in southern Scotland who have experienced an increased onset and duration of flooding in recent years and are part of a wider network overseen nationally by the Scottish Flood Forum. They work to reduce the flood risk from the River Annan to their community by identifying key priorities and issues for the local area and working with partners such as the local council and other responsible parties such as the environment regulator. Activities undertaken by flood groups include mapping out their own flood plain; monitoring river levels at local community-run gauging sites; raising awareness of community issues and impacts; identifying vulnerable locations and infrastructure, and; generally providing a focal point for community-led action on mitigating flooding impacts. Seven people were present at the focus group with the MFAG. There were several reasons for approaching flood groups in Scotland. The first is that they were likely to be a group of informed residents, knowledgeable about the local area and its particular challenges. They were also more likely to have had exposure to planning-related procedures with local authorities and to have liaised with first responders to alleviate the impacts of adverse flood risks to resident individuals and property than the average household. The flood groups were therefore considered to be a useful starting point to understand some of the pressures and requirements arising from one of the key applications of hydrometric data. A second reason for approaching the flood groups was to identify a list of relevant hydrometric attributes and to compare and contrast their preferences with those of professional users working in both the public and private sectors. A third reason was to test the cognitive level at which a questionnaire might designed so as to make it relevant to and reflective of an average household context. Although members of the group likely to be more informed participants than non-volunteer households, they provided a helpful grounding opportunity for the final questionnaire. Fourth, they were likely to be a source of additional information on other river users, networks and interest groups. Fifth, engagement across a range of spatial settings in Scotland was sought in order to gain an insight in to both the regional divergences and commonalities across a range of physical settings in Scotland. Moffatt Flood Action Group was selected as a key domestic stakeholder in the south of Scotland, while the Inverness Community Council forum was approached as a willing consultee in the highlands. Fifteen members attended this focus group. The MFAG meeting was held in a local hotel during the evening which is a convenient time for resident volunteers. Following a conclusion of the group's main business, a presentation about the hydrometric valuation study was made to members. A handout with questions was distributed, followed by an informative and lively discussion. A similar format was followed at the Inverness Community Council forum which was held at the Inverness Town House. A helpful discussion was held after an introduction to the study, however the degree of unfamiliarity with hydrometric systems was in general much higher amongst this group which in itself provided an insight into a suitable information level for questionnaire design. Additional perspectives were also received by correspondence from the co-ordinators of the Edzell Village residents (eastern Scotland) and the Smithton and Culloden Community Council (Highlands). Finally, telephone interviews and emails were exchanged with officers of the Scotland Canoe Association (SCA) which is the national governing body for canoeing in Scotland. It is a membership organisation comprising approximately 3200 individual members including around 1,750 qualified coaches. Several canoeing disciplines such as sea kayaking, white water rafting, wild water racing, canoe sailing and paddle-boarding make use of river and loch gauge data in order to assess conditions for river use. A perspective from the association was therefore helpful to further understand some of the diverse uses for river gauging data. A summary of the various stakeholder consultations undertaken to inform the choice experiments are displayed in Table 4.1.

Table 4.1: Summary of Key Stakeholder Consultations

Date	Location	Type of User	Organisation
Conferences, Symposia and Workshops			
19 September 2014	London	Professional	Cabinet Office - National Information Infrastructure
25-29 May 2015	Edinburgh	Professional	International Water Resources Association (IWRA)[1]
10 June 2015	Liverpool	Professional	British Hydrological Society[2]
02 February 2016	Edinburgh	Professional	Scotland and Northern Ireland Forum for Environmental Research (SNIFFER)[3]
Correspondence by Email			
04 July 2014	Liverpool	Professional	JBA Consulting
07 January 2016	Liverpool	Household	Edzell Village Residents
Field Trips			
26 May 2015	Edinburgh	Professional	Harlaw Hydro
27 May 2015	Edinburgh	Professional	Eddleston Waters Project
28 May 2015	Edinburgh	Professional	Seafield Wastewater Treatment Works
Focus Groups			
20 May 2015	Edinburgh	Professional	Scottish Hydrological Group (SHG)[4]
08 October 2015	Moffat	Household	Moffat Flood Action Group
13 October 2015	Inverness	Household	Inverness Community Council Forum
Interviews (in-person and by telephone)			
14 April 2014	Holytown	Professional	Scottish Environment Protection Agency (SEPA)*
20 June 2014	Liverpool	Professional	Mott MacDonald
20 June 2014	Liverpool	Household	Scottish Canoe Association
23 June 2014	Liverpool	Professional	Atkins
23 June 2014	Liverpool	Professional	Tweed Forum
23 June 2014	Liverpool	Professional	University of Liverpool
23 June 2014	Liverpool	Professional	Scottish Water
24 June 2014	Liverpool	Professional	Centre for Ecology and Hydrology (CEH)
24 June 2014	Liverpool	Professional	Hutton Institute
24 June 2014	Liverpool	Professional	University of Plymouth
25 June 2014	Liverpool	Professional	Scottish and Southern Energy (SSE)
03 July 2014	Liverpool	Professional	Heriot-Watt University
06 August 2014	Oxford	Professional	Centre for Ecology and Hydrology (CEH)*
24 November 2014	Holytown	Professional	Scottish Environment Protection Agency (SEPA)*
25 November 2014	Glasgow	Professional	Atkins
26 November 2014	Edinburgh	Professional	Scottish Environment Protection Agency (SEPA)*
26 November 2014	Edinburgh	Professional	Kaya Consulting Ltd.
28 November 2014	Stirling	Professional	Scottish Environment Protection Agency (SEPA)*
02 December 2014	Perth	Professional	Scottish Environment Protection Agency (SEPA)*
03 December 2014	Perth	Professional	Scottish and Southern Energy (SSE)
05 December 2014	Dingwall	Professional	Scottish Environment Protection Agency (SEPA)
10 December 2014	Liverpool	Professional	Centre for Ecology and Hydrology
19 December 2014	Liverpool	Professional	Scottish Environment Protection Agency (SEPA)
06 January 2015	Liverpool	Professional	Pernod-Ricard
03 September 2015	Leeds	Professional	Environment Agency

Notes: *Multiple interviews conducted with several representatives. [1] Attendance and interviews at XV World Water Congress. [2] Presentation and feedback at Peter Wolff Early Career Researchers' symposium; [3] Attendance and interviews at Annual Flood Risk Management Conference 2015. [4] Presentation and feedback at Annual General Meeting. [5] Interviews with National River Flow Archive (NRFA) team.

4.3. Construction of Choice Sets

Choice sets for both the household and professional questionnaires were generated using Ngene software version 1.1.2. Following Liebe et. al (2015; unpublished manuscript) both designs were specified to provide five options including a downgrade alternative (zero cost), a positive cost status quo option, two generic upgrade options and an opt-out alternative. Although SEPA hydrometric service users do not currently pay a charge for river gauging data, the status quo option was designed to carry positive (non-zero) costs in order to evaluate the willingness-to-pay for this alternative, and also because present information provision does in fact have an actual cost that is met by a combination of Scottish Government funds and SEPA receipts from abstraction licensing. A hypothetical downgrade option was specified as a near-50% cut to the current network from 392 stations to 200, 'level-only' stations. This was included in order to minimise any potential status quo bias, and also because it represents a realistic worst-case scenario where only the bare minimum of stations are operated in order to meet only the minimum obligations as required by the Flood Risk Management Act 2009 and the Civil Contingencies Act 2004. The main use for such stations would be to trigger flood warnings and to maintain readings on relevant hydrographs on the SEPA water levels website pages. In addition, two upgrade options were included offering strictly better-off (but more costly) attribute combinations compared with the status quo and downgrade options. Finally, an opt-out alternative ('none of the above') was included so as to avoid forcing study participants to make trading choices. Again, this alternative was intended to model real market conditions where sovereign consumers are free to walk away from a proposed sale if they so please. The choice sets were generated using efficient designs constructed to minimise the D-error (determinant of the asymptotic variance-covariance matrix) using 2/3 Gaussian draws. In the case of the household sets, a blocking strategy was used to divide thirty-six choice scenarios into six blocks so that each respondent faced a series of only six rather than the full 36 choice situations. For the professional questionnaire, 70 choice scenarios were divided across 35 blocks so that each respondent had only to make two valuations each. This approach was considered to minimise the time and cognitive demands placed on professional participants who were being asked to make more complex trade-offs and who were also regarded as a more time-sensitive cohort relative to households. The statistical output obtained for both sets of choice cards (i.e. households and professionals) are provided below. They display the design efficiency statistics for four error measures; however as mentioned the D-error was specified for minimisation. The S-error provides an estimate of minimum sample size required for variables to attain at least a 95% level of significance. However, note that this indicator is only meaningful if prior values have been entered when generating the choice sets. In this study, pilot studies were carried out for both households and professionals, however plausible prior values (mean and standard deviation) were only forthcoming for the household cohort; a sufficient number of pilotees were not available for the professional survey in order for prior values to be credible estimators of actual preferences. Thus in the case of the households, about 332 responses were recommended on the basis of the output while for professionals, this number stretched to infinity. Contents of the choice cards are reported in Appendix 3. Statistical efficiency measures of both choice set designs are given in Tables 4.2 and 4.3.

Table 4.2: Household Survey: MNL Choice Set Efficiency Measures

Efficiency Measure	Fixed	Bayesian mean
D error	0.001445	0.001504
A error	0.095263	0.098988
B estimate	51.98373	0.497105
S estimate	332.6726	237.8154

Table 4.3: Professional Users' Survey: MNL Choice Set Efficiency Measures

Efficiency Measure	Fixed	Bayesian mean
D error	0.0028	0.0028
A error	0.080571	0.080571
B estimate	99.999991	1
S estimate	1.13572E+12	1.15E+31

4.4. Research Questions and Hypotheses

River gauging stations across Scotland continuously measure and record river levels. Most gauging stations are designed and operated to produce a record of river flow, which is the volume of water moving downstream over a period of time and also known as the 'discharge'. A continuous record of discharge is derived by relating a continuous measurement of river level with sample flow measurements (gaugings). River level is measured continuously by sensors and the data is recorded every 15 minutes using a digital data logger. The data is normally downloaded remotely from SEPA's offices via the telephone network. All readings are collected and verified by trained hydrometry officers from SEPA.

River level and discharge figures are therefore the two main measurements of interest for computing available water quantity in rivers and are known collectively as hydrometric data.

The goal of this research is to estimate the benefits of improving the quality and quantity of hydrometric data provision. Households' and professionals' willingness-to-pay is estimated for various aspects of the public river gauging system that delivers a given level of information on the state of the fluvial environment. In a Choice Experiment survey, individuals are presented with two or more alternatives and asked to select their most preferred one. The alternatives represent competing programmes for river gauging activity and hydrometric data provision. A river gauging programme is defined as the total number of stations continuously measuring and recording river levels; the frequency or time intervals at which river levels are updated (number of readings per hour); the type of data collected at stations (level only, versus both level and flow data), and; the cost of delivering each option. In addition, because visual conditions around a river channel also provide information to river users, the availability of real-time river views enabled by a web-linked camera at station sites was also included as a potential defining feature of the river gauging network.

River gauging programmes composed of the five key features displayed in Table 4.3 were presented to both households and professionals. In addition, professionals were presented with six further hydrometric aspects in order to investigate the significance of these features for the gauging requirements of direct hydrometric data users: data precision (error margin of the data observations); enhanced metadata (contextual information detailing data collection conditions and processing decisions); advanced diagnostics (digital imagery and visualisations into bed/bank/flow profiles); integrated supply (hydrometric data provision is integrated horizontally with other types of environmental data collected by SEPA and local authorities, and vertically with hydrometric records held in archives and by other major water users. E.g. utilities); availability of online access to data, and; data delivery time (days taken to supply the data). These aspects were considered to directly affect the data consumption experience of professional users and were therefore included in order to test for the extent to which they drive the value of river gauging programmes.

Tables 4.4, 4.5 and 4.6 illustrate the attribute levels associated with each attribute featured in the two different experiments. The theoretical and econometric models used for analysing household and professional choices are discussed in the next section.

Table 4.4: Selection of Attributes and Hypotheses.

Attribute Descriptions	Presented to	Hypotheses
STATIONS: The total number of river level gauging stations across Scotland.	Households and Professionals	Number of stations do not have an impact on WTP.
REAL-TIME VIEW: Whether the river can be viewed 'live' on the internet by means of a web-enabled camera installed at all station sites. Recorded footage available during abnormal flow conditions.	Households and Professionals	Availability of real-time views do not have an impact on WTP.
DATA TYPE: Whether stations are operated to record river level only, or to also collect river discharge/flow data.	Households and Professionals	Type of data does not affect WTP.
FREQUENCY: The time interval between new readings of river level each hour.	Households and Professionals	Frequency of data collection does not affect WTP.
COST: Amount payable each time the data requested.	Households and Professionals	The cost of provision does not affect WTP.
DATA PRECISION: The level of scientific quality control applied to meet error-free data standards. Resulting figures published within a specified error margin of true value.	Professionals only	Level of data precision does not affect WTP.
ENHANCED METADATA: Enhanced contextual documentation informs level/flow gaugings in high level of detail and to agreed international standards.	Professionals only	Availability of enhanced metadata does not affect WTP.
ADVANCED DIAGNOSTICS: 3D spatial river data and digital elevation imagery provided for high resolution insight into bed/bank profile and level/flow characteristics using advanced methods (e.g. LSPIV), equipment (e.g. ACDPs, UAVs) and linked data (e.g. LiDAR).	Professionals only	Availability of advanced diagnostics do not affect WTP.
INTEGRATED SUPPLY: Additional hydrometric data is provided by digitising analogue archives and through service-level agreements with other organisations (e.g. universities, local authorities, utilities). Different types of environmental data collected by SEPA (e.g. rainfall, water quality) are also available. All data is interoperable and georeferenced.	Professionals only	Integrated data supply does not affect WTP.
ONLINE ACCESS TO DATA: Whether data is available for online access and direct download.	Professionals only	Online access to data does not affect WTP.
DATA DELIVERY TIME: Number of days taken to supply the requested data.	Professionals only	Data delivery time does not affect WTP.

Table 4.5: Household Choice Attribute Levels

Attribute Name	Attribute Description	Levels
STATIONS	Total Number of River Gauging Stations in Hydrometric Network	200, **392**, 431, 490, 588, 686, 784 stations
FREQUENCY	Frequency of Data Readings Per Hour	Every 1 min, 2 mins, 5 mins, **15 mins**, 30 mins, 60 mins
WEBCAM	Real-Time Views of Gauging Site using a Web-Enabled camera	**No**, Yes.
DATA TYPE	Type of Data collected at River Gauging Stations	River Level only; **River Level and Discharge**.
COST	Cost of River Gauging per Household in GBP (£)	27, 32, 35, 40, 47, 55, 63

Note: Figures in bold font display current or typical level of provision.

Table 4.6: Professionals' Choice Attribute Levels.

Attribute Name	Attribute Description	Levels
STATIONS	Total Number of River Gauging Stations in Hydrometric Network.	200, **392**, 431, 490, 588, 686, 784 stations
REAL-TIME VIEW	River can be viewed 'live' on the internet by means of a web-enabled camera installed at all station sites. Recorded footage available during abnormal flow conditions.	**No** , Yes
DATA TYPE	Type of Data collected at River Gauging Stations.	River Level only (Grade= 0); **Mostly Flow Some Level Only** (Grade= 1); All Flow (Grade=2).
DATA PRECISION	Level of scientific quality control applied to meet error-free data standards. Resulting figures published within a specified error margin of true value.	Est. within 50%, 25%, 15%, 10% and 5% of True Value
FREQUENCY	Time interval between new readings of river level each hour.	Every 1 min, 5 mins, **15 mins**, 30 mins, 60 mins
ENHANCED METADATA	Additional documentation provided to agreed international standards in order to illustrate institutional context, environmental conditions and other limitations under which observations were made.	**No** , Yes
ADVANCED DIAGNOSTICS	3D spatial river data and digital elevation imagery provided for high-resolution insight into bed/bank profiles and level/flow characteristics using advanced methods (e.g. LSPIV), equipment (ACDPs, UAVs) and linked data (e.g. LiDAR).	**No** , Yes
INTEGRATED PROVISION	Additional hydrometric data is supplied by digitising analogue archives and through service-level agreements with other organisations which also collect similar data (e.g. universities, local authorities, universities). Different types of environmental data collected by SEPA (e.g. rainfall, water quality) are also available. All data is interoperable and geo-referenced.	**No** , Yes
ONLINE PROVISION	Data is available for online access and direct download.	**No** , Yes
DELIVERY TIME	Number of days taken from date of request to supply requested data.	0 (Same Day), 7, **14,** 21, 30 days
COST	Cost of River Gauging per Organisation in GBP (£).	0, 105, 121, 133, 152, 182, 212, 243

Note: Figures in bold font display current or typical level of provision.

4.5. Theoretical Framework and Econometric Model

Conditional Logit Model

Following McFadden (1974), a Random Utility Model (RUM) is assumed. The utility function can be deconstructed into two components: deterministic and stochastic.

$$U_{ij} = V(X, \beta)_{ij} + \varepsilon_{ij} \tag{4.1}$$

Where $V(X, \beta)_{ij}$ is the deterministic component and ε_{ij} is a random error term. X is a vector of explanatory variables for individual *i*. It is the vector of all attributes of alternatives *j* including cost and other socioeconomic characteristics such as income, age, gender and education. The vector β is a set of parameters to be estimated.

The deterministic indirect utility function in equation (4.1) can be expressed as:

$$V_{ij} = ASC_j + \sum_k \beta_k Z_{ijk} \tag{4.2}$$

where ASC is an Alternative Specific Constant which captures any systematic variation in choice observations that are associated with a given alternative *j* but not captured by attributes or individual characteristics; Z_{ijk} is the *k*th attribute value of *j*th alternative, and; β_k is the vector of coefficients of the *k*th attributes. The above model can be extended to capture respondent heterogeneity by including socio-demographic characteristics of households and individuals:

$$V_{ij} = ASC_j + \sum_k \beta_k Z_{ijk} + \sum_n \delta_n X_{in}.\mathrm{ASC}_j \tag{4.3}$$

where X_{in} is the n^{th} socio-economic characteristic of the i^{th} individual, and δ_n is the corresponding vector of coefficients associated with *n* socio-economic characteristics for the i^{th} individual interacted with the ASC of an alternative. Where an opt-out is provided, for example where respondents can select not to choose any of the given alternatives, the second term of equation 4.3 drops out of the estimation process and only an ASC effect is estimated for the opt-out alternative (Veldwijk et al., 2014).

Parameters β_k and δ_n can be estimated by maximizing the likelihood function. The indirect utility function (*V*) can be calculated after estimating coefficients (β_k). Under the assumption that the error terms are Independent and Identically Distributed (IID) and follow a Type 1 Extreme Value Distribution, the probability function can be written as:

$$P_i(j) = \frac{e^{\mu V(X;\,\beta)_{ij}}}{\sum_{k=1}^{J} e^{\mu V(X;\beta)_{ik}}}$$

(4.4)

where μ is a scale parameter and is inversely related to the standard deviation of the error distribution which is normalized to unity for modelling purposes.

The probability of the choice made for individual *i* is:

$$P_i = \prod_{j=1}^{J} P_i(j)^{d_{ij}}$$

(4.5)

where d_{ij} is a binary indicator such that d_{ij}= 1 if individual *i* selects alternative *j*; 0 otherwise.

The Log Likelihood function for the choices made for all individuals is:

$$lnL = \sum_{i=1}^{N}\sum_{j=1}^{J} d_{ij}\ .lnP_i(j)$$

(4.6)

The conditional logit model (CLM) function given above can be estimated by using Maximum Likelihood Estimation (MLE).

The Marginal Willingness-to-Pay (MWTP) for an attribute is the derivative of the utility with respect to attribute divided by the negative of the derivative of utility with respect to price (Greene, 2003; Hanemann, 1984; Hensher and Button, 2007). Thus the ratio of the coefficient of any attribute to the coefficient of cost attribute is:

$$MWTP = -\frac{\beta_k}{\beta_C} \tag{4.7}$$

where β_k and are β_C coefficients of *k*th attribute and the cost attribute respectively.

Random Parameter Logit Model

In the conditional logit model (CLM), ε_{ij} is assumed to be IID with extreme value type 1 across individuals, alternatives and choice situations. The IID assumption can be relaxed by introducing additional stochastic elements that will take into account the heteroscedasticity and autocorrelation across alternatives (Hensher et al., 2007).

$$U_{ij} = V(X;\beta)_{ij} + [\eta_{ij} + \varepsilon_{ij}] \tag{4.8}$$

In addition to the error term ε_{ij}, η_{ij} is introduced to take into account the heteroscedasticity and autocorrelation across alternatives. For a given value of η_{ij}, the remaining error term ε_{ij} is IID distributed with extreme value 1. Thus, the conditional probability is logit and the probability that individual *i* will choose alternative *j* is given by Hensher et al. (2007) as:

$$P_i(\eta) = \frac{e^{V(X;\beta)_{ij}+\eta_{ij}}}{\sum_{k=1}^{J} e^{V(X;\beta)_{ik}+\eta_{ik}}} \tag{4.9}$$

The value of η_{ij} is not given. The unconditional probability can be found by integrating equation (4.9) over all values of η_{ij}:

$$P_i(\eta) = \int \frac{e^{V(X;\beta)_{ij}+\eta_{ij}}}{\sum_{k=1}^{J} e^{V(X;\beta)_{ik}+\eta_{ik}}} f(\eta|\theta)\, d\eta \tag{4.10}$$

$P_i(\eta)$ is the logit probability evaluated for different parameters of η and $f(\eta|\theta)$ is the density function and θ is the fixed parameter of the distribution η.

$$P_i(j) = \int \frac{e^{V(X;\beta)_{ij}+\eta_{ij}}}{\sum_{k=1}^{J} e^{V(X;\beta)_{ik}+\eta_{ik}}} f(\eta|\theta)\, d\eta \tag{4.11}$$

The above integral has no closed form solution, and thus parameters are estimated using Simulated Maximum Likelihood Estimations (SMLE). For any value of θ, the average of the simulated probability that an individual *i* chooses alternative *j* is given by:

$$S\,P_i(j) = \frac{1}{R}\sum_{r=1}^{R} P_{ij}(\eta^r)$$

(4.12)

where R is the number of draws and $S\,P_i(j)$ is the unbiased estimator of P_i.

The probability of the choice made for one individual is then:

$$P_i = \prod_{j=1}^{J} S\,P_i\,(j)^{d_{ij}}$$

(4.13)

where d_{ij} is binary indicator such that $d_{ij} = 1$ if the individual selects alternative *j*; 0 otherwise.

The above probability in log form can be written as:

$$lnP_i = \sum\nolimits_{j=1}^{J} d_{ij} \ln S\,P_i(j)$$

(4.14)

Finally, the log likelihood function of the simulated probability is given by:

$$SlnL = \sum_{n=1}^{N}\sum_{j=1}^{J} d_{nj} \ln S\,P_i\,(j)$$

(4.15)

Latent Class Model

One refinement of the mixed logit model is the latent class model (Hensher et. al., 2015). In this specification it is assumed that respondents are divided into distinctive classes where each class displays its own unique profile in terms of the behaviour, preferences and characteristics of its members. At the level of the sample data one might thus expect to encounter a small number of segments in which members' preferences and characteristics are similar within a segment but different between segments. This often provides more insightful information about group-based consumption characteristics based on typologies revealed through the probability of an individual being assigned to a particular class or segment. In a marketing context for example it is often helpful for sellers to understand the characteristics of different segments within their customer base so that products and services can be differentiated and designed according to the specific requirements of each segment (Gupta and Chintagunta, 1994). In a hydrometric context it would be useful to investigate whether group-based preferences exist for river gauging services in order to focus both investment and resources in a way that best meets the requirements of different classes of user. A formal derivation of the latent class specification is provided below as detailed by Holmes et. al., (2017).

Imagine that in the population there are S segments in total, each with different preference structures and that individual *k* belongs to segment s (s = 1 … S). The conditional indirect utility function can then be expressed as: $V_{ik|s} = v_{ik|s} + \varepsilon_{ik|s}$. For simplicity, we can write the deterministic part of utility as $v_{ik|s} = \beta Z_i$ where again Z_i s a vector of attributes that now includes the monetary attribute. The preference parameters, (β), vary by segment so that we can write the indirect utility function as: $V_{ik|s} = \beta_s Z_i + \varepsilon_{ik|s}$. The probability of choosing Alternative *i* depends on the segment to which one belongs and can be expressed as:

$$P_{ik|s} = \frac{\exp(\beta_s Z_i)}{\sum_{j=1}^{N} \exp(\beta_s Z_k)}$$

(4.16)

Where the β's are segment-specific utility parameters (note that scale is fixed at 1).

Now let there be a process describing the probability of being included in a particular segment as a function of demographic (and other) information. Following Boxall and Adamowicz (2002), Swait (1994), and Gupta and Chintagunta (1994), that process can be specified as a separate logit model to identify segment membership as:

$$P_{ik|s} = \frac{\exp(\delta_s X_i)}{\sum_{j=1}^{N} \exp(\beta_s Z_k)}$$

(4.17)

Where X is a set of individuals-specific characteristics such as gender, age, income and education that do not vary across alternatives. Delta is a vector of parameters.

Now let $P_{ik|s}$ represent the joint probability that individual *k* belongs to segment *s* and chooses Alternative *i*. This is also the product of the probabilities defined in the equations above: $P_{iks} = P_{ik}|s \times P_{ks}$. The probability that individual *k* chooses *i* then becomes the key component in the latent class approach:

$$P_{ik|s} = \sum_{s=1}^{S} P_{ik|s} P_{ks} = \sum_{s=1}^{S} \frac{\exp(\beta_s Z_i)}{\sum_{j=1}^{N} \exp(\beta_s Z_k)} \cdot \frac{\exp(\delta_s X_i)}{\sum_{j=1}^{N} \exp(\beta_s Z_k)}$$

(4.18)

The joint distribution of choice probability and segment membership probability is specified and estimated in this model. Note that this approach provides information on factors that affect or result in preference differences. That is, the parameters in the segment membership function indicate how the probability of being in a specific segment is affected by age, wealth, or other elements included in the segment membership function. Further details on this approach to heterogeneity can be found in Swait (1994), Boxall and Adamowicz (2002), or Shonkwiler and Shaw (1997).

Note that the ratio of probabilities of selecting any two alternatives would contain arguments that include the systematic utilities of other alternatives in the choice set. This is the result of the probabilistic nature of membership in the elements of S. The implication of this result is that independence of irrelevant alternatives need not be assumed (Shonkwiler and Shaw 1997).

One issue with latent class models is the choice of number of classes, S. The determination of the number of classes is not part of the maximization problem, and it is not possible to use conventional specification tests such as a likelihood ratio test. Some sort of information criteria are sometimes used (Scarpa and Thiene, 2005), as well as stability of the parameters in the segments as tools to assess the best number of classes to represent the data.

During the last decade a limited range of studies have developed methods that allow for the features of both mixed logit and latent class structures to be combined within the same model (Keane and Wasi, 2013). The lack of segmentation capability in the pure mixed logit specification means that group-based preferences are not identified, while in pure latent class models, the heterogeneity of preferences within groups are held fixed, which is also a restrictive assumption. Accordingly Bujosa, Riera and Hicks (2010) and Greene and Hensher (2013) developed what is known as the Mixed-Mixed Multinomial Logit (MM-MNL) or the

Latent Class Random Parameter (LC-RPAR) model which allows for parameters within each class to vary randomly. Consider the case where the heterogeneity distribution is generalized to a discrete mixture of multivariate normal distributions. In this case we have:

$$\beta_i \sim N(\beta_q, \Sigma_q)$$

With probability ω_{iq} for q = 1,…., Q.

(4.19)

Using a Gaussian mixture for the heterogeneity distribution is useful in that any continuous distribution can be approximated by a discrete mixture of normal distributions (Train 2008). Note that the MM-MNL with only one class is equivalent to the MIXL model. Also observe that as $\Sigma \rightarrow 0$ for all q, the above model becomes a LC-MNL model (Bujosa, Riera and Hicks, 2010; Keane and Wasi 2013). Thus, MM-MNL nests both MIXL and LC. The choice probabilities for the MM-MNL are given by:

$$\mathrm{P}_i(\theta) = \sum_{q}^{Q} \omega_{iq} \int \left\{ \prod_{t}^{T} \prod_{j}^{J} \left[\frac{\exp\left(X_{ijt}^{\intercal} \beta_i\right)}{\sum_{j=1}^{J} \exp\left(X_{ijt}^{\intercal} \beta_i\right)} \right]^{y_{ijt}} f_q(\beta_i) d\beta_i \right.$$

Where $f_q(\beta_i) d\beta_i = \left(\beta_q, \Sigma_q\right)$.

(4.20)

For further information on this model, including methods for programming in R, see Sarrias and Daziano (2017). An estimation of household hydrometric preferences using this technique is presented in Chapter 6 of the thesis.

4.6. Key Extension: Spatial Effects on the Value of Nonmarket Goods and Services

The role played by space, place and location in estimations of nonmarket value are of increasing interest to both economic geographers and spatial economists (Goodchild, 2000). Three key factors have driven research into the spatial undercurrents of social phenomena. The first is attributed to advances in spatial detection and mapping technologies, particularly Geographical Information Systems (GIS). Second and linked to this is the increasing availability of geocoded data, and third is the recognition that space provides an essential unifying basis for not just geography and economics but also for other social science disciplines. All human activity is situated and constructed in a particular time and place and both the characteristics and development of one place relative to another is a fundamental influence on socio-economic phenomena occurring there. From an economic perspective, the calculation of costs and benefits of a public good, service or policy intervention at the aggregate level of society is carried out by totalling individual-level costs and benefits (Bateman, et al., 2006). Nonmarket valuation, which seeks to measure benefits at the individual level, thus needs to be scaled-up across the wider population in order to reach society-wide estimates for the impacts of a given change in resources or policy. This first requires an understanding of the spatial extent of the population which is likely to be affected by the proposed change. Identifying the sphere of influence commanded by the good/service – or, in other words, the extent of the market for the public good – provides an answer to how broadly the marginal benefits (i.e. addition to total benefits arising from the proposed change) can be summed across a specific area. Second, the degree to which the resulting benefits will impact the population provides an insight into the relative strength of demand distributed across the area. Both elements have important implications for how and where public investment is targeted.

The precise effects of spatial factors on nonmarket value are challenging to determine. The first difficulty arises when considering whether benefits accruing to individuals should be limited to people living within the immediate environs of a public good or extended further across the region, country or internationally. Before the study is carried out, the optimal sample area is typically unknown. Distinguishing between use and non-use values further complicates the matter as political and economic jurisdictions are frequently mismatched. That is, all those who hold economic value for the good/service may not reside within the politically-defined boundaries of a selected area. However, Bateman et al. (2006) suggest that where a site generates use value then the majority of users are likely to be found near the site, while non-users are more likely to be spread out across a wider hinterland away from the site. Moreover, since users are more likely to attach higher value to the public good than non-users, a 'distance decay' effect on valuation is likely to obtain – i.e. values are likely to fall with increasing distance from a public good/service site. The resulting heterogeneity in individual value appraisals is important for reaching more representative estimates for mean WTP. Failure to account for distance decay may lead to erroneous statistical results if the mean value used to scale-up from the individual to group level is unreflective of diverse benefit estimates within a confined area. Since the tendency is to survey the population spatially concentrated around the good/service, value estimates are at risk of being overestimated in light of the higher value that is likely to be attached to the commodity within the vicinity's immediate confines. A second limitation is that those who hold the highest value for the commodity in question are more likely to respond to valuation surveys than those whose core value estimates are lower. Thus self-selection bias is likely to increase with distance from the good (Heckman, 1974). In these circumstances, underlying values are likely to reflect distance-decay however higher values are more likely to be forthcoming than lower values within the sampled cohort. As a result, a strategy for addressing these problems is needed when scaling-up from the individual to the population level.

Bateman et. al. (2005) compare different aggregation methods and assess the impacts of neglecting distance effects. Rather than simply adding up different sample means to test for distance-decay they apply a spatially sensitive value function which takes account of distance to the site and the socio-economic characteristics of the population in the calculation of values. In so doing the variability of values across the entire economic market area is better represented in the total WTP. They found that not accounting for distance in the aggregation procedure can lead to an overestimation of total benefits by up to 600 per cent.

The rate of distance decay is likely to vary across ecosystem services. Direct use values are generally expected to decline with distance to a public good but the rate of decay will vary across different commodities depending on how far the beneficiaries/consumers are willing to travel to access each specific service, the differentiated availability of substitute services or the spatial scale at which the nonmarket good or service is supplied to a given population. The market size or economic constituency (i.e. the user group) for a nonmarket commodity will therefore vary across alternative services. For example, consumers may be willing to travel a longer distance to visit natural areas of outstanding natural beauty (distance decay of value is low and people in a wide geographic area hold values for the landscape and other features of interest) than perhaps they would be to access clean water for swimming (distance decay is high due to the availability of substitute sites for swimming and only people within a short distance of the amenity hold values for maintaining water quality to allow swimming). Non-use values may also decline with distance between the nonmarket good and user although this relationship may be less related to distance than to cultural or political boundaries. The spatial discounting literature suggests that non-use values should have much lower spatial discount rates than use values (Brown et al 2002). In some cases, non-use values may not decline at all with distance – i.e. the rate of spatial discounting is said to be zero. This might be the case for instance with existence values for unique plant or animal species that are known worldwide (e.g. giraffes in the wild, Californian redwoods etc). Loomis (2000) investigates spatial discounting for preserving a range of threatened species and environmental goods in the US (e.g. spotted owls, salmon, wetland and 62 additional threatened or endangered species). The first finding is that WTP does indeed fall with distance however there are still benefits accruing for households located more than 1000 miles away from the habitat areas of these species. This suggests than limiting the scale of potential benefits to only immediately proximate locations to public good sites may in fact underestimate total value. Thus as one moves beyond politically defined boundaries WTP may decline without falling entirely to zero. The fact that WTP remains positive even at 1000 miles further suggests that generalising values obtained from the near environs of a nonmarket public good to wider population is at risk of overestimating value figures for WTP. Loomis (2000) proposes that there may be a 20% discount in values per household at 1000 miles and a 40%-50% discount at 2000 miles for high profile species or habitats.

Several other papers find evidence of spatial value decay in household WTP for environmental commodities. Hannon (1994) captures human preferences for nearness to objects they like and distances from objects they dislike. His results are acquired from public opinion surveys and indicate that the spatial decay function is one of exponential decline with respect to distance. In other papers, economists have used valuation methods to estimate relationships between WTP and distance of household to the asset being protected. Sutherland and Walsh (1985) use travel-cost analyses of WTP for recreational amenities. They conclude that not only does WTP fall with an increase in the distance, but, in contrast to Loomis (2000), it also reaches zero beyond a given geographic distance. Moreover, Pate and Loomis (1997) find that distance has a marked effect on WTP for environmental programs with higher values attached to local use against declining values for amenities with nationally recognized non-use value. Hanley, Schlapfer and Spurgeon (2003) propose that distance-decay relationships vary between different types of environmental goods (but also between the same category of goods) due the availability of substitute assets within relative proximity to the good/service being evaluated. For instance the level of demand (and associated WTP) for residential properties with an aesthetic waterfront view may be moderated by the proximity of similar properties which are located nearby in a unique parkland area. Although both areas provide environmentally desirable residential locations, the mere availability of choice for consumers within the confines of a spatially-defined zone will influence the overall WTP for any one set of properties because prospective homebuyers may consider access to a park to be an acceptable substitute for the recreational amenities afforded by the waterfront. By extension any proposed improvements to say, waterfront amenities, is likely to be of greater value to those living nearer the waterfront than to those living further away. As distance from the amenity increases, the WTP of residents declines according to some proportional function. This distance-decay function defines the extent of the market and is a useful economic parameter. Johnston, Swallow and Bauer (2002) similarly show that distance and substitutes have a major impact on the willingness to pay for water quality improvements in areas containing a large number of natural water bodies such as rivers and lakes. The role played by spatial characteristics – location, distance from service users and the proximity of substitutes – has only been reported in a handful of papers within the vast universe of non-market evaluation studies (Bateman, et al., 2006). Of these only twenty-five or so papers examine the effects of distance from the respondents' home to the asset under valuation (Schaafsma et al., 2013).

Studies beyond the valuation literature also suggest the incidence of spatial value decay. Albers, Ando and Chen (2008) find that in Massachusetts, private conservation agents seem largely to protect township resources to an extent that varies with income and education levels in the town, rather than making tradeoffs across different parts of the state based on ecological richness. Nelson, Adger and Brown (2007) and Kotchen and Powers (2006) document widespread support for local referendums that dedicate resources to environmental conservation initiatives in local areas. Ando and Shah (2010) advance at least three explanations for spatial value decay. First, close proximity increases access to use values. Put simply, people living near an environmental asset such as a nature reserve may visit it more frequently that those living further away or derive direct use values from its supporting amenities even if the frequency of visitation is low. Second spatial discounting may arise from a cognitive sense of place which is less localised and more widely defined, particularly for individuals with high geographic and occupational mobility (Hannon 1994). Third, spatial proximity increases the probability that a person will be aware about environmental assets being valued (Sutherland and Walsh 1985). Ando and Shah (2009) argue that since the latter two sources of this phenomenon are not related to physical access, there is distinct scope for education and outreach initiatives that may reduce the effects of spatial value decay in WTP for environmental amenities.

Spatial Autocorrelation

In addition to distance decay and self-selection bias, a third type of spatial effect relevant to this study concerns spatial autocorrelation. Two types of spatial autocorrelation may be important. First, there may be a clustering of sample respondents given the uneven distribution of population across a given territory. In Scotland for example most people are located in the dense ‘central belt’ corridor and it is likely that the sample would reflect this distribution. This clustering may lead to biased estimates of hydrometric value if sufficient areas outside the central belt are not effectively polled. A second source of spatial autocorrelation might arise through the endogenous effects of location on distance-decay parameters relative to say distance from the river. In order to estimate the effect of such distance on user valuations, a researcher might typically ask the question of how close a respondent lives to the river (serving as an imperfect proxy based on cognitive estimation) or to calculate the straight-line distance (‘as the crow flies’)between a respondent’s home and the nearest river. These variables may then be used to analyse the impact of either cognitive or Euclidean distance measures on data valuation figures. However, Scotland is a water-rich environment with a very high density of rivers across its territory and, in effect, most people are likely to live close to a river or stream, or more than one river or stream at the same time. In these circumstances it is possible that neither cognitive nor GIS-based proxies are capable of offering sufficiently precise model inputs for estimating distance-decay or to correct for potential autocorrelation bias. Several statistical measures may be calculated in order to account for the size of the potential bias arising from spatial autocorrelation. These include Moran’s I number, Geary’s C or Local Indicators of Spatial Association (LISAs). While they do not permit a retrospective correction of the obtained sample valuations, they are useful estimators that quantify the problem and thereby assist our interpretations of core model outputs.

Conclusion:

This chapter described the economic models to be used for estimating user preferences elicited from the household and professional users’ questionnaires. A list of attributes and their associated levels were provided along with a description of the construction of choice sets to be included in each experiment. Key extensions to the research were also discussed. Results of the household survey will be presented in the next chapter.

Chapter 5

Household Preferences for Hydrometric Data:

Conditional and Mixed Logit Models

5.1. Introduction

The household survey was in the field from 06 December 2016 to 16 January 2017. It was designed and hosted electronically using the commercial, online software, Survey Monkey. Survey Monkey makes it possible to embed images and video objects alongside text and also to host surveys on the World Wide Web by automatically publishing survey contents to a web-enabled interface. Study participants receive a URL (uniform resource locator) link which, upon clicking, opens up a new screen window displaying the survey. The first page of the questionnaire provided a brief introduction to the topic followed by a consent statement which participants were invited to read, and to then indicate whether or not they wished to proceed voluntarily with the survey. The questionnaire was designed with four key objectives in mind:

[1]. to inform participants about the technical background to river hydrometry in Scotland and present some of the main issues pertaining to costs, benefits and uses of hydrometric data.

[2]. to mentally prepare participants for the valuation task by aiding recall of relevant experiences, events and opinions.

[3]. to elicit participants' attitudes towards the environment and environmental issues.

[4]. to elicit participant preferences for future hydrometric data provision in Scotland.

5.2. Questions were formulated in order to elicit participant information across seven key domains. These included the demographic features of households; their socio-economic characteristics; experiences; location; attitudes and beliefs; awareness of the uses of hydrometric data, and; data consumption characteristics.

5.2. Sampling

A company with a panel of household contacts was contracted to disseminate the questionnaires. Pure Profile (UK) Ltd specialises in market research and maintains a register of willing users who agree to take part in surveys in return for a small fee per completed questionnaire. The survey was circulated to panel members above the age of 18 years across all areas of Scotland. The aim was to collect responses from a wide variation of household residents in terms of income level, age, education, gender and location. Prior to undertaking the survey Pure Profile advised that in terms of representativeness many online panels tend to have a population which is slightly skewed towards females, and the 18-24 age group is harder to engage, so numbers could be limited for this group. Overall, they offered a good spread of age, gender, regional location, education and income within the sampling population that was well-matched to national representation (see Table 5.1). The survey was divided in to a total of six versions where each version was identical except for the choice sets which were grouped by version according to a statistical blocking strategy determined when generating the choice sets using Ngene software version 1.1.2. Choice sets were generated to an efficient design programmed to minimise the D-error and S-error per block; see section 4.16 for more information on the construction of the choice sets.

5.3. Results

Demographic Characteristics

Responses were received from a total of 453 study participants in Scotland of which 434 were complete and usuable. Responses where choice set valuations were missing or incomplete were removed. In order to evaluate the representativeness of this cohort the Scottish Household Survey 2016/17 was used in order to benchmark the characteristics of the obtained sample with a weighted national survey comprising approximately 10,500 households (SHS 2016). Given the differences in category bands and terminology used between the hydrometric choice and SHS surveys the most closely reflective categories were compared and are reported in Table 5.1. The female-to-male ratio was 50:50 with an almost equal representation of both sexes in the choice and Scottish Household surveys. In terms of the age distribution young people aged between 16-24 years were under-represented in the choice survey (12%) relative to the national average (24%). Middle aged to senior groups aged 35 years and above were similarly over-represented in the choice experiment sample (88%) compared with the national household average (58%) . Most sampled householders were well-educated with at least 50% reporting qualifications to the level of a first degree and above. This was very close to the national average of 51%. About one-fifth (21%) of study participants had received an A-level (or equivalent) high school education compared with 17% nationally. Only 3% of the study cohort lacked any formal qualifications while nationally this figure was 17%.

Table 5.1.: Socio-Economic and Demographic Characteristics of Households

Hydrometric Choice Household Survey		Scottish Household Survey 2016-17	
Gender	Per cent	Per cent	
Male	50	49	Male
Female	50	51	Female
Age (Years)			
18-24	2	11	16-24
25-34	10	13	25-34
35-49	33	12	35-44
50-64	36	21	45-59
65-84	19	17	60-74
85-100	0	8	75+
Education (Qualifications)			
Level 4: Degree/Diploma	50	51	Degree/Prof. Qual.+ HNC/HND
Level 3: A-Levels/NVQ	21	17	Higher, A-Level.
Level 2+1 (O-Levels/GCSE)	20	20	'O' Grade, Std. Grade
No Formal Qualifications	3	17	No Qualifications
Other Qualifications	7	4	Other Qualification
Working Status			
Business Owner/Self-Employed	8	6	Self-Employed
In Work	55	47	Employed (FT+PT)
Home Duties	5	5	Looking after the home of family
Student	2	8	Education/Training
Retired	24	25	Permanently retired from work
Unemployed: Seeking Work	2	3	Unemployed and seeking work
Unemployed: Not Seeking Work	4	4	Permanently sick or disabled
Number of People in Household			
One	14	34	One
Two	48	36	Two
Three	18	15	Three
Four and More	19	5	Four and More
Household Income (£)			
0 – 7,999	4	3	0 – 6000
8,000 – 15,999	10	9	6,001 – 10,000
16,000 – 23,999	12	17	10,001 – 15,000
24,000 – 29,999	17	15	15,001 – 20,000
30,000 – 49,999	32	13	20,001 – 25,000
50,000 – 69,999	15	10	25,001 – 30,000
70,000 – 99,999	7	14	30,001 – 40,000
100,000 and above	3	20	40,001 and above
Property/Dwelling Type			
House (Terraced+Detached+Semi-Detached+Bungalow)	67	64	A House or Bungalow
Flat/Apartment (Converted, Purpose-Built, High Rise or Low Rise)	33	35	A Flat, Maisonette or Apartment

These statistics indicate that choice sample members were relatively older and better educated than the national average. In terms of household size, the choice sample attracted a higher proportion of respondents living in larger households (2, 3 and 4-member homes) than the national average, while single-person households which account for over a third of Scottish residents were under-represented (14% of sample).

Socio-Economic Characteristics

All respondents were invited to select an annual household income band (before tax) in order to gain an insight into the balance and distribution of monetary resources across the sample population. Households earning over £30,000 constituted the largest single income class, accounting for 57% of the study cohort. The corresponding figure at the national level was 34%. Similarly, whereas 14% of the study sample could be classified in the lowest income categories earning between £0-16,000, about a third of Scots were in this bracket nationally. Most respondents across both surveys were in paid employment (55% in the study vs. 47% in the SHS). Retired, Unemployed, Home Duties and Self-Employed individuals were well-represented in the study cohort while students and those in education or training were under-represented (2% surveyed compared to 8% nationally). A house rather than a flat or apartment was predominant type of dwelling across both surveys where the relative shares of either property type were almost equally matched.

Experiences

Personal experiences are a critical component of perceived value. In the case of hydrometric data it was expected that general public awareness of river gauging activity was low with little or no personal practice of reading and processing river level or discharge data. As a result there was a risk that societal evaluations of hydrometric data value would remain understated if some of the applications of environmental observations were left unexplored by the sample population. Given circumstances characterised by a high degree of imperfect information arising from unfamiliarity with the role of hydrometric infrastructure, a potential source of systematic bias was identified in undertaking the valuation. Consequently it was considered necessary to inform participants about the basic procedures of collecting hydrometric data along with the costs and uses of hydrological information. However, by way of a precursor to introducing the relevant facts and issues affecting river hydrometry, participants were polled on their experiences of weather events, general levels of participation in outdoor activities and their existing level of engagement with hydrometric information that is provided publicly on the SEPA water-level webpages. This line of questioning aimed primarily to establish a baseline typology of the study cohort's level of environmental cognition and, second, to aid recall of relevant experiences which might help to place river gauging activity within a household-specific context.

Responses to questions on extreme weather events indicated that at least 76% of all participants had experienced intense rainfall in Scotland, and almost a third (29%) had experienced some form of river flooding during the last five years. Of these, 26 households (6% of the overall cohort) had directly experienced flooding in their current dwelling. A river/stream overflowing its banks was identified as the leading cause of flooding. The modal expenditure on cleaning up the damage resulting from floods and restoring flooded property to a re-liveable state was between £1,000-4,999. Over half the flooded residents (54%) reported an increase in the insurance premium they subsequently had to pay in order to secure their properties and 19% (5 households) were part of a government-supported scheme aimed at assisting Scottish residents to obtain flood insurance. In addition, at least 76% of all respondents (330 households) knew close friends, relatives, neighbours, other local residents who had also experienced a flooding of their home, workplace or other extreme weather events in the last 5 years.

Participation in some form of group or outdoor activity might provide residents with a higher degree of appreciation for the natural environment and, possibly, with a greater understanding of the need to measure and manage natural processes than those who do not engage in such activities. Similarly, residents living close to a river or loch might be more cognitively attuned to local issues arising from river level variability regardless of whether this had overtly negative or positive impacts on the local community. Focus group discussions and interviews for instance had revealed that anglers and paddlers regularly consulted river level updates in order to evaluate conditions for kayaking or fishing before undertaking trips to the sites designated for these activities. Accordingly, households were first asked about their engagement with external group activities in general; second, about their residential proximity to water bodies, and; third, about their direct frequency of visitation/use of these water bodies. Results demonstrated that almost a quarter (24%) of respondents participated in some form of outdoor or group activity with walking and canoeing being the most popular pursuits. In addition, over a third (38%) of all households visited the river either highly or somewhat frequently. Visitation of water sites was more variable ranging from about a third of all households frequently visiting rivers and the seaside to only 7% of residents visiting a nearby reservoir or dam. In general however the majority of the 434 surveyed households were neither active participants of outdoors activities nor regular utilisers of local water bodies in Scotland.

Table 5.2: Past Experiences of Flooding

Have you ever experienced flooding in your current dwelling?		How did the flooding incident(s) affect the insurance premium you subsequently had to pay for your property?			Are you part of any Government-supported scheme to assist Scottish residents to secure flood insurance?	
Yes	No	No change	Premium increased	Premium decreased	Yes	No
26	408	11	14	1	5	21
6%	94%	42%	54%	4%	19%	81%

If your dwelling has been flooded in the past what was the main source of flooding?					
River or stream overflowed	Loch overflowed	High tide or waves	Drains overflowed	Rainwater ingress	Other Cause
14	2	5	8	7	3
54%	8%	19%	31%	27%	12%

What was the approximate total cost in Pounds (£) of cleaning up the damage resulting from floods and restoring your property during the last 5 years?							
£ 0 - 99	£ 100 - 249	£ 250 - 499	£ 500 - 999	£ 1,000 - 4,999	£ 5,000 - 9,999	Over £10,000	Other Amount
4	2	0	4	6	2	4	4
15%	8%	0%	15%	23%	8%	15%	15%

Have you directly experienced any of the following weather events in Scotland during the last 5 years?							
Intense Rainfall	Snowstorms	High Winds	River Flooding	Loch Flooding	Sea Flooding	Unusually Hot and Dry Weather	Not experienced these events/Other
331	199	362	127	34	23	92	52
76%	46%	83%	29%	8%	5%	21%	12%

To the best of your knowledge, which of the following people experienced extreme weather events or measures in the last 5 years?	Close Friends	Relatives	Neighbours	Other Residents in Village/Town/City	Someone Else I Know
Flooding of Home	45 (14%)	30 (9%)	29 (9%)	87 (26%)	68 (21%)
Flooding of Workplace	29 (9%)	17 (5%)	13 (4%)	49 (15%)	33 (10%)
Hose Pipe Ban	20 (6%)	29 (9%)	10 (3%)	16 (5%)	23 (7%)
Disruption to daily water supply at home	45 (14%)	45 (14%)	40 (12%)	55 (17%)	39 (12%)
Disruption to daily water supply at work	16 (5%)	10 (3%)	5 (2%)	15 (5%)	22 (7%)
Other extreme event	71 (22%)	67 (20%)	60 (18%)	68 (21%)	21 (6%)

Table 5.3: Participation in Group Activities and Visitation of Water Sites

Do you participate in any of the following activity or interest groups?										
Flood Action Group	Learned Society	Angling Club	Boating/Canoeing/Rafting Club	Outdoor Swimming Club	Local Environmental Stewardship Group	Walking Club	Bird Watching Club	Other Activity or Interest Group(s):	Don't participate	Total
10 (2%)	4 (1%)	12 (3%)	33 (8%)	9 (2%)	12 (3%)	35 (8%)	9 (2%)	26 (6%)	331 (76%)	434(100%)

Other Activities: Sailing, Skiing, Wetland Bird surveying, Cycling, Pictures and Video, Climbing, Park Running, Golfing, Arts and Crafts, Outdoor Sports and Fitness.

Other Interest Groups: Local Development Charity, Duke of Edinburgh Award scheme, Community Association, Area Forum, Mountain Rescue, River Don Trust, Water Safety Scotland policy group, Lawn Bowling Club, Community Development Trust, Horse Riding Club, BDMLR WDC Shorewatch, Jackton and Thorntonhall Community Council, Allotment Society, Tennis Club.

How frequently do you visit or utilise these water bodies?							
	River	Stream	Canal	Reservoir/Dam	Lake/Loch	Sea	Other Water Body
Very Frequently	64 (15%)	32 (8%)	13 (3%)	3 (1%)	8 (2%)	30 (7%)	3 (1%)
Somewhat Frequently	98 (23%)	51 (13%)	40 (10%)	23 (6%)	65 (17%)	95 (24%)	8 (3%)
Somewhat Infrequently	50 (12%)	38 (10%)	29 (8%)	32 (9%)	72 (19%)	85 (21%)	7 (3%)
Very Infrequently	73 (17%)	59 (15%)	56 (15%)	67 (18%)	58 (15%)	67 (17%)	18 (7%)
Never	139 (33%)	212 (54%)	243 (64%)	249 (67%)	182 (47%)	127 (31%)	207 (85%)
Total	424 (100%)	392 (100%)	381 (100%)	374 (100%)	385 (100%)	404 (100%)	243 (100%)

Attitudes and Beliefs

The effects of deeply held beliefs and attitudes on perceived value have been recognised as important psychological determinants of individual choice (Meyerhoff, 2002; Moisseinen, 1999; Fishbein and Ajsen, 1975). Hoyos et al (2015) note that, in an environmental context, economists are increasingly interested in the cognitive organisation of beliefs and attitudes which act as either motivators or barriers to pro-environmental decisions. In a choice-based valuation exercise respondents differ in terms of their socio-economic characteristics, prior levels of information, their attitudes towards the environment in general and specifically in terms of their perception of the environmental issue under consideration (Dietz, et al., 2005). According to Bateman et al (2005) the willingness-to-pay (WTP) for an environmental good or service can also be interpreted as behavioural intention and the analytical task is then to assess the extent to which attitudes are good predictors of WTP.

In order to test the effects of underlying household attitudes on the perceived value of hydrometric data, a validated psychometric instrument, the BSEAI (Beliefs in Support of Environmental Action and Inaction) scale, was included in the survey to provide additional insight into societal preferences for the public provision of hydrometric information following Hoyos et al (2015). The table below shows the response distributions on a 5-point Likert scale. For each statement, values closer to one indicate strong agreement while values closer to five imply strong disagreement. The results demonstrated that respondents were generally aware of the increasing environmental degradation of the planet and were worried about the quality of environment bequeathed to future generations. For example, 80% of households agreed with Item 1 of the scale ("environmental protection will provide a better world for me and my children") while 69% disagreed with Item 6 (we do not need to worry much about the environment because future generations will be better able to deal with these problems than us).

Household beliefs were also assessed on the basis of a second dimension. This included an exercise to evaluate the overall importance attached by households to: (i) environmental policy in general, relative to other areas of public policy such as transport, housing, education and welfare; (ii) river management in particular, relative to other areas of environmental management such as agriculture, air quality, forestry and lochs. Respondents were asked to allocate a rank from 1 – 10 against each policy area in order to indicate their most-to-least preferred level of priority for each area respectively. Results showed that the majority of households (31%) rated welfare and unemployment as the most important policy area, followed by education and training (21%) and the natural environment (15%). In terms of priorities for environmental management, the majority of households believed that the top three candidates were wildlife/biodiversity, air quality and agriculture. River and coastal management were both equally important at fourth place on this scale. These outcomes demonstrated that both environmental policy in general and river management in particular were fairly important, ‘top 5’ priorities for national development.

Beliefs Supporting Environmental Action and Inaction (BSEAI) Scale Assessment	Strongly Agree	Somewhat Agree	Neither Disagree nor Agree	Somewhat Disagree	Strongly Disagree	Total
Environmental protection will provide a better world for me and future generations.	38%	42%	17%	1%	1%	100%
Environmental protection is beneficial to my health.	29%	42%	27%	2%	1%	100%
Claims that current levels of pollution are changing the Earth's climate are exaggerated.	5%	16%	24%	27%	28%	100%
Environmental protection benefits everyone.	40%	38%	17%	4%	1%	100%
Environmental protection will help people to have a better quality of life.	34%	42%	20%	3%	1%	100%
Tropical rainforests are essential to maintain a healthy planet Earth.	56%	27%	14%	1%	1%	100%
The effects of pollution on public health are worse than we realise.	22%	34%	37%	4%	2%	100%
Pollution generated here harms people all over the Earth.	27%	38%	29%	4%	1%	100%
Over the next several decades thousands of species will become extinct.	26%	40%	29%	4%	1%	100%
Modern development threatens wildlife.	38%	41%	18%	2%	1%	100%
Protecting the environment will threaten jobs for people like me.	4%	9%	33%	28%	27%	100%
Laws to protect the environment limit my choice and personal freedoms.	4%	12%	34%	30%	20%	100%
We don't need to worry much about the environment because future generations will be better able to deal with these problems than we are.	2%	7%	22%	29%	40%	100%
While some local plants and animals may have been harmed by environmental degradation, over the whole Earth there has been little effect.	3%	9%	24%	30%	34%	100%
A clean environment provides me with better opportunities for recreation.	33%	40%	23%	2%	2%	100%

Notes: Number of respondents = 434.

Table 5.4.: Beliefs Supporting Environmental and Inaction (BSEAI).

Table 5.5: Importance of the natural environment relative to other areas of public policy

Ranking	Welfare and Unemployment	Arts Culture and Tourism	Enterprise and International Trade	Transport	Banking and Finance	Housing and Regeneration	Information, Communication and Digital Technology	Education and Training	Aid and Assistance to Developing Nations	Natural Environment	Total
Most Important	31%	5%	4%	6%	5%	10%	3%	21%	2%	15%	100%
Second	16%	7%	7%	12%	6%	17%	4%	17%	3%	10%	100%
Third	14%	4%	9%	12%	7%	15%	7%	17%	3%	11%	100%
Fourth	10%	7%	9%	18%	6%	15%	10%	9%	4%	13%	100%
Fifth	7%	9%	11%	14%	12%	9%	11%	10%	4%	12%	100%
Sixth	5%	11%	14%	13%	11%	12%	13%	7%	5%	8%	100%
Seventh	5%	14%	14%	10%	13%	8%	16%	6%	6%	9%	100%
Eighth	5%	14%	15%	7%	12%	7%	18%	10%	7%	6%	100%
Ninth	4%	16%	13%	6%	14%	5%	13%	4%	17%	8%	100%
Tenth	3%	13%	4%	2%	13%	1%	6%	1%	48%	8%	100%

Notes: Number of respondents = 434.

Table 5.6: Importance of river management relative to other areas of environment policy

	Wildlife and Biodiversity	Forestry	Coastal Management	Agriculture	Air Quality	Wastewater	Lochs	Invasive Species Control	Fisheries	River Management	Total
Most Important	31%	5%	6%	8%	28%	5%	3%	3%	4%	6%	100%
Second	15%	15%	11%	11%	13%	11%	5%	4%	6%	9%	100%
Third	11%	16%	13%	12%	11%	8%	8%	7%	6%	9%	100%
Fourth	10%	15%	11%	14%	10%	10%	7%	8%	6%	8%	100%
Fifth	7%	11%	10%	12%	11%	12%	9%	9%	10%	9%	100%
Sixth	5%	10%	14%	10%	7%	15%	10%	6%	10%	12%	100%
Seventh	7%	9%	9%	9%	6%	10%	18%	10%	9%	13%	100%
Eighth	4%	9%	10%	8%	6%	10%	12%	17%	13%	11%	100%
Ninth	6%	7%	7%	9%	4%	10%	15%	15%	18%	9%	100%
Tenth	4%	4%	9%	8%	4%	7%	13%	21%	17%	13%	100%

Notes: Number of respondents = 434.

Awareness

The capacity of choice-based valuations to reflect accurate societal preferences for public goods and services depends on a high degree of individual awareness of the features, uses, issues and alternatives associated with both providing and consuming a good/service. However, in practice, standards of familiarity are likely to vary along a spectrum of cognitive insight ranging from no knowledge at all to a detailed and studied understanding of the relevant characteristics of an asset being valued. Intermediate stages of awareness are also possible, for example based on analogous experiences of consuming similar goods/services. Even where direct parallels of consumption are not available to inform the perceptions of valuators, more indirect items of experience and knowledge may be called upon to form a basic understanding and independent opinion of a good's intrinsic worth. In the context of this study, this concept was termed 'cognitive distance'; that is, the extent to which one's imagination was required to 'travel' in order to form an opinion of the value of hydrometric data and to then make an independent decision on an ideally-preferred data profile by way of a valuation exercise.

A 4-point likert scale was used to elicit the cognitive distance of households from a state of perfect (or near-perfect) information on the uses and applications of hydrometric data. On this scale 'fully aware' meant that individual respondents could easily grasp the various competing uses for hydrometric data based on directly related, personal experience; for example, due to professional work or training undertaken in the area. 'Moderately aware' meant that respondents had a little more cognitive distance to travel in order to appreciate the uses of hydrometric data but analogous experiences from the past made this relatively easy; for example, due to involvement in corresponding projects and activities which reflected a similar structure to a given hydrometric data application. 'Unaware but could deduce based on past experience' implied further perceptive and experiential remoteness suggesting a fairly high degree of cognitive burden/distance travelled by the respondent yet an understanding of the applications of hydrometric data could be acquired at a broad, mainly conceptual level. Finally, the category 'completely unaware' suggested total ignorance of hydrometric concepts and uses, the perception of which would require a very high exertion of the imagination on the respondent's part.

Five headline uses of hydrometric data were listed in the survey. Each heading was subdivided into specific applications against which respondents were invited to select corresponding levels of awareness best approximating their state of knowledge on the issue. The main headings included monitoring and impact assessment; design, planning and management; teaching and research; legislation, reporting and reporting, and; extreme events. Participants were also asked if they were aware of any additional uses for hydrometric data. Results showed a consistent divide between 'aware' participants (30-40%) and those 'unaware' (60-70%) across all uses. As discussed in section 5.5., this line of questioning aimed not only to elicit current levels of awareness, but also to increase it prior to participant responses in the choice-based section of the survey. In so doing the intention was allow respondents to approach the valuation tasks from a more informed perspective of the several diverse requirements currently associated with hydrometric data deployment.

Table 5.7: Levels of Awareness of Hydrometric Data Applications

	Level of Awareness based on Past Experience				
Monitoring and Impact Assessment	Fully aware	Moderately aware	Unaware but could deduce	Completely unaware	Total
Monitor and control water abstraction from rivers by major users such as water supply companies, hydropower schemes, farms (for irrigation), industries and whisky distilleries.	26 (6%)	128 (29%)	129 (30%)	151 (35%)	434 (100%)
Assess the impact of proposed property and infrastructure development on river flows	33 (8%)	111 (26%)	147 (34%)	142 (33%)	433 (100%)
Determine the dilution and dispersion capacity of rivers for sewage, industrial and agricultural effluent releases that affect water quality.	25 (6%)	100 (23%)	148 (34%)	161 (37%)	434 (100%)
Inform the development of flood risk management strategies including natural flood management.	52 (12%)	136 (32%)	119 (28%)	122 (28%)	429 (100%)
Alert beach, loch and river users to risk of poor bathing water quality from diffuse pollution and storm overflows.	57 (13%)	129 (30%)	118 (27%)	127 (29%)	431 (100%)
Track the impacts of river flow on erosion of channel and its effects on sediment accretion, quality and range of biodiversity.	25 (6%)	117 (27%)	136 (32%)	152 (35%)	430 (100%)

	Level of Awareness based on Past Experience				
Extreme Event Forecasting	Fully aware	Moderately aware	Unaware but could deduce	Completely unaware	Total
Develop Drought Indices for rivers at risk of running low or dry during periods of high temperature or low rainfall.	23 (5%)	105 (24%)	152 (35%)	153 (35%)	433 (100%)
Generate timely warnings of river level rise especially when this is known to flood near key residential, transport or other critical infrastructure such as homes, roads, railway tracks, bridges, energy installations, or for evacuation of residents.	73 (17%)	121 (28%)	121 (28%)	117 (27%)	432 (100%)

Teaching and Research	Level of Awareness based on Past Experience				
	Fully aware	Moderately aware	Unaware but could deduce	Completely unaware	Total
Teach college and university courses in river hydrology, engineering, meteorology, geography and data science.	28 (6%)	103 (24%)	167 (39%)	133 (31%)	431 (100%)
Undertake research by academics and scientists.	42 (10%)	113 (26%)	154 (35%)	125 (29%)	434 (100%)
Understand how river behaviour has been changing over the last decade(s) to inform all above functions and predicting like future course and issues.	35 (8%)	128 (30%)	144 (33%)	126 (29%)	433 (100%)
Evaluate the predictions made by mathematical models to see if they reflect processes accurately against real-world river gauge data.	25 (6%)	89 (21%)	160 (37%)	155 (36%)	429 (100%)

Design, Planning and Management	Level of Awareness based on Past Experience				
	Fully aware	Moderately aware	Unaware but could deduce	Completely unaware	Total
Determine the timings and frequency of reservoir releases to increase water flows for kayaking, angling and fish passage.	29 (7%)	83 (19%)	140 (32%)	181 (42%)	433 (100%)
Design infrastructure like bridges, roads, property, reservoirs and drainage systems.	32 (7%)	126 (29%)	135 (31%)	141 (32%)	434 (100%)
Design landscapes and urban areas.	23 (5%)	112 (26%)	136 (32%)	158 (37%)	429 (100%)
Plan and manage the policies and processes affecting a River Basin as a whole	26 (6%)	99 (23%)	149 (35%)	154 (36%)	428 (100%)
Contribute to planning applications received by Local Authorities.	29 (7%)	118 (27%)	128 (30%)	158 (36%)	433 (100%)
Determine the suitability of rivers for water sports events, e.g. during Commonwealth Games in Glasgow - and by boating/rafting/canoeing and canoeing clubs.	33 (8%)	97 (22%)	138 (32%)	164 (38%)	432 (100%)
Check local conditions for safe passage by scientists, wishing to collect samples from a river.	19 (4%)	95 (22%)	126 (29%)	190 (44%)	430 (100%)
Develop and deploy flood risk management strategies.	49 (11%)	137 (32%)	119 (28%)	122 (29%)	427 (100%)

Legislation, Regulation and Reporting	Level of Awareness based on Past Experience				
	Fully aware	Moderately aware	Unaware but could deduce	Completely unaware	Total
Produce water situation reports for emergency responders (Councils, Police, Flood Action Groups), planners, and politicians.	37 (9%)	129 (30%)	129 (30%)	139 (32%)	434 (100%)
Compile evidence for legal cases and disputes over environmental impacts	18 (4%)	106 (25%)	147 (34%)	160 (37%)	431 (100%)
Meet the requirements of environmental legislation, regulation and enforcement as laid out in Scottish, UK and European Law.	32 (7%)	127 (29%)	134 (31%)	141 (32%)	434 (100%)
Provide scientific evidence for river restoration and other environmental schemes when bidding government and other institutional funding.	33 (8%)	107 (25%)	143 (33%)	146 (34%)	429 (100%)

Are you aware of any other uses for hydrometric data?
Recreational use of rivers.
My wife, friends and I use SEPA data prior to river canoeing.
Other kayakers.
SCA river levels on web site for kayaking.
Checking river levels prior to kayaking.
Water (gorge walking) and paddle sports users both commercial and recreational.
To help aid paddle sports user judge water levels.
Kayakers use level data to plan kayaking trips.
The recreational use by the commercial outdoor sector is underplayed in the previous sections. Remember extreme events are sought after for the challenge.
Protect environment and rivers.
Power-generation.
Sustainability of threatened species in areas of SSI (Special Scientific Interest).
For the production of electricity.
One possible use would be to force Network Rail to maintain their river bridges to a higher standard e.g. Lamington Viaduct.
Ecological monitoring.
Indication of good fishing conditions particularly for salmon.
Predict suitability of conditions for angling.
Charting how changes in demand have been met and how.
Tides and Fishing trawlers.
Political statistic manipulation.
Fish stocking times.

Data Consumption Characteristics

Household utilisation patterns of hydrometric data were the final sets of information sought via the survey. Participants were first asked if they obtained any hydrometric data, whether from SEPA or another source. Responses revealed that 87% of households did not obtain any data while 11% acquired both river level (10% equivalent to 43 households) and discharge (1% or 6 households) data from SEPA. Additionally around 58 households (14%) frequently visited the SEPA website in order to view online river level updates. A small number of households obtained data from other sources such as water level gauges operated by local councils or secondary data providers (likely to be based on SEPA gauges). Key reasons cited for obtaining the data were to assess conditions for paddling/canoeing (35%); assessing flood risk conditions (25%); and general or personal interest (17%). Around 11 respondents also indicated that they further processed the data after obtaining it. Purposes for this included building up a wider picture of weather-related or catchment-wide processes by combining with other types of information (e.g. rainfall and wind); evaluating river level trends over time, and; communicating river level information to a community flood action group via social media.

Flood alerts and warnings provided to both households and businesses in Scotland depend on timely, accurate updates from river gauging stations. A flood alert is defined as notice of a potential risk of flooding in an area, say in expectation of high levels of rainfall; a warning is issued when a flood is imminent or currently underway. Out of the 434 households which responded to the survey, 37 (9%) had signed up to receive such warnings from an official government agency or other organisation. These included SEPA (17 households, around 4%), local councils (3 households), the Meteorological Office (2 households). The remaining 397 (91%) households had not registered to receive flood alerts and warnings.

Having considered both personal and external uses of hydrometric data, respondents were presented with competing aspects of environmental data collection and asked to rank them in order of importance. The aspects included (i) improving the accuracy of environmental observations; (ii) providing full explanatory notes about the environmental data to help other people use the data effectively; (iii) increasing the frequency with which environmental data is updated with new readings; (iv) minimising the costs of collecting, cleansing, maintaining and providing data to other users; (v) increasing the number of locations at which data is collected to get the most realistic information about an area, and; (vi) collecting more types of data about the object of interest. Rankings were again listed as a Likert scale where 1 = most important and 6 = least important. Responses demonstrated that the most important aspects of environmental data from households' perspective were the accuracy of observations; the number of locations at which data was gathered, and; the costs of data processing and supply. Increasing the frequency with which data was updated was the second and third most essential factor for the majority of households.

Table 5.8: Distribution of users vs. non-users of hydrometric data

Do you obtain hydrometric data from SEPA?				
River Level Data	River Discharge (Flow) Data	No but I do obtain data from other sources	Don't obtain any data	Total
43	6	7	384	440
10%	1%	2%	87%	100%

Other Sources of Data: Scottish Canoe Association *Where's the Water* website (4), Angus Council Gauge Wishop on Edzell Burn (1), Tide tables and various weather forecasts (1), Fishpal(1).

Do you visit the SEPA website to view data from gauging stations?					
Very frequently (daily to several times a week)	Somewhat frequently (a few times a year)	Moderately frequently (fortnightly-to-monthly)	Infrequently (only on occasion)	No - I do not visit the SEPA website for this purpose	Total
25	16	17	30	346	434
6%	4%	4%	7%	80%	100%

What is your main purpose(s) for obtaining the gauging station data readings?						
General or Personal Interest	Assessing Conditions for Flood Risk	Assessing Conditions for Fishing/Angling	Assessing Water Quality	Assessing Conditions for Paddling or Canoeing	Other Predictive Purposes	Total
10	15	6	3	21	5	60
17%	25%	10%	5%	35%	8%	100%

Have you signed up to receive any flood warnings from an official government agency or other organisation?	
Yes	No
37 (9%)	397 (91%)

Data received from: SEPA (17), Meteorological Office (2), Neighbourhood Alert (1), Scottish Borders Council (1), Moray Council (1), Police Scotland (1), Floodwatch, Aberdeenshire (1), Unspecified (15).

Table 5.9: Ranking of important attributes prior to Choice Experiment

Thinking about measurements of the environment in general, which of the following aspects of data collection should be the most important? Please rank each feature in order of its importance to you (where 1=most important, 6=least important).

Ranking	Improving the accuracy of environmental observations	Providing full explanatory notes about the environmental data to help other people to use the data effectively	Increasing the frequency with which environmental data is updated with new readings	Minimising costs of collecting, cleansing, maintaining and providing data to other users	Increasing the number of locations at which data is collected to get the most realistic information about an area	Collecting more types of data about the object of interest
Most Important	183 (42%)	41 (9%)	34 (8%)	46 (11%)	101 (23%)	29 (7%)
Second	83 (19%)	70 (16%)	81 (19%)	53 (12%)	78 (18%)	69 (16%)
Third	64 (15%)	81 (19%)	111 (26%)	60 (14%)	66 (15%)	52 (12%)
Fourth	59 (14%)	70 (16%)	84 (19%)	88 (20%)	72 (17%)	61 (14%)
Fifth	23 (5%)	83 (19%)	72 (17%)	77 (18%)	82 (19%)	97 (22%)
Least Important	22 (5%)	89 (21%)	52 (12%)	110 (25%)	35 (8%)	126 (29%)
Total	**434 (100%)**	**434 (100%)**	**434 (100%)**	**434 (100%)**	**434 (100%)**	**434 (100%)**

5.4. Estimation of Value from Household Choices

In this section, household choice data is analysed using multinomial or conditional logit (abbreviated to MNL or CL) and mixed logit (MIXL) models in order to derive, compare and contrast the parameters characterising household choice. A theoretical overview of this was provided in Chapter 4. Results from model estimations are presented in order to account, first, for the effects of the main hydrometric attributes on consumer choice and, second, for the impacts of individual-specific characteristics such as age, income, gender and education on hydrometric preferences. Additionally the influence of personal beliefs, attitudes and prior levels of awareness are estimated as cognitive factors underlying household decisions on the size and shape of future river gauging activity in Scotland.

Data

Estimation Procedure

Estimations for both the conditional and mixed logit models were conducted using the packages *Mlogit* (Croissant, 2015) and *Support.CEs* (Aizaki, 2015), available online from the Comprehensive R Archive Network (CRAN). The mixed logit models were simulated with 1000 halton draws each. All main attributes, including Cost, were allowed to vary randomly according to a Normal distribution, which yielded the most optimal model fit statistics and parameter estimates for both utility and willingness-to-pay. Correlation was permitted across the parameters and optimisation was conducted according to the 'Bfgs' method. Willingness-to-Pay and 95% confidence intervals were calculated using the Krinsky-Robb method

Results

Alternative Specific Constants

All the models in this chapter were estimated with the inclusion of alternative-specific constants (ASCs). ASCs are included in order to identify residual heterogeneity left unmeasured by other factors included in the models and to detect any intrinsic preferences for the available options (Hensher et. al., 2015). Given that a quasi-labelled design was adopted, the effect of an ASC provides insights into population preferences for alternative states of the environment as represented by the four available hydrometric options. These alternatives included whether to continue the current facility or to upgrade/downgrade it for the river gauging requirements of future generations. Responses declining to select any of the available options were also counted as a valid choice with an ASC rather than excluding them from the estimation. This was in order to allow for the possibility that genuine, plausible reasons existed for opting-out of choosing all presented alternatives; for example, because a respondent was undecided or indifferent to the considered alternatives, or desired a different set of hydrometric options which were unavailable (Balcombe et.al., 2009). In addition, the choice of three alternatives to the status quo, one of which was a deterioration in current provision, was designed deliberately with the intention of offering a fuller and more realistic coverage of the choice space and also to reduce hypothetical bias, protest voting, status quo bias and lexicographic preferences following the findings of Liebe et al., (2015; unpublished manuscript) and Rolfe and Bennett (2009).

Main Effects

A distribution of responses across all alternatives for both models is given in Table 5.11. Both models show significant and negative estimates for ASCs associated with each of the non-status-quo options. This suggests an intrinsic desire for change away from these alternatives in favour of the existing network. Although in practice most respondents opted for an upgrade to the current hydrometric facility, the relatively low levels of awareness, decision complexity and low levels of direct data usage among household participants may result in a residual preference to leave things unchanged for several respondents. The high significance levels associated with ASC figures also suggest that leaving them out of the modelling procedure would have resulted in biased estimates for the other parameters.

Main effects in both models were defined as the impact of core hydrometric attributes on user satisfaction or utility. In the conditional logit model the number of stations, provision of a web-enabled camera providing real-time river views, and operating stations to collect discharge rather than simply river level data were all estimated as significantly different from zero. These factors all increased household utility. Also as expected, higher costs associated with collecting and disseminating data were disliked, as was a reduction in the total number of hourly data readings. This last variable however was estimated as being only mildly significant at the 95% level. In the mixed logit model, mean coefficients are required to be interpreted in correspondence with standard deviation estimates of the preference distributions specified for each random parameter. The significance of these values are listed as elements of the Cholesky matrix (Tables 5.17, 5.18 and 5.19), which suggests that the preferences for most attributes do indeed vary across individuals and that this heterogeneity is captured by the model.

Interaction Effects

Interaction effects between the main attributes were tested for both the CL and MIXL models however they did not provide stable estimates or improve model fit. They were thus excluded from the estimation procedure. In addition two other sets of variables were tested in order to determine the effects of: (i) socio-economic and demographic (SED) characteristics on model performance, and (ii) cognitive factors on household utility from river gauging activity. Cognitive factors refer to several aspects of a person's psychology which influence their decisions for taking a certain course of action or for making pro-environmental/anti-environmental choices. These factors refer to behavioural determinants such as beliefs, attitudes and awareness which are not observed but which nevertheless affect the process of identifying and ordering preferences and hence of making selections between competing alternatives (Moisennen, 1999; Hoyos et. al, 2015). Adding first the socio-economic and demographic (SED) variables and secondly cognitive variables to the model estimation demonstrably improved the statistical fit of the Mixed Logit models according to the Log-Likelihood and Akaike Information Criteria (AIC) indicators. Both SED and Cognitive variables were interacted with the ASC of all hydrometric options in order to assess the impact of the individual-specific characteristic on the utility received from each alternative relative to a baseline alternative. The results are presented in Table 5.13.

Socio-Economic and Demographic Effects

<u>Gender:</u> The effect of gender on future states of the world for Scottish river hydrometry was tested by creating a dummy variable which took the value of 1 if the respondent was female, and zero if male. The MIXL results showed that women were significantly more likely than men to receive satisfaction from river gauging upgrades in Scotland.

<u>Income:</u> Respondents were invited to specify the band of their annual household incomes (before tax) in the survey. Individuals earning between £0 and £24,000 were classified as low income; those earning between £24,000 and £50,000 as middle income and those earning £50,000 or more were specified as high income households. Of these, the low income group was selected as a category of special interest to in order to assess preferences for river hydrometry. Results from the best-fitting MIXL model demonstrated that low income groups disliked the prospect of a gauging network upgrade compared to members of the other two groups.

<u>Distance from River:</u> In the survey, respondents were asked to specify the approximate distance from their homes to the nearest stream or river. These figures were then entered as a continuous variable in the model estimation. The best-fitting MIXL model (which included cognitive variables) suggests that people living further away from a river or stream are less likely to appreciate an upgrade in the river gauging network and more likely to prefer a downgrade. However, this effect was not statistically significantly different from zero, suggesting that cognitive perceptions of distance to the river were unimportant determinants of hydrometric value.

Dwelling Flooded: When embarking on the survey one hypothesis was that the personal experience of household flooding would make affected individuals automatically sympathetic to increased river gauging activity. It was considered that, from the perspective of someone whose home may have been flooded, improved hydrometric capabilities might be recognised as an increase in the national capacity for early warning systems and an enhanced catchment science that could ultimately provide more timely and accurate predictions as to the location, duration and scale of future flooding incidents. Results showed that flood victims' preferences were positive for all alternatives, however, none of these effects was significantly different from zero.

Data Users: Individuals who reported that they visited the online water level pages maintained and updated by SEPA were defined as being hydrometric data users for estimation purposes. Of the 88 identified individuals, several were canoeists, anglers, people with a lay interest in river behaviour and those concerned about localised flooding. Taking account of this group's choices showed clear preferences for an improvement in the state of future hydrometry with both upgrade alternatives generating utility for users.

Families: A family was defined as a household containing three or more members. MIXL model results clearly showed that such homes were significantly in favour of upgrading the Scottish river gauging network. This may indicate a specific concern amongst families for improving levels of freshwater security for the sake of future generations.

Degree Holders: the impact of a respondent's education on preferences for hydrometric data was considered to be a relevant influence for investigation. All else being equal, it was hypothesised that the more educated an individual the more sympathetic they were likely to be on the role of data as *prima materia* for the advancement of scientific research, education and evidence-based policymaking, perhaps to due personal experience of working with data during past courses of study. All respondents who reported the attainment of at least a bachelor's degree (and higher) were coded as one for estimation purposes and zero otherwise. As expected, results showed that more educated individuals were more likely to derive satisfaction from a hydrometric upgrade, and to dislike a downgrade in national river gauging capabilities.

Homeowners: Owner-occupants are considered to be important stakeholders in the future state of public river hydrometry. Damage to property, mortgage commitments and lower residential mobility following adverse weather events all place a higher, direct and unavoidable financial risk on this group in comparison with individuals renting their current dwellings. Assuming that an upgraded river gauging network is capable of reducing the vulnerability of property owners to complex climate risks then, *ceteris paribus*, this group is more likely than tenant occupants to value investment in improving national hydrometric capabilities. In line with these expectations results demonstrated that homeowners received significantly greater utility from upgrades to the present river gauging network in comparison to tenant occupants.

Senior Citizens: All members of age groups above 65 years were defined as senior citizens. The longevity of the baby-boomer generation means that they are an important and increasing segment of the population. As such their preferences may establish an important baseline for the environmental protection priorities of future generations. Model results showed that reducing national hydrometric capabilities in the form of a downgrade to the current network was disliked by senior citizens. This may reflect a special concern for the quality of environment bequeathed to younger generations and a concomitant need to maintain current river surveillance and protection levels on the part of this group.

Workers: People in employment are an important demographic group in their role as economically-active, current contributors to the national tax base. Findings from the mixed logit model incorporating both socio-economic and cognitive effects demonstrated a strong and clear disutility for expanding Scotland's river gauging network on the part of this cohort, perhaps reflecting a different order of priorities for public and private intervention.

Business Owners: The private sector has often been characterised as being driven by entrepreneurial self-interest, concerned to greater degree by profit motivations than by altruistic desires for environmental protection or improvement (Meadowcroft, 2007; Berman and Small, 2012). However, results from the full effects mixed logit model, which took into consideration both socio-economic and cognitive factors, showed that business owners were significantly in favour of upgrading national capacity for river gauging. Proposals to downgrade the hydrometric network also generated significant disutility for this cohort. Although the effects were only mildly significant at the 10% level, these findings challenge conventional dichotomies that view self-interest and environmental concerns as being mutually exclusive determinants of commercial behaviour.

Cognitive Effects

A validated psychometric scale, Beliefs in Support of Environmental Action and Inaction (BSEAI), was used to elicit cognitive values from respondents. This scale is a reinterpretation of the Awareness of Consequences scale (Ryan and Spash 2012) which tests the degree of individuals' egocentric, biospheric and altruistic beliefs using a set of fifteen statements. Respondents were invited to express their level of agreement or disagreement with the statements on a scale of 1-5 (where 1=strongly disagree to 5=strongly agree). The mean score of these responses was taken following Grisolia et. al.

(2013) and interacted with the ASCs of each alternative in order to test for the impact of environmental beliefs on household choices for the future state of river hydrometry in Scotland. Two scores were included; one for beliefs favouring environmental action and another for beliefs favouring environmental inaction. It was hypothesised that: (i) individuals in whose worldview the environment is being seriously harmed and that environmental protection has positive consequences would favour upgrades of the river gauging network, whereas; (ii) individuals who felt that the environment is not being seriously harmed, and that environmental protection has negative consequences, were more likely to choose not to upgrade the river gauging network.

<u>Environmental Beliefs: Pro-Action and Pro-Inaction:</u> Findings from the mixed logit model showed, as expected, that pro-environmentalists had strong preferences for upgrading the river gauging network and received significant discomfort from potential alternatives lying outside of the choice experimental remit. In contrast, hydrometric upgrades generated strong dissatisfaction for environmental apathists. The negative but statistically unimportant coefficients for the downgrade option also suggests that, for this group, there was no significant difference in preferences between the current gauging facility and a reduced network. This indifference seems to lend further validation (and indeed to reflect a certain statistical irony) on the impact of apathetic beliefs on environmental choice.

<u>Level of Information and Awareness:</u> The extent to which a respondent was informed about the role and applications of hydrometric data was considered to be an important determinant of individual preferences for river gauging activity. It was hypothesised that participants who were more familiar with data uses from past or related experiences were more likely to welcome improvements in the national hydrometric infrastructure. Accordingly, respondents were presented with five sets of hydrometric uses, each comprising several specific hydrometric applications, which they were invited rank on a scale from 1-4 in terms of their prior levels of awareness ('completely unaware' to 'fully aware' from past experience). A mean awareness score was then calculated for each respondent across all five sets of uses and included as an individual-specific variable in the MIXL estimation. The findings showed that respondents scoring highly on the awareness scale were indeed more likely to prefer gauging network upgrades.

<u>Level of Decision Certainty:</u> A major design issue aimed at improving the validity of choice experiments is to include measures for minimising the incidence of strategic responses (Carson and Groves, 2011). The theoretical nature of alternatives in a choice experiment may lead some participants to select options without fully considering all relevant information or equally selecting alternatives in which only some effective attributes, such as cost, are minimised (Vossler et al., 2012). This introduces

hypothetical bias in to model estimates. One approach to addressing hypothetical bias is to ask respondents how certain they were about decisions taken in a choice situation (Blumenschein et. al., 2008) with a view to inducing further consideration of all available alternatives and information. Respondents in this study were asked to rank their level of certainty on a scale from 1-5 ('not at all certain' to 'very certain') after each choice situation. A mean certainty score was then calculated and included in the mixed logit model as an individual-specific variable. This was shown to be significant for hydrometric upgrades, suggesting that high levels of personal conviction were important in explaining respondent preferences for these alternatives. Reviews in Ready et. al. (2010) have shown that uncertain preferences for a policy intervention, and particularly one concerning several non-status quo alternatives in a passive use context, can often lead to status quo alternatives being chosen over the available alternatives. However, the findings in this model together with the fact that most household respondents chose to 'trade' by engaging in a potential market for hydrometric upgrades suggests that the size of hypothetical bias underlying model estimates is likely to be small.

5.5. Welfare Analysis

Mean Willingness to Pay

Estimates of willingness to pay from Model 4 (full model) which incorporated both socio-economic and corporate effects is selected as the preferred model due to the usual data fit criteria of Log-Likelihood and AIC. The estimates in general provide an indication of the intensity of household preferences and represent the implicit price of each attribute. Confidence intervals were calculated at the 95% level using the Krinsky and Robb method. Mean willingness-to-pay figures represent the average monetary amount that an individual in the sample was prepared to pay (or accept) in order to secure a single unit of the attribute as defined in the choice sets. The figures show that households are willing to pay 6 pence per station, varying between 4p and 10p as the upper and lower bounds of this estimate. Households are also willing to pay £12.72 for real-time views of the river channel (although some are only willing to pay £6.04 while others will pay up to £23.03) and £19.75 for securing flow data rather than just river level data. As with other attributes the importance of flow data also varies across households with some respondents prepared to part with only £14.87 compared with others who would pay up to £27.34 for the higher grade discharge statistics. Also as expected, reducing the number of hourly data collections is disliked by households who would, on average, have to be compensated 53 pence per minute's delay between readings of river level. More time-sensitive households, for example those living in flood zones, would require additional compensation, to a limit of £1.29, for each minute's delay while less time-sensitive households would be willing-to-accept only 2 pence instead 53 for enduring an additional minute between hydrometric data readings. These findings are as expected and consistent with views expressed during focus groups and in the choice questionnaire. One flood group for example advised that the time taken for their local stretch of river to reach bank full stage from normal flow conditions could be as little as 20 minutes. Clearly a standard 15 minute frequency would not be sufficient to secure timely flood warnings for residents of such communities who might be willing to pay more for higher frequency updates of river levels. The mean WTP from all models is illustrated in Table 5.20.

Marginal Willingness-to-Pay

Real-Time Views and Discharge (Flow) Data

Building on mean willingness-to-pay estimates, an interesting question focuses on how much the sampled households were prepared to contribute (or receive) in order to secure (or endure) a change in the levels of hydrometric attributes. In terms of the qualitative attributes (webcam and data type), a marginal change simply refers to a conversion in absolute provision, that is, from real-time views and full stage-discharge figures becoming available following circumstances in which they were not originally provided. The value of these changes are the same as the mean WTP estimates given in Table 5.20 for Data Type and Webcam; a household would pay an average of £12.72 for real-time views of the river channel and £19.75 for data to be refined to flow grade rather than provided as estimates of river levels alone.

Stations

In contrast to webcams and data type, the continuous attributes (Number of Stations and Frequency) can be analysed further to reveal the marginal value of each level of provision. Table 5.21 for example displays the impact on mean willingness-to-pay if the gauging station network were expanded or downgraded. Starting with a base value of 6 pence per station, households would be willing to pay (£0.06 x 392=) £24.92 for the current network which hosts 392 river gauging stations. Note that some rounding error exists in the figures reported here as these are significant to two decimal places; the estimates reported in tables were calculated correct to eight decimal places. From this basic level, they would then be willing to contribute an additional £2.48 for expanding the gauging network by 10%, which would deliver 39 new stations. The total value per household of a gauging network comprising 431 stations rather than the current 392 is thus (£24.92 + £2.48 =) £27.40. Similarly, each household would be willing to pay an additional £6.23 for a 25% expansion in the number of gauging stations; £12.46 for a 50% expansion and £24.92 for a doubling of the current network, from 392 to a total of 784 stations. All along the reader should keep in mind the variation in each of these figures, presented as the confidence intervals associated with each estimate. The table also shows that households would not welcome a downgrade of current river gauging facilities. In order to live with this change, the average household would require compensation to the tune of £12.21 for a 50% reduction in the number of stations, such that only 200 stations were now available across the network rather than the current 392. This reduces their net willingness-to-pay to (£24.92 – 12.21=) £12.71 for a downgraded network.

Frequency

Table 5.22 presents a similar set of estimates for the value of time, or frequency of river level readings. A household would be willing to *accept* (£0.53 x 15mins=) £7.98 for a basic 15 minute interval between readings of river level. A further delay of a 15 minutes would require compensation of an additional £7.98, bringing the total willingness to accept a 30 minute time interval between river level readings to (£7.98+7.98=) £15.96. A single hourly collection would increase this figure to £31.92. Similarly, a household would be willing to pay an extra £5.32 for a 10 minute saving or 8 more readings of river level per hour, which reduces their overall willingness-to-accept to (£7.98 - £5.32=) £2.66. Reducing the time-interval between river level readings even further to a 1 minute frequency (60 observations per hour) would thus reduce the total willingness-to-accept value from £7.98 to (£-7.98+7.45=) £0.53.

Table 5.10: Distribution of Household Choices for Hydrometric Alternatives

Current Facility	Upgrade 1	Upgrade 2	Downgrade	None
26%	32%	32%	4%	6%

Table 5.11: Conditional and Mixed Logit Models: Main Effects

	Conditional Logit Model: Main Effects			Mixed Logit Model: Main Effects		
Alternatives & Attributes	**Beta**	**Std. Error**	**T-Statistic**	**Beta**	**Std. Error**	**T-Statistic**
ASC: Upgrade One	-0.477	0.197**	-2.418	-0.071	0.308	-0.231
ASC: Upgrade Two	-0.505	0.199**	-2.540	-0.169	0.308	-0.549
ASC: Downgrade	-1.311	0.297****	-4.417	-7.034	0.510****	-13.784
ASC: None	-0.512	0.183***	-2.804	-5.178	0.388****	-13.334
STATIONS	0.002	0.000****	9.117	0.002	0.000****	6.156
FREQUENCY	-0.010	0.006*	-1.744	-0.030	0.010***	-3.095
WEBCAM	0.489	0.066****	7.431	0.611	0.110****	5.575
DATA TYPE	0.524	0.046****	11.429	0.748	0.080****	9.356
COST	-0.022	0.003****	-6.881	-0.055	0.005****	-10.146
	LL: -3518.6 AIC:7055.2			LL: -2564.3 AIC: 5176.7		

Significance Levels: **** 0.01 per cent *** 1 per cent ** 5 per cent * 10 per cent

Table 5.13: Conditional and Mixed Logit Models: Socio-Economic and Cognitive Effects

	Main and Socio-Economic Effects				Main, Socio-Economic & Cognitive Effects			
Alternatives & Attributes	**Beta**	**Std. Error**	**T-Stat.**		**Beta**	**Std. Error**	**T-Stat.**	
ASC: Upgr. One	-2.363	0.612****	-3.862		-7.983	1.823****	-4.380	
ASC: Upgr. Two	-2.191	0.613****	-3.574		-5.214	1.768***	-2.950	
ASC: Downgrade	-4.701	1.290****	-3.645		-4.272	6.141	-0.696	
ASC: None	-2.414	1.102**	-2.190		5.341	11.375	0.470	
STATIONS	0.003	0.001****	6.690		0.005	0.001****	5.925	
FREQUENCY	-0.057	0.015****	-3.697		-0.045	0.024*	-1.890	
WEBCAM	0.635	0.143****	4.426		1.083	0.266****	4.070	
DATA TYPE	0.975	0.114****	8.522		1.682	0.220****	7.652	
COST	-0.051	0.007****	-6.935		-0.085	0.014****	-6.171	
Socio-Economic Variables	Upgr. One	Upgr. Two	Downgrade	None	Upgr. One	Upgr. Two	Downgrade	None
	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)	Coefficient (S.E.)
Female	1.430 (0.289)****	1.426 (0.287)****	-0.241 (0.722)	-0.202 (0.862)	1.929 (0.445)****	1.583 (0.435)****	-1.901 (2.543)	-2.634 (3.484)
Low Income	-0.541 (0.376)	-0.594 (0.385)	-1.715 (1.261)	1.194 (1.563)	-2.013 (0.561)****	-2.556 (0.599)****	-2.283 (3.602)	5.974 (10.408)
Distance to River	0.002 (0.005)	-0.005 (0.005)	0.037 (0.044)	-0.156 (0.158)	-0.006 (0.007)	-0.004 (0.007)	0.029 (0.183)	-0.935 (0.848)
Dwelling Flooded	-0.267 (0.581)	0.074 (0.575)	3.619 (0.956)****	-0.919 (1.151)	1.136 (0.991)	1.240 (0.985)	1.573 (2.131)	0.150 (12.693)
Data User	1.656 (0.317)****	1.831 (0.309)****	1.419 (0.813)*	0.579 (0.954)	0.961 (0.513)*	1.414 (0.506)***	0.473 (1.881)	-3.330 (8.230)
Family Household	0.429 (0.276)	0.655 (0.278)**	-1.032 (0.571)*	-0.767 (0.768)	1.342 (0.437)***	1.685 (0.452)****	-1.738 (1.386)	-3.762 (4.153)
Degree Holder	0.069 (0.264)	-0.278 (0.263)	-2.483 (0.609)****	-0.825 (0.992)	0.914 (0.400)**	0.534 (0.405)	-3.131 (1.535)**	-0.791 (5.654)
Owner Occupant	1.029 (0.329)***	1.083 (0.324)****	0.189 (0.790)	-2.269 (1.035)**	1.679 (0.500)****	1.827 (0.498)****	-0.836 (2.532)	-9.707 (6.601)
Senior Citizen	0.378 (0.384)	-0.033 (0.396)	-3.498 (0.940)****	-1.511 (1.353)	0.242 (0.564)	-0.640 (0.586)	-6.936 (4.035)*	-1.087 (7.828)
Working	-0.312 (0.321)	-0.516 (0.336)	-0.049 (0.634)	0.287 (0.978)	-1.126 (0.485)**	-1.760 (0.524)****	0.376 (2.143)	3.200 (6.506)
Business Owner	0.786 (0.480)	0.215 (0.496)	-1.899 (1.361)	1.988 (1.205)*	1.387 (0.769)*	0.041 (0.767)	-5.584 (3.061)*	6.182 (6.201)
Cognitive Variables								
Environmental Beliefs: Pro-Action					1.485 (0.262)****	1.066 (0.257)****	-1.243 (0.756)	-6.241 (2.602)**
Environmental Beliefs: Pro-Inaction					-1.025 (0.319)***	-1.792 (0.337)****	-0.979 (1.663)	0.845 (3.325)
Uses for Hydrometric Data: Awareness Level					0.952 (0.300)***	0.588 (0.304)*	-1.381 (1.443)	1.224 (2.677)
Level of Decision Certainty					0.540 (0.293)*	0.793 (0.319)**	1.673 (1.055)	0.544 (3.463)
Environment as a Public Policy Priority					-0.082 (0.659)	-1.667 (0.721)**	2.394 (4.569)	3.300 (8.208)
LL: -1515					-1353.4			
AIC: 3165.9					2942.8			

Significance Levels: **** 0.01 per cent *** 1 per cent ** 5 per cent * 10 per cent

Table 5.14: Random Parameter Distribution for Mixed Logit Model: Main Effects

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
STATIONS	-Inf	-0.00038	0.002312	0.002312	0.005004	Inf
DATA TYPE	-Inf	0.696765	0.747605	0.747605	0.798446	Inf
WEBCAM	-Inf	-0.14261	0.610978	0.610978	1.364571	Inf
FREQUENCY	-Inf	-1.058	-0.03028	-0.03028	0.997447	Inf
COST	-Inf	-0.10918	-0.05545	-0.05545	-0.00173	Inf

Table 5.15: Random Parameter Distribution for Mixed Logit Model: Main and Socio-Economic Effects

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
STATIONS	-Inf	0.000578	0.003401	0.003401	0.006224	Inf
DATA TYPE	-Inf	0.910163	0.975036	0.975036	1.03991	Inf
WEBCAM	-Inf	-0.07144	0.634939	0.634939	1.341316	Inf
FREQUENCY	-Inf	-1.02515	-0.05679	-0.05679	0.911567	Inf
COST	-Inf	-0.1044	-0.05125	-0.05125	0.001906	Inf

Table 5.16: Random Parameter Distribution for Mixed Logit Model: Main, Socio-Economic and Cognitive Effects

Attribute	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
ASC:Upg1	-Inf	-8.0535	-7.9825	-7.9825	-7.9115	Inf
ASC:Upg2	-Inf	-6.3881	-5.2142	-5.2142	-4.0403	Inf
ASC:Dngr	-Inf	-5.8983	-4.2724	-4.2724	-2.6464	Inf
ASC:None	-Inf	5.2539	5.3406	5.3406	5.4272	Inf
STATIONS	-Inf	-2.3025	0.0054	0.0054	2.3134	Inf
DATA TYPE	-Inf	-1.6330	1.6821	1.6821	4.9971	Inf
WEBCAM	-Inf	-4.0954	1.0830	1.0830	6.2614	Inf
FREQUENCY	-Inf	-8.6358	-0.0453	-0.0453	8.5452	Inf
COST	-Inf	-0.0888	-0.0852	-0.0852	-0.0815	Inf

Table 5.17: Cholesky Matrix for Mixed Logit Model: Main Effects

	Estimate	Std. Error	T-Stat.
STNS.STNS	0.004	0.000****	8.737
STNS.DTYP	-0.063	0.006****	-10.310
STNS.WBCM	0.042	0.122	0.347
STNS.FREQ	0.543	0.122****	4.448
STNS.COST	0.028	0.006****	4.662
DTYP.DTYP	0.041	0.006****	6.792
DTYP.WBCM	-0.995	0.134****	-7.439
DTYP.FREQ	0.476	0.126****	3.792
DTYP.COST	-0.001	0.005	-0.232
WBCM.WBCM	0.507	0.123****	4.136
WBCM.FREQ	1.308	0.134****	9.741
WBCM.COST	0.029	0.004****	6.614
FREQ.FREQ	-0.298	0.116***	-2.578
FREQ.COST	0.066	0.007****	9.903
COST.COST	0.017	0.022	0.756

Significance Levels: **** 0.01 per cent *** 1 per cent ** 5 per cent * 10 per cent

Table 5.18: Cholesky Matrix for Mixed Logit Model: Main and Socio-Economic Effects

	Estimate	Std. Error	T-Stat.
STNS.STNS	-0.004	0.001****	-5.663
STNS.DTYP	0.037	0.012***	3.201
STNS.WBCM	-0.148	0.172	-0.865
STNS.FREQ	-0.013	0.173	-0.073
STNS.COST	-0.024	0.008***	-2.825
DTYP.DTYP	0.089	0.011****	7.958
DTYP.WBCM	-0.362	0.161**	-2.250
DTYP.FREQ	-0.198	0.157	-1.258
DTYP.COST	-0.010	0.008	-1.383
WBCM.WBCM	0.971	0.204****	4.768
WBCM.FREQ	-0.151	0.201	-0.751
WBCM.COST	0.006	0.008	0.767
FREQ.FREQ	1.414	0.184****	7.698
FREQ.COST	0.000	0.006	0.083
COST.COST	0.074	0.008****	9.745

Significance Levels: **** 0.01 per cent *** 1 per cent ** 5 per cent * 10 per cent

Table 5.19: Cholesky Matrix for Mixed Logit Model: Main, Socio-Economic and Cognitive Effects

	Estimate	**Std. Error**	**T-Stat.**
STNS.STNS	3.422	1.057***	3.239
STNS.DTYP	4.617	1.151****	4.010
STNS.WBCM	3.805	1.710**	2.225
STNS.FREQ	5.934	2.490**	2.383
STNS.COST	0.002	0.001	1.617
STNS.ASC_Upg1	0.036	0.033	1.077
STNS.ASC_Upg2	-0.539	0.309*	-1.748
STNS.ASC_Dngr	0.166	0.244	0.680
STNS.ASC_None	0.030	0.015*	1.943
DTYP.DTYP	1.686	0.317****	5.326
DTYP.WBCM	-3.484	1.673**	-2.082
DTYP.FREQ	-6.567	3.081**	-2.131
DTYP.COST	-0.003	0.001****	-3.799
DTYP.ASC_Upg1	0.049	0.018***	2.783
DTYP.ASC_Upg2	-0.452	0.250*	-1.805
DTYP.ASC_Dngr	-0.376	0.218*	-1.721
DTYP.ASC_None	-0.038	0.014***	-2.707
WBCM.WBCM	5.686	1.569****	3.623
WBCM.FREQ	5.209	3.101*	1.680
WBCM.COST	-0.003	0.001**	-2.278
WBCM.ASC_Upg1	-0.028	0.022	-1.311
WBCM.ASC_Upg2	0.713	0.320**	2.226
WBCM.ASC_Dngr	-0.647	0.310**	-2.088
WBCM.ASC_None	0.025	0.018	1.337
FREQ.FREQ	7.533	3.918*	1.923
FREQ.COST	-0.003	0.001**	-2.171
FREQ.ASC_Upg1	0.036	0.020*	1.814
FREQ.ASC_Upg2	0.169	0.334	0.506
FREQ.ASC_Dngr	1.032	0.332***	3.109
FREQ.ASC_None	0.038	0.018**	2.116
COST.COST	0.000	0.001	-0.209
COST.ASC2_Upg1	-0.027	0.019	-1.457
COST.ASC3_Upg2	-0.391	0.328	-1.195
COST.ASC4_Dngr	0.291	0.301	0.967
COST.ASC5_None	-0.063	0.018****	-3.410
ASC_Upg1.ASC_Upg1	0.067	0.019****	3.590
ASC_Upg1.ASC_Upg2	-1.286	0.312****	-4.120
ASC_Upg1.ASC_Dngr	-0.234	0.297	-0.789
ASC_Upg1.ASC_None	-0.020	0.017	-1.202
ASC_Upg2.ASC_Upg2	-0.435	0.430	-1.012
ASC_Upg2.ASC_Dngr	-0.710	0.384*	-1.852
ASC_Upg2.ASC_None	-0.057	0.014****	-4.010
ASC_Dngr.ASC_Dngr	1.875	0.410****	4.569
ASC_Dngr.ASC_None	-0.021	0.014	-1.540
ASC_None.ASC_None	0.064	0.016****	4.059

Significance Levels: **** 0.01 per cent *** 1 per cent ** 5 per cent * 10 per cent

Table 5.20: Mean Willingness to Pay Estimates from the Conditional and Mixed Logit Models

Attributes	[1]. Conditional Logit Model	[2]. Mixed Logit Main Effects Model	[3]. Mixed Logit Main and Socio-Economic Effects	[4]. Mixed Logit Main, Socio-Economic and Cognitive Effects
STATIONS	0.10 (0.07 to 0.15)	0.04 (0.03 to 0.06)	0.07 (0.04 to 0.10)	£0.06 (£0.04 to £0.10)
FREQUENCY	-0.46 (-1.14 to 0.05)	-0.55 (-0.98 to -0.19)	-1.11 (-2.05 to -0.46)	-£0.53 (-£1.29 to £0.02)
WEBCAM	22.26 (13.94 to 36.16)	11.02 (6.51 to 16.96)	12.39 (5.93 to 22.25)	£12.72 (£6.04 to £23.03)
DATA TYPE	23.84 (18.06 to 32.98)	13.48 (10.55 to 17.22)	19.03 (14.19 to 26.41)	£19.75 (£14.87 to £27.34)

Notes: (1). Figures in brackets represent 95% confidence intervals for Willingness-to-Pay estimates. (2). Confidence intervals calculated using the Krinsky-Robb method. (3). Negatively-valenced figures imply that users would be willing to accept compensation for a change in the level of the attribute. (4). All figures are in GBP (£).

Table 5.21: Marginal Willingness-to-Pay for Hydrometric Stations: Mixed Logit Model with Cognitive Effects

Total Number of Stations	Additional Stations	Hydrometric Network Adjustment	Mean Willingness-to-Pay
200	-192	-50% (approx.)	-£12.21 (-£19.43 to -£7.56)
392	**0**	**0**	**£24.92 (£15.44 to £39.67)**
431	+39	+10%	£2.48 (£1.54 to £3.95)
490	+98	+25%	£6.23 (£3.86 to £9.92)
588	+196	+50%	£12.46 (£7.72 to £19.84)
686	+294	+75%	£18.69 (£11.58 to £29.76)
784	+392	+100%	£24.92 (£15.44 to £39.67)

Notes: (1). 95% confidence intervals for mean willingness-to-pay (wtp) estimates are shown in brackets. (2). Estimates are relative to a baseline of 392 stations which approximates the size of the current river gauging network in Scotland. All figures above represent marginal values and should be added/subtracted from the baseline value to arrive at the net value per household for a given change in attribute level. For example the baseline value for stations is (£0.06 x 392 stns=) £24.92. Installing ninety-eight more stations adds value of £6.23 to this figure. (3).The average household would require compensation of at least £12.21 in order to accept a 50% reduction in the number of river gauging stations. This is shown by the negative sign preceding the wtp estimate in column four. Thus the mean willingness-to-pay for a reduced network of 200 stations would decline to (£24.92 - £12.21 =) £12.71 per household.

Table 5.22: Marginal Willingness-to-Pay for Hydrometric Frequency: Mixed Logit Model with Cognitive Effects

Frequency of River Level Measurement	Time Loss	Total Observations Recorded	Additional Observations Recorded	Mean Willingness-to-Pay
Every 1 min	-14 mins	60	+56	£7.45 (-£0.25 to £18.12)
Every 2 mins	-13 mins	30	+26	£6.92 (-£0.23 to £16.82)
Every 5 mins	-10 mins	12	+8	£5.32 (-£0.18 to £12.94)
Every 15 mins	**0**	**4**	**0**	**-£7.98 (-£19.41 to £0.26)**
Every 30 mins	+15 mins	2	-2	-£7.98 (-£19.41 to £0.26)
Every 60 mins	+45 mins	1	-3	-£23.94 (-£58.24 to £0.79)

Notes: (1). 95% confidence intervals for mean willingness-to-pay (wtp) estimates are shown in brackets in column four. (2). Estimates are relative to a frequency baseline of 15 mins (4 river level measurements per hour) which approximates the temporal resolution of the current river gauging network in Scotland. All figures above represent marginal values and should be added/subtracted from the baseline figure to arrive at the net value for a given change in the attribute level. For example the baseline compensation for collecting data every 15 mins is (£0.53 x 15 mins =) £7.98. A further £7.98 would be required in order for households to accept an additional time loss of 15 mins (or two fewer data readings per hour than the four observations currently made). This is shown by the negative signs preceding the wtp estimate in column five. (4). Households would be willing-to-pay for additional observations per hour. For example, 60 observations of river level per hour, or a 1-min temporal resolution, implies that the net compensation due to households reduces to (-£7.98 + £7.45 =) £0.53. Note that this is the mean willingness-to-accept figure per minute's delay identified in Table 5.20.

5.6. Conclusion

This chapter presented the results of a conditional logit model, and a series of mixed logit models analysing household preferences for hydrometric data. The best fitting model included the effects of socio-economic and cognitive factors, which outperformed models in which neither or only a single set of these sources of observed heterogeneity were present. Results from the model showed that households received significant utility from additional river gauging stations, and also from real-time views connecting them visually to river channels of interest. Households were also strongly in favour of operating gauging stations to collect discharge (flow) statistics rather than just river level data. At the same time, higher costs associated with river hydrometry and a lower frequency with which river level observations were updated were not favoured. Cost-effectiveness and timeliness of data were thus key drivers of value for households. The chapter also contained an analysis of the mean willingness-to-pay for all attributes, and the marginal willingness-to-pay for different levels of provision for stations and gauging frequency. These figures are helpful when planning and forecasting the impacts on society of changes in hydrometric provision levels. Finally, the acceptability of competing hydrometric programmes was assessed. In this analysis the impact of household and individual characteristics such as age, gender, income, education, employment, awareness and beliefs were evaluated on the residual willingness-to-pay for alternative hydrometric programmes. Results showed that a scaling-down of hydrometric capabilities was favoured by individuals on a low income, those in employment and those for whom the environment ranked low on a hierarchy of public policy priorities. In contrast, females, senior citizens, owner-occupants, families, business owners, those educated to degree level and people with pro-environmental beliefs preferred upgrades and did not favour a downgrade of Scotland’s river gauging infrastructure. In the next chapter, a series of latent class models are presented which allows the heterogeneity in preferences to be modelled along group-definitive lines.

Chapter 6

Household Preferences for Hydrometric Data:

Latent Class Models

6.1. Introduction

In chapter 5 we analysed household choice data using two different model specifications. The first was a conditional logit model in which individuals were assumed to have identical or homogenous preferences for hydrometric data. In the second model, this assumption was relaxed, and a mixed logit specification was used in order to allow for preferences to vary randomly across individuals. This was programmed by pre-specifying a population distribution for each attribute parameter and then using simulation techniques in order to identify those parameter values which maximised the simulated log-likelihood function (Train, 2009). Additionally, the effects of including individual-specific variables such as gender, household size, income and age were also tested for their impacts on tastes for competing hydrometric network configurations in Scotland. Finally, the effects of an individual's attitudes and beliefs were included within the modelling process in order to reveal whether certain cognitive orientations were important determinants of the population's environmental choices for river gauging activity. In this chapter, a related analysis to the mixed logit estimation is undertaken in order to ascertain whether respondent preferences can be classified according to key individual identifiers such as gender, age, income and education levels. The theory and econometric models underlying latent class estimation, including the Latent Class Random Parameter Model, have been discussed in chapter 4.

6.2. Model Estimations

Data

Four models in total were estimated. First, a latent class model with main effects (main attributes only) was tested in order to determine whether respondent preferences fell into discernible groups, such that preferences within a group were alike but dissimilar between groups. Second, a range of individual-specific socio-demographic variables were introduced to check if these factors resulted in the emergence of any stronger group profiles. In the third model cognitive variables were added to investigate the effects of psychological values on the delineation of noteworthy preference characteristics between groups. Finally a latent class structure with random parameters was estimated which allowed for preference parameters within groups to vary randomly in accordance with a pre-specified normal density. This model nested aspects of both the mixed logit and latent class structures. The results demonstrate that the model fit steadily improves as measures of individual heterogeneity are added in order to determine class assignment probabilities for group preferences. Results from the estimation of all four models are displayed in Table 6.1.

Number of Classes: Throughout the modelling process two classes were selected based on multiple criteria. First, given the low level of general household awareness on river gauging it was unlikely that respondent preferences were sufficiently developed as to merit multiple segments in data consumption. Second, testing for any more than 2 classes led to model convergence issues possibly owing to sample size or matrix invertability issues (Sarrias and Daziano, 2017). Third, using the Akaike and Bayesian Information statistics as model selection criteria showed that these indicators were minimised in the 2 class case for both full-effects models (with random and non-random parameters). A comparison of the model fit statistics is shown in Table 6.4 for two, three and four classes estimated across all models.

Table 6.1: Latent Class Models of Household Preferences for Hydrometric Data

Alternatives & Attributes	[1]. Main Effects Model		[2]. Main and Socio-Economic Effects		[3]. Main, Socio-Economic Cognitive Effects	
Class One	Beta	S.E.	Beta	S.E.	Beta	S.E.
ASC : Upgrade One	-2.172	0.832***	-1.658	0.762**	-1.993	0.835**
ASC : Upgrade Two	-2.772	0.878***	-1.831	0.792**	-1.953	0.869**
ASC : Downgrade	-3.278	0.946****	-3.239	0.941****	-2.758	1.022***
ASC : None	-2.364	1.003**	-2.929	0.802****	-2.355	0.884***
STATIONS	0.001	0.002	0.001	0.001	0.002	0.001
FREQUNCY	0.006	0.010	-0.007	0.014	-0.004	0.014
WEBCAM	0.636	0.502	0.689	0.398*	0.483	0.421
DATA TYPE	-0.029	0.133	0.244	0.147*	0.129	0.156
COST	-0.061	0.020***	-0.081	0.017****	-0.065	0.018****
Class Two						
ASC : Upgrade One	0.717	0.276***	0.843	0.379**	0.730	0.358**
ASC : Upgrade Two	0.673	0.278**	0.826	0.379**	0.695	0.359*
ASC : Downgrade	-2.699	0.482****	-2.346	0.712****	-2.601	0.674****
ASC : None	-1.596	0.326****	-1.193	0.439***	-1.546	0.437****
STATIONS	0.002	0.000****	0.003	0.000****	0.003	0.000****
FREQUENCY	-0.006	0.009	-0.013	0.012	-0.013	0.011
WEBCAM	0.444	0.074****	0.375	0.094****	0.391	0.093****
DATA TYPE	0.840	0.064****	0.939	0.087****	0.924	0.084****
COST	-0.033	0.004****	-0.029	0.005****	-0.030	0.005****
Class Two Membership Variables						
Constant	0.886	0.045****	-0.312	0.223	-3.225	0.490****
Female			0.553	0.131****	0.914	0.154****
Low Income			-0.075	0.208	-0.539	0.265**
Distance to River			0.012	0.015	0.024	0.020
Dwelling Flooded			-1.090	0.301****	-0.998	0.378***
Data User			1.551	0.198****	1.214	0.260****
Family Household			0.318	0.141**	0.836	0.175****
Degree Holder			0.255	0.131*	0.245	0.155
Owner Occupant			0.393	0.161**	0.221	0.207
Senior Citizen			0.124	0.187	0.403	0.235*
Working (in employment)			0.062	0.153	0.090	0.199
Business Owner or Self-Employed			0.810	0.290***	0.710	0.367*
BSEAI: Pro-Action Beliefs					0.780	0.081****
BSEAI: Pro-Inaction Beliefs					-0.385	0.107****
Hydrometric Awareness Level					0.558	0.118****
Decision Certainty Level					0.371	0.110****
Competing Public Policy Priorities					-1.094	0.315****
Log-Likelihood		-2956.2		-1765.2		-1744.5
AIC:		5950.5		3590.4		3558.9
BIC:		6061.9		3751.7		3747.1

Significance Levels: **** 0.01 per cent *** 1 per cent ** 5 per cent * 10 per cent

Table 6.2: Latent Class Random Parameter Model of Household Hydrometric Preferences

Alternatives & Attributes	Mean		Standard Deviation	
Class One	Beta	S.E.	Beta	S.E.
ASC: Upgrade One	-2.870	3.617	3.710	2.038*
ASC: Upgrade Two	-4.490	3.870	1.203	2.025
ASC: Downgrade	-24.479	9.160***	4.345	2.505*
ASC: None	-71.758	26.285***	45.021	17.149***
STATIONS	-0.022	0.010*	0.080	0.028***
FREQUNCY	-0.078	0.056	0.060	0.035*
WEBCAM	2.338	2.154	3.275	1.755*
DATA TYPE	0.624	0.599	2.174	1.134*
COST	-0.438	0.153***	0.004	0.054
Class Two				
ASC: Upgrade 1	0.643	0.513	0.980	0.265****
ASC: Upgrade 2	0.593	0.518	1.367	0.223****
ASC: Downgrade	-5.336	1.130****	3.013	0.478****
ASC: None	-7.944	1.535****	6.468	1.027****
STATIONS	0.003	0.001****	0.003	0.001****
FREQUENCY	-0.031	0.018*	0.042	0.011****
WEBCAM	0.733	0.161****	0.872	0.216****
DATA TYPE	1.542	0.150****	1.428	0.182****
COST	-0.039	0.008****	0.051	0.008****
Class Two Membership Variables				
Constant	-2.392	0.519****		
Female	1.093	0.168****		
Low Income	0.081	0.302		
Distance to River	0.147	0.027****		
Dwelling Flooded	1.116	0.501**		
Data User	-0.178	0.229		
Family Household	-0.112	0.174		
Degree Holder	-0.247	0.165		
Owner Occupant	0.700	0.213***		
Senior Citizen	0.272	0.254		
Working (in employment)	0.375	0.205*		
Business Owner or Self-Employed	1.030	0.402**		
BSEAI: Pro-Action Beliefs	0.514	0.091****		
BSEAI: Pro-Inaction Beliefs	-0.348	0.114***		
Hydrometric Awareness Level	0.956	0.130****		
Decision Certainty Level	0.034	0.114		
Competing Public Policy Priorities	-0.772	0.334**		
Log-Likelihood		-1421.2		
AIC:		2948.3		
BIC:		3233.2		

Significance Levels: **** 0.01 per cent *** 1 per cent ** 5 per cent * 10 per cent

Table 6.3: Class Membership Probabilities for all models by class

	[1]. Main Effects Model	[2]. Main & Socio-Economic Effects Model	[3]. Main, Socio-Economic & Cognitive Effects Model	[4]. Latent Class Random Effects Model
Class One	29.19%	29.48%	27.26%	29.36%
Class Two	70.81%	70.52%	72.74%	70.64%

Table 6.4: Model Fit Statistics for two, three and four classes.

Model	**Number of Classes**	**Model Selection Criteria Measure**		
		Log-Likelihood	**AIC**	**BIC**
Latent Class with Main Effects	2 Classes	**-2956.2**	5950.5	6061.9
	3 Classes	Undefined	6012.979	6130.275
	4 Classes	Undefined	5816.466	5974.815
Latent Class with Socio-Economic Effects	2 Classes	**-1765.2**	3590.4	3751.7
	3 Classes	Undefined	3720.696	3946.457
	4 Classes	Undefined	3450.755	3773.271
Latent Class with Socio-Economic and Cognitive Effects	2 Classes	**-1744.5**	**3558.9**	**3747.1**
	3 Classes	Undefined	3706.238	3985.751
	4 Classes	Undefined	3662.841	4065.985
Latent Class with Socio-Economic and Cognitive Variables: Random Effects	2 Classes	**-1421.2**	**2948.3**	**3233.2**
	3 Classes	Undefined	3340.519	3958.674
	4 Classes	Undefined	3187.899	4042.565

Alternative Specific Constants: All models were fitted with Alternative Specific Constants (ASCs) for each hydrometric programme, namely, a downgrade, upgrades one and two, and an undefined 'none' alternative. The effects of these constants were tested relative to the current facility as the reference, *status quo* option. Behaviourally, ASC parameters can be interpreted as the average utility obtained from any transformation of the hydrometric network relative to its current state. Across the four models, the ASCs in both classes were found to have highly significant effects, statistically different from zero at the 5% level and above. In Class One, all ASC estimates carried a negative sign, suggest that members of this class had an intrinsic preference for the current state of hydrometry in Scotland over-and-above the specific merits delivered by either network improvements or attempts at rationalisation. Proposals to upgrade or downgrade the river monitoring network yielded a general sense of apprehension, possibly owing to satisfaction with current provision and, by extension, viewing hydrometric changes as a less essential intervention. A prior level of unfamiliarity with river gauging activity may also have prompted some participants to opt for the status quo alternative in spite of the background information offered to respondents as part of the choice experiment questionnaire. In Class 1 the ASC coefficients also had the largest effect in comparison with the other attributes across all models, suggesting a strong desire to leave the current state of river hydrometry unchanged. By contrast, findings across all models for Class 2 showed that the overall impact of ASC coefficients was much smaller than in Class 1. Estimates for Class 2 also demonstrated that while a downgrade and an undefined 'none' option were both preferred less to the current facility, members of this group had significant preferences in favour of upgrades to the river hydrometric network. This was evident in the positive sign accompanying the mean utility estimates associated with the Class 2 ASC figures for both upgrades.

Models:

Model 1: Latent Class Model with Main Effects.

Model 1 consists of only the effects of the main attributes on class-based utility; that is the satisfaction that respondents in a particular class are likely to have received from increasing the number of stations, number of hourly data collections, real-time river views and flow-operated stations. The findings showed the emergence of two clear segments of preferences among the respondent population. In the first segment, members had a very strong overall preference for the current river gauging facility over other alternatives. The ASC coefficients for Upgrades 1 and 2 were -2.172 and 2.772 respectively, both significant at the 99% level. The ASC associated with a downgrade produced even stronger negative effects on Class One's utility with a coefficient of -3.278. This effect was statistically different from zero at the 99.9% level. The ASC coefficient associated with an undefined 'none' option also generated significant disutility for members of Class One. Its coefficient was -2.364, statistically different from zero at the 95% level. Members of this group appreciated more stations however the size of the effect was extremely small at 0.001 and not statistically different from zero. Class One members also received positive utility from a reduction in the number of hourly data readings with a coefficient of 0.006. Again, however, this effect was not statistically significant at any conventional level. Providing a webcam similarly pleased the occupants of Class One with a positive model coefficient of 0.636 but was statistically insignificant. In contrast it appears that operating stations to collect river discharge (flow) data over and above level data was not welcomed by this group as demonstrated by a negative coefficient of -0.029. However this effect was also not statistically different from zero and therefore unimportant in explaining the preferences of this group. Finally, and in line with expectations, higher costs of river hydrometry held a strong sense of aversion for Class One. The coefficient associated with the 'Cost' attribute was -0.061 as shown in Table 6.1 and very highly significantly differently from zero at the 99% level. Members of Class Two also had an intrinsic preference for the current hydrometric facility in Scotland compared with an option to rationalise it. This is shown by a coefficient size of -2.699 that is highly significant at the 99.99% level. However this effect was smaller in overall magnitude for Class Two than for Class One occupants, suggesting that Class One members disliked a change more than members of Class Two. At the same time, and contrary to the preferences of Class One, the prospects of upgrading the river gauging network was welcomed by Class Two as demonstrated by positively-valenced coefficients of 0.717 and 0.673 for upgrades 1 and 2, both effects of which were significant at the 99% and 95% levels respectively. The prospects offered by an undefined 'none' option, which may have: (i) captured a level of indecision/indifference to the alternatives available in the choice experiment, or; (ii) identified preferences for an outcome not presented in the choice experiment or; (iii) been interpreted as an option for no gauging whatsoever, also held disutility for Class Two compared with the current state of river gauging. The coefficient for this effect was -1.596, statistically different from zero at the 99.99% level. Members of Class Two also had small but highly statistically significant preferences in favour of more river gauging stations. The coefficient associated with gauging stations was 0.002, significant at the 99.99% level. Other attribute coefficients had the expected signs and all, excepting frequency, were statistically different from zero. In particular, Class Two members were more displeased by a loss of hourly data readings than Class One members, but the effect was not important in the main effect model. However, real-time river views held considerable appeal for Class Two members. The effect was highly statistically different from zero at the 99.99% level and the coefficient was 0.444. The collection of discharge (flow) data rather than simply river level data was the fourth attribute which defined Class Two's hydrometric preferences. The coefficient associated with this variable is 0.84 and significant at the 99.99% level. Finally, the price coefficient was -0.03 which demonstrates that Group Two occupants, like the members of Group One, received disutility from the costs associated with river gauging activity than members of Group One. This effect was again significant at a 99.99% level of confidence. The emerging picture of two distinct groups identified by the latent class procedure is thus of: (i) a passive or minimalist cohort which attaches a high level of importance to minimising costs and maintaining the *status quo* in terms of the national river gauging capacity, versus (ii) an activist, pro-environmental group which strongly prefers greater levels of river monitoring. The model fit statistics for the main effects latent class model are also important to mention. The log-likelihood score was -2956.2 while the Akaike and Bayesian Information Criteria measured 5950.5 and 6061.9 respectively. These figures constitute the baseline from which the fit of extended models incorporating the effects of socio-economic and cognitive variables will be examined below.

Model 2: Latent Class Model with Socio-Economic Effects.

A second model was estimated in order to determine whether class assignment was influenced by key sources of observed heterogeneity across the respondent population. In order to examine a consistent set of effects with the mixed logit models estimated in chapter 5 the following individual-specific socio-economic variables were selected for inclusion in the membership function:

Table 6.3: Socio-economic variables selected to test class assignment in membership function.

Socio-Economic Characteristic	Description
Gender	Whether the respondent was a female.
Income	Whether the respondent had a low income defined as falling within the range £0 – £24,000 per year (before tax).
River	Approximate distance to nearest river or stream from respondent's residence as evaluated by the participant.
Dwelling Flooded	Whether respondent had experienced flooding in their current dwelling.
Data User	Whether the respondent visits the website of the Scottish Environmental Protection Agency (SEPA) to view data from river gauging stations at any level of frequency from daily or several times a week (very frequently) to only on occasion (infrequently).
Family	Household comprising three or more members.
Education	Whether the respondent had achieved a diploma, bachelor's degree, or higher.
Tenure	Whether the respondent owned their current dwelling.

Age	Whether respondent was a senior citizen aged 65 and above.
Employment	Whether the respondent described themselves as being in-work relative to other classes of occupation including business owner/self-employed; home duties; student; retired or unemployed.
Business Owner	Whether the respondent described themselves as being self-employed and/or running a business.

Results from model 2 were again consistent with the distinction of at least two classes based on respondent valuations of hydrometric alternatives. Taking individual characteristics into account first showed an improved model fit compared with model 1. In particular, the log-likelihood ratio increased from -2956.2 in the main effects model to -1765.2 in model 2, while the AIC and BIC statistics were both further minimised, respectively, from 5950.5 (main effects) to 3590.4 and 6061.9 (main effects) to 3751.7.

In Class One, all parameter estimates showed the expected signs. The mean ASC estimates associated with the two upgrade alternatives, downgrade and 'none' option were, respectively, -1.658; -1.831; -3.239 and -2.929. All ASC effects were statistically important at the 95% level and above, reflecting a degree of stability in preferences for the current facility in comparison with Model 1 (main effects). The coefficient associated with the number of stations was 0.001 but not statistically different from zero. The coefficient associated with data frequency was -0.07 telling us that respondents did not welcome a decline in the number of hourly data readings of river levels. Although this only detracted from their utility by a small amount the effect was not statistically significant, yet again at any conventional level. Real-time river views had a coefficient 0.689 mildly significant at the 90% level. Being able to view river conditions from the comfort of one's home or digital device clearly held a slight but evident sense of wellbeing for respondents. Operating stations to collect discharge (flow) data instead of just river level readings was also weakly preferred by study participants. The utility coefficient for this attribute was 0.244 and statistically different from zero at the 90% level. Finally, the cost coefficient for members of Class One was as expected and estimated at -0.081. This effect was very highly significant at the 99.99% level.

In Class 2, the ASC coefficients associated with both the downgrade and 'none' option were negative and significantly different from zero at the 99% levels. The size of the effects were large with mean estimates of -2.346 and -1.193 respectively. Members of Class Two therefore continued to reveal an enduring general preference for the current river gauging facility over potential downgrade options. Equally, the two upgrade options, which were estimated with coefficients of 0.843 and 0.826 , held statistically important effects for Class Two members at the 95% level. These findings clearly showed that members of Class Two could more easily be convinced to vote in favour of hydrometric network upgrades than members of Class One. Further in line with our expectations, preferences for the number of gauging stations was associated with a positive and statistically significant figure of 0.003 at the 99.99% level of confidence. Although a reduced frequency of data collection was disliked, as shown by a coefficient of -0.013, this effect was not significantly different from zero. The provision of a web-enabled camera providing real-time river views continued to attract the approval of individuals in Class Two. This was signified by a positively-weighted coefficient of 0.375, statistically different from zero at the 99.99% level. The coefficient for data type (0.939) showed that members of Class Two received a high level of utility from the knowledge that gauging stations were being operated to collect flow data rather than river level data alone. This effect was significant at the 99.99% level. Finally, members of Class Two felt that higher costs associated with river hydrometry would leave them worse-off. This was indicated by a negative cost parameter of -0.029 significantly different from zero at the 99.99% level.

The membership function used to determine an individual's class assignment normalised Class One so that each socio-economic model parameter indicated the probability that an individual characterised by a selected variable was a member of Class Two relative to Class One. Findings showed that members of the following groups were more likely to belong to Class 2 than to Class 1: females, data users, family households, degree holders, owner occupants, senior citizens, working individuals, business owners and those living further away from a river/stream. However the only class membership coefficients which were significantly different from zero among these categories were effects associated with females (0.553; significant at the 99.99% level); data users (1.551; significant at the 99.99% level); degree holders (0.255; significant at the 90% level); homeowner-occupants (0.393 significant at the 95% level); family households (0.318; significant at the 95% level) and business owners (0.810; significant at the 99% level). The effects associated with senior citizens, employees and those residing further away from a river /stream were not statistically different from zero. On the other hand, the results also showed that individuals with a low income (-0.075; not significantly different from zero) and the past flooding of a respondent's dwelling (-1.090; statistically significant at the 99.99% level) were most likely to be assigned to Class One.

The picture which emerges from the inclusion of socio-economic variables to determine class assignment is again of: (i) a passive, minimalist set of users who strongly prefer to leave the river gauging network alone but who nevertheless desire opportunities to engage more visually with rivers by means of digitally-enabled footage of the river. Such individuals are likely to be on a low income and to have experienced flooding in their current dwelling in the past, and; (ii) a more activist cohort which prefers an expansion of the river gauging network and all of its concomitant features such the number of hourly data updates, real-time river views and flow-grade data capability. Such individuals are more likely to be female, home and business owners and to hold a degree. It is also likely that members of this group visit the SEPA webpages and consult water level readings provided for individual stations, perhaps in order to assess level and flow conditions for recreational activities such as canoeing or fishing; that is, they are likely to be hydrometric data users.

Model 3: Latent Class Model with Cognitive Effects.

A third model was estimated in order to assess the impacts of 'soft' indicators such as attitudes and beliefs on the class assignment probabilities of respondents. These variables were designed to measure cognitive aspects of individual decision-making processes and were added to the socio-demographic characteristics examined in Model 2. The variables included:

Table 6.4: Indicators used to measure cognitive influences on class assignment probability.

Indicator	Description
BSEAI Mean Action Score	Average score taken from total of responses to statements indicating beliefs in support of environmental action. Statements were scored from 0-4 with 0 indicating no opinion, 1 indicating strong disagreement and 4 indicating strong agreement. Intermediate levels were coded as 2 for 'somewhat disagree' and 3 for 'somewhat agree'. That is, scores arranged to represent a continuum from disagreement (low score) to agreement (higher score).
BSEAI Mean InAction Score	Average score taken from total of responses to statements indicating beliefs in support of environmental inaction. Statements were scored from 0-4 with 0 indicating no opinion, 1 indicating strong disagreement and 4 indicating strong agreement with the statement. Intermediate levels were coded as 2 for 'somewhat disagree' and 3 for 'somewhat agree'. That is, scores arranged to represent a continuum from disagreement (low score) to agreement (higher score).

Awareness Mean	Average score taken from total of responses to statements describing specific hydrometric data applications. Statements were scored from 0-3 where 0 indicated total unfamiliarity of an application while 3 indicated full awareness of the application. Thus scores were arranged to represent a continuum of awareness from poor awareness (low score) to high awareness (high score).
Certainty Level Mean Score	Average score taken from level of respondent certainty in selecting a given hydrometric alternative. Levels were scored from 1 to 5 where 1 indicated no certainty and 5 indicated full certainty.
Public Policy Ranking	Score out of ten calculated for importance of Natural Environment as an area of public policy relative to nine competing public policy areas. These included Welfare and Unemployment; Arts, Culture and Tourism; Enterprise and International Trade; Transport; Banking and Finance; Housing and Regeneration; Information, Communication and Digital Technology; Education and Training; Aid and Assistance to Developing Nations.

Results from Model 3 reflected findings from earlier modelling iterations showing the formation of preferences along two key profiles. Importantly, it was witnessed that the model fit statistics also improved with a rise in the log-likelihood ratio from -1765.2 (model 2) to -1744.5 (model 3) and a further minimisation of the AIC and BIC statistics, respectively, from 3590.4 (model 2) to 3558.9 (model 3) and 3751.7 (model 2) to 3747.1 (model 3). However it is also important to point out the smaller scale of improvements in model fit statistics, not least the BIC. This highlights the different values prioritised by competing information criteria used for model selection.

In Class One the coefficients associated with each of the Alternative Specific Constants (ASCs) were estimated at -1.993 (Upgrade 1, statistically significant at the 95% level); -1.953 (Upgrade 2, statistically significant at the 95% level); -2.758 (Downgrade, statistically significant at the 99% level) and -2.355 (‘None’, statistically significant at the 99% level). These figures showed that Class One preferences remained stable across alternative (and increasingly complex) model specifications when additional heterogeneity in the sample population was taken into account: hydrometric transformation options were disliked overall in reference to the current facility. More river gauging stations were also seen as being desirable as demonstrated by a coefficient of 0.002, however the effect was not significant. The addition to class utility from gauging stations was thus small and unimportant in explaining the preferences of this group. A loss of frequency in data collections was disliked. The coefficient associated with this variable was -0.004, but also insignificant in explaining group-based preferences. Real-time river views were welcomed according to the positive sign associated with the coefficient of 0.483, but yet again the effect was not statistically different from zero at any conventional level. The effect for data type, estimated at 0.129, was also not statistically different from zero for Class One in Model 3. This variable aimed to capture respondent preferences for collecting discharge (flow) data in addition to river level readings. A comparison of the parameter's magnitude across preceding modelling iterations seems to show a level of variability in preferences for the importance of flow data within the group, suggesting that some members probably value flow data more highly than others. Finally, the cost variable was estimated significantly different from zero at the 99.99% level with a coefficient of -0.018, once again showing that higher costs associated with river hydrometry were disliked.

In Class Two, members also continued to demonstrate a general preference for upgrades to the hydrometric facility. The ASC coefficients associated with network upgrade alternatives were estimated at 0.358 and 0.359, significant at the 95% and 90% levels respectively. Similarly, the downgrade and 'none' options were not welcomed, with very strong effects at the 99.99 levels for the two coefficients. These were estimated at -2.601 and -1.546 respectively.

Increased numbers of continuous river gauges were welcomed (coefficient 0.003; highly significant at the 99.99% level), as was an opportunity for real-time river views enabled by a web-enabled water camera (coefficient 0.391, significant at the 99.99% level) and the enhanced operation of stations to produce not just river level measurements but also river discharge (flow) estimates (coefficient 0.924 significant at the 99.99% level). At the same time, reductions in data collection frequency were unappealing (coefficient -0.013 but not significant at any conventional level) as were prospects of rising river hydrometry costs. The cost coefficient was estimated at -0.030 and was significantly different from zero at the 99.99% level.

Socio-economic indicators in Model 3 showed that females, data users, families (households comprising three people or more), senior citizens and business owners were more likely to be members of Class Two than of Class One. Effects associated with these indicators were highly statistically different from zero. Other socio-economic features suggesting a higher probability of assignment to Class Two included education to degree level, living further away from a river, being employed and a homeowner. However the estimated effects of these parameters were not statistically different from zero in Model 3. At the same time, respondents on a low income and those whose dwellings had been previously flooded were more likely to be members of Class One. The coefficients associated with these factors were -0.539 (low income) and -0.998 (dwelling flooded) estimated significantly different from zero at the 95% and 99% levels respectively. When compared with Model 2, these figures demonstrate the effects of senior citizens as fresh determinants of Class 2 membership and low income as a mildly significant determinant of belonging to Class One. Conversely the effects of education and homeownership are no longer important as determinants of class membership when progressing from Model 2 to Model 3.

The most interesting results from Model 3 are estimates of cognitive or 'soft' determinants of class membership. These variables aim to capture the influence of individual beliefs and attitudes on group-based preferences for river hydrometry in Scotland. The first of five variables tested within the model included the BSEAI Mean Action Score. This was a summary measure for beliefs in support of environmental action, allowing us to examine whether people with pro-environmental perspectives were likely to constitute a discernible decision group within the wider the population. Model estimates showed that participants with a high mean score for environmental action were significantly more likely, at the 99.99% level, to be members of Class Two (coefficient 0.780). The second cognitive variable was the BSEAI Mean Inaction Score which aimed to determine if individuals supporting environmental inaction were also likely to have bespoke group preferences for the future state of river hydrometry in Scotland. Model estimates demonstrated that respondents with a high mean score for environmental inaction were significantly less likely to be members of Class Two and more likely to belong to Class One (coefficient -0.385). Again, this effect was significantly different from zero at the 99.99% level. A mean Awareness Score was the third factor estimated in the model. The aim of this metric was to test whether respondents with differing levels of knowledge on the many uses of hydrometric data were also likely to belong to a particular class within the population. Model estimates showed that participants with higher levels of awareness about competing hydrometric data uses were much more likely to be members of Class 2 (coefficient 0.558). This effect was significantly from zero at the 99.99% level. Fourth, the effect of participant confidence was tested as determinant of class membership. This variable sought to establish whether individuals who were more certain of their choices for river hydrometry were also likely to belong a bespoke group with distinct preferences. Findings showed that the more certain a respondent was of their hydrometric choices, the more likely they were to be a member of Class Two. The coefficient associated with the Certainty Score was 0.371 and the effect was significantly different from zero at the 99.99% level. Finally, the political importance of the natural environment was tested as a determinant of group-based preferences for river hydrometry. In particular, we wished to investigate whether individuals attaching a higher importance to the natural environment relative to competing public policy areas displayed any group affinities with their associated preference profiles. Results showed that participants who prioritised competing areas of public policy above the natural environment were less likely to be members of Class Two. In other words, individuals for whom the natural environment was unimportant relative to other public policy areas were more likely to belong in Class One. The coefficient for this effect was -1.094, significant at the 99.99% level.

Findings from Model 3 support the typologies seen to emerge from earlier versions of the latent class series. Class One is seen to take further shape and structure as a minimalist, environmentally-passive group whose members are likely to be on a low income and to have experienced flooding in their homes in the past. They are also likely to hold beliefs and attitudes supporting environmental inaction and to attach a low level of political priority to the natural environment. This group does not receive much utility from an expansion in the river gauging network and generally prefers a maintenance of the status quo infrastructure but strongly welcomes digitally-enabled real-time views of the river channel relative to other facilities. In contrast members of Class Two receive much more peace-of-mind from an expanded river gauging network and all its features across the board; more stations, more sub-hourly updates, provision of real-time river views and an enhanced capacity for collecting river discharge (flow) data. Individuals found in this class are more likely to be female, data users, families, senior citizens and business owners. They are also likely to hold beliefs supporting environmental action and to be more aware of the usefulness of hydrometric data for various purposes. Finally, they are also likely to be more certain of their environmental preferences and to rate the natural environment as a high political priority.

Model 4: Latent Class Model with Random Parameters.

In Models 1-3 it was assumed that preferences within classes were homogenous. In other words, all members within a class were assumed to have the same (fixed) parameters associated with the main attributes, and that these parameters varied only across different classes (heterogeneity across classes). However, such an assumption might be unrealistic, as preferences of individual members *within* a group are also likely to vary in their sensitivity to the available alternatives and attributes. Accordingly, several researchers have derived models with discrete-continuous mixing distributions of unobserved heterogeneity in the form of a finite mixture of normal densities (Rossi et. al., 2005; Bujosa et. al., 2010). This type of model is known as a Latent Class Model with Random Parameters (LC-RPL) (Hensher et.

al. 2015) or a Mixed-Mixed Multinomial Logit Model (MM-MNL) (Keane and Wasi, 2013). A formal definition of the economic model is given in Chapter 4. For further information on estimating these models see Sarrias and Daziano (2017).

Following these studies Model 4 was estimated by including the same socio-economic and cognitive characteristics featured in Models 2 and 3 while the main attribute parameters were allowed to vary randomly according to a Normal distribution. Results from this model specification are displayed in Table 6.2. Alongside the individual-specific mean parameter estimates it is also important to examine the standard deviations of the estimated parameters. These are displayed in an adjacent set of columns to main (mean) parameters in the same table. The significance of several standard deviation estimates clearly suggests that preferences for several hydrometric attributes are indeed heterogeneous within both groups. In terms of overall model performance the key difference to note is the improvement in model fit as reported by the Log-Likelihood ratio (-1421.2) and both Akaike and Bayesian information criteria (2948.3 and 3233.2 respectively).

In terms of the parameter estimates, Class One ASC coefficients are again all negative. The strongest effects are witnessed in the aversion of this class's members to a downgrade and an undefined 'none' outcome relative to the current facility. The coefficients associated with these ASCs are estimated at -24.479 and -71.758 respectively where both effects are important at the 99% level. Taking account of within-class heterogeneity also shows that there are significant variations in Class One's preferences for the Upgrade One, Downgrade and None alternatives as shown by the increasing levels of statistical significance in the standard deviations associated with these figures. The coefficient associated with the number of stations is -0.0022 and significant at the 90% level. This shows that the expansion in number of river gauging stations holds a small and mild disutility for members of Class One. Again, the preferences for this attribute are heterogeneous as captured by the standard deviation coefficient which is estimated with a statistically significant effect at the 99% level. The coefficient for number of data collections per hour (Frequency: -0.078) is negative as expected but not significantly different from zero for members of Class One. However the model does show that a mild degree of heterogeneity is present in preferences for this attribute as demonstrated by the standard deviation parameter that is significantly different from zero at the 90% level. Similarly, although the mean coefficients for real-time river views and flow-operated stations are positively valenced, the effects of the attributes are unimportant overall in explaining class utility, and preferences within the group are seen to vary to a mild degree for both hydrometric features. The cost parameter (-0.438) was negative as expected and of larger magnitude to results from earlier model iterations. Also, there is no significant deviation in preferences against increasing costs among members of Class One.

Results for Class Two demonstrate that upgrades to the current hydrometric facility are generally welcomed, and that a high degree of heterogeneity exists among members of the group. This is shown by the positively valenced mean estimates for both Upgrade ASCs and the statistically significant standard deviations at the 99.99% level. An even stronger finding however is that a hydrometric downgrade and a catchall 'None' option are significantly disliked by Class Two members. The coefficients associated with the mean ASCs of these options are -5.336 and -7.944 respectively, statistically different from zero at the 99.99% level. The model also shows that preferences for these outcomes vary significantly within the group. This is shown by the standard deviation coefficients which are estimated as statistically important at the 99.99% level.

The coefficient for stations (0.003) was broadly in line with earlier model estimates and significant at the 99.99% level. In contrast to previous findings however increased sub-hourly updates of river levels were now mildly welcomed lending validity to the expected impact of this attribute (coefficient -0.031 significant at the 90% level). Real-time river views brought positive utility to member of Class Two (coefficient 0.733 significant at the 99.99% level) and again the impact on utility was considerably higher than earlier model estimates. The coefficient associated with Data Type was 1.542 and statistically different from zero at the 99.99% level. As expected collecting river discharge (flow) data was preferred to readings of river levels alone, while higher costs associated with river hydrometry were disliked (cost coefficient -0.039, significant at the 99.99% level). In all cases, it is interesting to note that a high level of heterogeneity exists for all attributes and alternatives among Class Two members. This is captured by the standard deviation estimates which are statistically different from zero at the 99.99% level.

In terms of the probability of being assigned to specific classes, results from Model 4 demonstrate both consistency and divergence from previous models. As before, females, owner-occupants and business owners are significantly more likely to belong to Class Two than to Class One. However, taking within-and-across class heterogeneity into account shows that those living further away from a river, flood survivors and working individuals are also now more likely to be assigned as Class Two members. Erstwhile individual and household characteristics (e.g. data users, family households and degree holders) and are no longer important determinants for this group when the variation in preferences across both classes is factored in to the model. In terms of cognitive factors, results from the model show that pro-environmentalists and hydrometrically aware individuals continue to be probabilistically assigned to Group Two. Equally those favouring environmental inaction and for whom competing policy areas take precedence over the environment are more like to belong in Class One. The estimated proportions of Class One and Class Two membership is given in Table 6.3. This shows that approximately 70% of the population is likely to be assigned to Class Two, while 30% belongs to Class One.

6.3. Welfare Analysis

Mean Willingness to Pay for Hydrometric Attributes

Coefficients obtained from the latent class models can be used to derive welfare estimates and, in particular, both mean and marginal willingness to pay figures (WTP) for the main attributes. The WTP can be obtained by dividing the coefficient of a hydrometric attribute by the coefficient of the cost attribute. These figures not only provide us with an idea of how valuable each attribute is in monetary terms, but also indicate the intensity of preferences for hydrometric service features.

Estimates of the mean willingness to pay for each hydrometric attribute by model and class are provided in Table 6.5 along with confidence intervals calculated according to the Krinsky-Robb method. Since Model 4 (latent class model with random parameters (LC-RPAR) offered the best fitting model, the WTP estimates obtained from the coefficients of this model are selected for discussion. The figures show that households in Class One are willing-to-*accept* 5 pence per station since increasing the size of the gauging network does not yield any utility for this group. Diverting resources to hydrometric stations would thus require compensation to this group in order to convince them to live with the change. Each minute of time added to the interval between data readings is valued at 18 pence for members of Class One. Households in this group are also willing to pay an average of £5.34 for real-time river views but only about £1.43 for flow grade data instead of 'level-only' readings. However the confidence intervals associated with each estimate provide an insight into the upper and lower limits of how much more or less members of the group are willing to pay/accept for each attribute.

Members of Class Two are willing to pay an average of 9 pence per station. Moreover every minute of delay between successive data readings would require compensation of 79 pence for members of this class. In order to secure real-time river views they would be prepared to pay an average of £18.84 (up to a maximum of £38.86) and operating stations to collect discharge-grade data rather than 'level-only' statistics would attract contributions of £39.65 on average, up to a maximum of £63.84. It is important to remember that these figures represent once-in-a-lifetime payment which was initially described to study participants when conducting the choice experiment. The LC-RPAR estimates also give us a more nuanced picture of the members of either class. Whereas earlier, we had speculated that Class One occupants were likely to be environmental minimalists, what this model seems to reveal is that this group might be better described as 'Hydrometric Satisficers'. In other words they wish to economise on what they view as non-essential aspects of river gauging activity and elect to focus their resources on the most critical features that are relevant to them and their lifestyles; good quality flow data and opportunities to assess river conditions visually for themselves when required. In comparison, members of Class Two might be described as 'Hydrometric Maximisers'. Members of this group are prepared to spend a higher amount across the board in order to achieve an enhanced river gauging network.

Marginal Willingness to Pay

Real-Time Views and Discharge (Flow) Data

Building on mean willingness-to-pay estimates, an interesting question focuses on how much the sampled households were prepared to contribute (or receive) in order to secure (or endure) a change in the levels of hydrometric attributes. In terms of the qualitative attributes (webcam and data type), a marginal change simply refers to a conversion in absolute provision, that is, from real-time views and flow-operated stations becoming available following circumstances in which they were not originally provided. These figures are same as the mean WTP estimates given in Table 6.5 for Data Type and Webcam for each class: £5.34 for real-time views (Class One) vs. £18.84(Class Two), and; £1.43 for Discharge-operated stations (Class One) vs. £39.65 (Class Two).

Stations

In contrast to webcams and data type, the continuous attributes (Number of Stations and Frequency) can be analysed in finer detail to reveal the value of each level of provision to members of either class. Table 6.6 for example displays the impact on mean willingness-to-pay if the gauging station network were expanded or downgraded by a specific magnitude. For example, if the preferences of Class Two are analysed by starting with a base willingness-to-pay value of 9 pence then households in this group would be willing to pay (£0.09 x 392=)

£35.03 for the current network which hosts 392 river gauging stations. From this basic level, they would then be willing to contribute an additional £3.49 for expanding the gauging network by 10%, which would deliver 39 new stations. The total value per household in Class Two of a gauging network comprising 431 stations rather than the current 392 is thus (£35.03+ £3.49 =) £38.52. Similarly, each household would be willing to pay an additional £8.76 for a 25% expansion in the number of gauging stations; £17.52 for a 50% expansion and £35.03 for a doubling of the current network, from 392 to a total of 784 stations. All along the reader should keep in mind the variation in each of these figures, presented as the confidence intervals associated with each estimate. The table also shows that households in Class Two would not welcome a downgrade of current river gauging facilities. In order to live with this change, the average household would require compensation to the tune of £17.16 for a 50% reduction in the number of stations, such that only 200 stations were now available across the network rather than the current 392. This reduces their net willingness-to-pay to (£35.03 – 17.16=) £17.87. A similar approach can also be employed to determine the marginal preferences of Class One.

Frequency

Table 6.7 presents a similar set of marginal estimates for the value of time, or frequency of river level readings. A household in Class Two would be willing to *accept* (£0.79 x 15mins=) £11.83 for a basic 15 min interval between consecutive measurements of river level. A further delay of a 15 mins would require compensation of an additional £11.83, bringing the total willingness to accept a 30 min time interval to (£11.83+11.83=) £23.66. A single hourly collection would increase this compensation figure to £47.33. Similarly, a household would be willing to pay an extra £7.89 for a 10-min saving or 8 more readings of river level per hour. This would lower their willingness-to-accept figure to (£11.83 - £7.89=) £3.94. Reducing the time-interval between river level readings even further to a 1 minute frequency (60 observations per hour) would thus reduce the total willingness-to-accept value from £11.83 to (£-11.83+11.04=) £0.79.

Aggregate Willingness-to-Pay

Aggregate willingness-to-pay estimates provide insights into the value of changes in levels of hydrometric attributes at the population level. These are presented for the mixed logit and latent class random parameter models in Table 6.8. The figures for mean willingness to pay were aggregated across 2.4 million households in Scotland as detailed in the last census (ONS, 2014). An example of how to read and interpret the figures is provided in the notes section at the bottom of the table. For example the baseline value for stations using utility estimates from the 'best fit' mixed logit model, which accounts for both socio-economic and cognitive effects, is (£0.06 x 392 stations x 2.4M households=) £59,806,656. Installing ninety-eight more stations adds £14,951,664 to this figure. Marginal estimates are useful in order to assess the value of changes to the current network based on the sensitivity of users to particular attributes. However, in order to determine the average current value of the hydrometric service to all households, a summing of the attribute baseline estimates is required. Selecting only the effective core attributes (i.e. stations, data type and frequency) yields a total gross value of £88,052,976. Net of operating costs of £3,427,414 (costs for financial year 2014-15), this indicates a residual non-market benefit to society of £84,625,562 arising from the standard provision of hydrometric data to households in Scotland. The net economic benefit-to-cost ratio for standard data provision is thus £24.69 in non-market benefits to every £1 of costs, or about 25 to 1. At the same time, if additional facilities such as real-time river views were provided then this would increase the net benefit value to society to £115,144,586. The additional feature would therefore produce a potential benefit-cost ratio of £33.60 in non-market benefits to every £1 of costs, or about 34 to 1 for households across Scotland. Further information is shown in Table 6.9. Similarly, if estimates from Latent Class with Random Parameters model are used to calculate aggregate benefits, then the net non-market benefit-to-cost ratio on the basis of the core attributes is £25.87 in economic benefits for £1 in costs; that is, also around 25 to 1. This rises to £36.29 in non-market benefits for every £1 expended in costs when the value of real-time river views is incorporated. These estimates are displayed in Table 6.10.

6.4. Conclusion

This chapter analysed household preferences for hydrometric data using a series of latent class models, and also a latent class random parameter model. The latter offers the benefits of both a mixed logit and latent class specification by delineating group-based heterogeneity and then allowing preferences to vary randomly within groups. Results showed that the latter model offered a more optimal fit of the data compared both with the simple latent class models and the mixed logit models. Utility estimates from the Latent Class Random Parameter model were then used to calculate mean, marginal and aggregate willingness to pay values for the alternative hydrometric attributes used to characterise the river hydrometric system in Scotland. Results showed that households were divided into two broad groups: Hydrometric Satisficers and Hydrometric Maximisers. Maximisers comprised approximately 70% of the population and were willing to contribute significant premiums over Satisficers in order to secure infrastructure upgrades to current river gauging facilities. In the next chapter, the preferences of business users of hydrometric data will be analysed.

Table 6.5: Mean Willingness to Pay by Class

	[1]. Main Effects Model	[2]. Main and Socio-Economic Effects Model	[3]. Main, Socio-Economic and Cognitive Effects Model	[4]. Latent Class Random Parameters Model
Class One				
STATIONS	0.01 (-0.04 to 0.10)	0.01 (-0.01 to 0.06)	0.02 (-0.01 to 0.11)	-0.05 (-0.09 to -0.01)
FREQUENCY	0.10 (-0.33 to 0.49)	-0.08 (-0.52 to 0.24)	-0.07 (-0.71 to 0.33)	-0.18 (-0.72 to 0.08)
WEBCAM	10.39 (-5.37 to 48.91)	8.53 (-0.85 to 24.60)	7.42 (-4.34 to 34.35)	5.34 (-5.20 to 22.54)
DATA TYPE	-0.47 (-5.95 to 5.02)	3.02 (-0.54 to 7.72)	1.98 (-3.13 to 8.13)	1.43 (-1.52 to 6.36)
Class Two				
STATIONS	0.07 (0.05 to 0.11)	0.09 (0.06 to 0.16)	0.09 (0.05 to 0.14)	0.09 (0.05 to 0.17)
FREQUENCY	-0.17 (-0.79 to 0.32)	-0.45 (-1.64 to 0.34)	-0.44 (-1.47 to 0.27)	-0.79 (-2.23 to 0.08)
WEBCAM	13.60 (8.06 to 21.68)	13.06 (5.53 to 26.53)	13.04 (5.73 to 25.17)	18.84 (8.98 to 38.86)
DATA TYPE	25.74 (21.07 to 32.51)	32.66 (24.77 to 47.00)	30.80 (23.61 to 42.89)	39.65 (28.18 to 63.84)

Notes: (1). Figures in brackets represent 95% confidence intervals for Willingness-to-Pay estimates. (2). Confidence intervals calculated using the Krinsky-Robb method. (3). Negatively-valenced figures imply that users would be willing to accept compensation for a change in the level of the attribute. (4). All figures are in GBP (£).

Table 6.6: Willingness-to-Pay for Hydrometric Stations: Latent Class Random Parameter Model

Total Number of Stations	Additional Stations	Hydrometric Network Adjustment	Mean Willingness-to-Pay		
			Class One	*Class Two*	*Average for Both Classes*
200	-192	-50% (approx.)	+ £9.45 (£16.59 to £1.68)	-£17.16 (-£9.45 to -£32.33)	-£9.35 (-£1.80 to -£22.34)
392	**0**	**0**	**-£19.28 (-£33.88 to -£3.43)**	**£35.03 (£19.29 to £66.00)**	**£19.09 (£3.68 to £45.62)**
431	+39	+10%	-£1.92 (-£3.37 to -£0.34)	+£3.49 (£1.92 to £6.57)	+£1.90 (£0.37 to £4.54)
490	+98	+25%	-£4.82 (-£8.47 to -£0.86)	+£8.76 (£4.82 to £16.50)	+£4.77 (£0.92 to £11.40)
588	+196	+50%	-£9.64 (-£16.94 to -£1.71)	+£17.52 (£9.64 to £33.00)	+£9.54 (£1.84 to £22.81)
686	+294	+75%	-£14.46 (-£25.41 to -£2.57)	+£26.27 (£14.47 to £49.50)	+£14.31 (£2.76 to £34.21)
784	+392	+100%	-£19.28 (-£33.88 to -£3.43)	+£35.03 (£19.29 to £66.00)	+£19.09 (£3.68 to £45.62)

Notes: (1). 95% confidence intervals for mean willingness-to-pay (wtp) estimates are shown in brackets. (2). Estimates are relative to a baseline of 392 stations which approximates the size of the current river gauging network in Scotland. All figures above represent marginal values and should be added/subtracted from the baseline value to arrive at the net value per household for a given change in attribute level. For example the baseline value for stations weighted across both classes is £19.09. Installing ninety-eight more stations adds £4.77 to this figure. (3). Class One accounts for preferences of 29% of the population; Class Two for 71%. (4). Average across both classes computed by weighting individual class estimates with the class membership distribution.

Table 6.7: Willingness-to-Pay for Hydrometric Frequency: Latent Class Random Parameter Model

Frequency of River Level Measurement	**Time Loss**	**Total Observations Recorded**	**Additional Observations Recorded**	**Mean Willingness-to-Pay**		
				Class One	*Class Two*	*Average for Both Classes*
Every 1 min	-14 mins	60	+56	£2.49 (£10.01 to -£1.07)	£11.04 (£31.24 to -£1.10)	£8.53 (£25.01 to -£1.09)
Every 2 mins	-13 mins	30	+26	£2.31 (£9.30 to -£1.00)	£10.25 (£29.01 to -£1.02)	£7.92 (£23.22 to -£1.01)
Every 5 mins	-10 mins	12	+8	£1.78 (£7.15 to -£0.77)	£7.89 (£22.32 to -£0.78)	£6.09 (£17.86 to -£0.78)
Every 15 mins	**0**	**4**	**0**	**-£2.67 (-£10.73 to £1.15)**	**-£11.83 (-£33.47 to £1.18)**	**-£9.14 (-£26.80 to -£1.17)**
Every 30 mins	+15 mins	2	-2	-£2.67 (-£10.73 to £1.15)	-£11.83 (-£33.47 to £1.18)	-£9.14 (-£26.80 to £1.17)
Every 60 mins	+45 mins	1	-3	-£8.00 (-£32.19 to £3.45)	-£35.50 (-£100.42 to £3.53)	-£27.42 (-£80.39 to £3.51)

Notes: (1). 95% confidence intervals for mean willingness-to-pay (wtp) estimates are shown in brackets in column four. (2). Estimates are relative to a frequency baseline of 15 mins (4 river level measurements per hour) which approximates the temporal resolution of the current river gauging network in Scotland. All figures above represent marginal values and should be added/subtracted from the baseline value to arrive at the net value for a given change in the attribute level. For example the baseline for the weighted average across both classes for data every 15 mins is -£9.14. Increasing the collection frequency to every 1 min adds £8.53 to this figure, bringing the overall compensation required to (£9.14 - 8.53=) £0.61. (3). The average household across both classes would require compensation of at least (£9.14+9.14=) £18.28 in order to accept a time loss of 15 mins (or two fewer data readings per hour than the four observations currently made). This is shown by the negative sign preceding the wtp estimate in column seven.

Table 6.8: Aggregate Willingness-to-Pay for River Hydrometry

	Aggregate Willingness-to-Pay Estimates			
Attributes	**Mixed Logit Model with Cognitive Effects**	**Latent Class Random Parameter Model**		
		Class 1	Class 2	Avg. across Both Classes
STATIONS *(baseline = 392 stns)*				
+39 stns [+10%]	**£5,950,152.00** (£3,687,840.00 to £9,473,256.00)	-£4,604,464.80 (-£8,088,912.00 to -£818,719.20)	£8,364,938.40 (£4,605,962.40 to £15,759,244.80)	**£4,557,121.62** (£878,747.28 to £10,891,954.57)
+98 stns [25%]	**£14,951,664.00** (£9,266,880.00 to £23,804,592.00)	-£11,570,193.60 (-£20,325,984.00 to -£2,057,294.40)	£21,019,588.80 (£11,573,956.80 to £39,600,153.60)	**£11,451,228.69** (£2,208,134.18 to £27,369,526.87)
+196 stns [+50%]	**£29,903,328.00** (£18,533,760.00 to £47,609,184.00)	-£23,140,387.20 (-£40,651,968.00 to -£4,114,588.80)	£42,039,177.60 (£23,147,913.60 to £79,200,307.20)	**£22,902,457.37** (£4,416,268.36 to £54,739,053.73)
+294 stns [+75%]	**£44,854,992.00** (£27,800,640.00 to £71,413,776.00)	-£34,710,580.80 (-£60,977,952.00 to -£6,171,883.20)	£63,058,766.40 (£34,721,870.40 to £118,800,460.80)	**£34,353,686.06** (£6,624,402.54 to £82,108,580.60)
+392 stns [+100%]	**£59,806,656.00** (£37,067,520.00 to £95,218,368.00)	-£46,280,774.40 (-£81,303,936.00 to -£8,229,177.60)	£84,078,355.20 (£46,295,827.20 to £158,400,614.40)	**£45,804,914.75** (£8,832,536.72 to £109,478,107.47)
-192 stns [-50%]	***-£29,293,056.00*** (-£18,155,520.00 to -£46,637,568.00)	£22,668,134.40 (£39,822,336.00 to £4,030,617.60)	-£41,181,235.20 (-£22,675,507.20 to -£77,583,974.40)	***-£22,435,060.29*** (-£4,326,140.44 to -£53,621,930.19)
FREQUENCY (baseline = every 15 min)				
-14 mins	**£17,877,216.00** (-£593,376.00 to £43,485,456.00)	£5,970,081.60 (-£2,572,416.00 to £24,035,256.00)	£26,504,889.60 (-£2,636,390.40 to £74,979,643.20)	**£20,475,869.97** (-£2,617,607.52 to £60,022,371.12)
-13 mins	**£16,600,272.00** (-£550,992.00 to £40,379,352.00)	£5,543,647.20 (-£2,388,672.00 to £22,318,452.00)	£24,611,683.20 (-£2,448,076.80 to £69,623,954.40)	**£19,013,307.83** (-£2,430,635.55 to £55,735,058.90)
-10 mins	**£12,769,440.00** (-£423,840.00 to £31,061,040.00)	£4,264,344.00 (-£1,837,440.00 to £17,168,040.00)	£18,932,064.00 (-£1,883,136.00 to £53,556,888.00)	**£14,625,621.41** (-£1,869,719.65 to £42,873,122.23)
+15 mins	***-£19,154,160.00*** (£635,760.00 to -£46,591,560.00)	-£6,396,516.00 (-£25,752,060.00 to £2,756,160.00)	-£28,398,096.00 (-£80,335,332.00 to £2,824,704.00)	***-£21,938,432.11*** (-£64,309,683.34 to £2,804,579.48)
+45 mins	***-£57,462,480.00*** (£1,907,280.00 to -£139,774,680.00)	-£19,189,548.00 (-£77,256,180.00 to £8,268,480.00)	-£85,194,288.00 (-£241,005,996.00 to £8,474,112.00)	***-£65,815,296.34*** (-£192,929,050.02 to £8,413,738.44)
WEBCAM				
Provided	**£30,519,024.00** (£14,501,736.00 to £55,270,656.00)	£12,817,795.20 (-£12,491,820.00 to £54,097,053.60)	£45,218,371.20 (£21,545,858.40 to £93,252,264.00)	**£35,705,562.09** (£11,552,396.02 to £81,756,294.23)
DATA TYPE				
Provided	**£47,400,480.00** (£35,680,176.00 to £65,610,192.00)	£3,424,113.60 (-£3,652,545.60 to £15,268,214.40)	£95,167,884.00 (£67,633,101.60 to £153,208,108.80)	**£68,231,913.01** (£46,703,635.58 to £112,708,955.80)

Notes: (1). Aggregate values refer to willingness-to-pay (wtp) across all households in Scotland. This was assumed at 2.4 million as at 2013 census (ONS 2014). (2). Confidence intervals for wtp estimates shown in brackets. (3). Attribute level changes which represent a worsening scenario relative to current provision are displayed in italics. Users would require compensation to accept this level of change so wtp estimates are preceded by a negative sign. (4). All figures above represent marginal values and should be added or subtracted from the baseline value to arrive at the net value for a given change in attribute level. For example, using the Mixed Logit estimates, the baseline value for stations is (£0.06 x 392 x 2.4M households =) £59,806,656. Installing ninety-eight more stations, or a 10% expansion in the current gauging network, adds £14,951,664 to this figure.

Table 6.9: Net Non-Market Benefits and Costs of providing Hydrometric Data to Scottish Households: Mixed Logit Model

Benefits of Data Provision		Cost of Data Provision	Net Benefits	Net Benefit-Cost Ratio
Core Attributes	£	£	£	
Stations	59,806,656.00	-	-	-
Data Type	47,400,480.00	-	-	-
Frequency	-19,154,160.00	-	-	-
Total	88,052,976.00	£3,427,414.00	£84,625,562.00	24.69
Additional Attributes				
Real-Time Views	30,519,024.00	-	-	-
Total	118,572,000.00	£3,427,414.00	£115,144,586.00	33.60

Notes: (1). Costs refer to annual operating costs of the Hydrometry Unit advised by the Scottish Environment Protection Agency (SEPA) for financial year 2014-15.

Table 6.10: Net Non-Market Benefits and Costs of providing Hydrometric Data to Scottish Households: Latent Class Model.

Benefits of Data Provision		Cost of Data Provision	Net Benefits	Net Benefit-Cost Ratio
Core Attributes	£	£	£	
Stations	£45,804,914.75	-	-	-
Data Type	£68,231,913.01	-	-	-
Frequency	-£21,938,432.11	-	-	-
Total	£92,098,395.65	£3,427,414.00	£88,670,981.65	25.87
Additional Attributes				
Real-Time Views	£35,705,562.09	-	-	-
Total	£127,803,957.74	£3,427,414.00	£124,376,543.74	36.29

Notes: (1). Costs refer to annual operating costs of the Hydrometry Unit advised by the Scottish Environment Protection Agency (SEPA) for financial year 2014-15.

Chapter 7

Business Preferences for Hydrometric Data:

Conditional and Mixed Logit Models

7.1. Introduction

A theoretical background to the multinomial logit, mixed logit (random parameters) and latent class models was provided in chapter 4. Chapters 5 and 6 presented the findings from a survey of hydrometric data preferences as reported by households in Scotland. Chapter 5 analysed the household data using the conditional (multinomial) logit and mixed logit model specifications while Chapter 6 focused on latent class modelling techniques in order to identify the preference profiles of different user segments among household respondents. Willingness-to-pay estimates were derived for the main attributes of hydrometric data and discussed in a household decision context. This chapter aims to conduct a similar analysis with data from a survey of hydrometric users in a professional setting.

7.2. Questionnaire and Construction of Choice Sets

Choice sets were generated using the software Ngene; statistical efficiency figures are presented in Chapter 4 and choice set outputs are provided in the appendices. As with the household survey, an efficient design was generated, intended to minimise the D-error of the choice sets. 70 choice occasions were created blocked in to 35 separate versions thereby resulting in 2 choice occasions per respondent. This blocking strategy was adopted in order to minimise the number of choice sets per respondent, as it was considered that in a professional, work-based environment, respondents would have little more time than 5-7 mins in order to complete the survey. The time-criticality of the business survey was also raised by participants in a pilot of the questionnaire undertaken in June 2016. Accordingly, the choice sets were swiftly presented to respondents following a concise introduction and a request for elementary professional and organisation-related information. Of this the main questions included type of organisation, number of employees in the organisation, annual turnover band, job title, number of years spent in current organisation, number of years spent using river hydrometric data, main purposes and uses for hydrometric data, gender, annual income band before tax, formal education and qualifications, and workplace postcode. Prior to embarking on the choice exercise, a detailed explanation of each attribute in the choice sets was also provided, and respondents were presented with a list of potential advantages and disadvantages of a hydrometric network expansion as a stimulus to an evaluative frame of mind for the forthcoming choice exercise. Following the two choice occasions, participants were asked if they had attached equal weight to all the attributes when making their choices and, if not, then which of attributes had proven most important. A graded scale from 'most important' to 'fifth-most important' was provided. Finally, at the end of the survey, participants were thanked for their responses, and a free-text box was provided for them to make any additional comments which the surveyed items had not identified.

7.3. Results

Recruitment of Participants

Professional users of hydrometric data were surveyed across Scotland between 17th and 31st May 2017. Potential participants were first sent an email one week before the survey date in order to introduce the research and to ascertain their interest in participating in the study. Those not wishing to take part were asked to reply to the introductory email with the word 'decline' in the subject line while those agreeing to participate were advised to simply await a link to the questionnaire without the need to do anything further. Participants were chosen on the basis of contacts recommended by SEPA; through contacts made at meetings, interviews, focus groups and events attended/conducted earlier during the project, and; by conducting independent research into relevant organisations and networks in the utility, higher education, local authority, private and voluntary sectors. Social media feeds, websites, emails, newsletters, brochures and published paper abstracts were used in order to identify suitable individuals for the study. A total sample of 403 people was compiled from which 118 responses were received. This yielded a response rate of 29%.

Descriptive Statistics

Over half of all professional respondents (59%) worked for commercial firms. Approximately one-third (35%) were small-to-medium sized organisations with 1-250 employees while one-half (50%) were large organisations employing over 1000 people. The modal annual turnover band was in excess of £100 million for 36% of organisations. About 70% of the respondents, or two-thirds of the cohort, had worked in the current organisation for between 1-10 years and 59% had been using hydrometric data for that same length of time. 92 respondents were male compared with 25 females. The annual modal income bracket was £30,000 - 49,000 for 58% of participants. Only 22% (26 professionals) reported earnings of over £50,000 per annum. Respondents were generally highly educated with over three-quarters (77%) having achieved a masters' or doctoral level qualification.

Table 7.1: Respondent Characteristics

Respondent & Organisation Characteristics		
	Responses	Per Cent
Formal Education/Qualifications:		
O'-Levels/GCSEs or Equivalent	2	2%
A'-Levels or Equivalent	0	0%
BA / BSc or Equivalent	23	19%
MA / MSc or Equivalent (incl. Chartered Accreditations)	55	47%
Doctoral or Equivalent	35	30%
Other	2	2%
No Formal Qualifications	1	1%
Total	**118**	**100%**
Annual Income (before tax)		
£ 8,000 - 15,999	4	3%
£ 16,000 - 23,999	8	7%
£ 24,000 - 29,999	12	10%
£ 30,000 - 49,999	68	58%
£ 50,000 - 69,999	22	19%
£ 70,000 - 99,999	4	3%
£ 100,000 and above	0	0%
Total	**118**	**100%**
Gender		
Male	93	78%
Female	25	21%
Total	**118**	**100%**
Type of Organisation		
Higher Education Institution	8	7%
Research/Scientific Organisation	8	7%
Commercial Firm - For Profit	70	59%
Non-Profit Organisation	8	7%
Voluntary Action/Interest Group	3	3%
Other Organisation	21	18%
Total	**118**	**100%**
Annual Turnover/Revenue for 2016/17		
£ 0 - 10,000	6	5%
£ 10,000 - 50,000	0	0%
£ 50,000 - 100,000	6	5%
£ 100,000 - 500,000	13	11%
£500,000 - 1,000,000	4	3%
£ 1 to 5 million	17	14%
£ 5 to 10 million	4	3%
£ 10 to 100 million	25	21%
Over 100 million	43	36%
Total	**118**	**100%**
Number of years spent in current organisation		
0 - 5 years	36	31%
6 - 10 years	47	40%

11 - 15 years	14	12%
16 - 20 years	11	9%
21 - 25 years	5	4%
26 - 30 years	1	1%
30 - 40 years	3	3%
40 - 50 years	1	1%
Total	**118**	**100%**
Number of employees in your entire organisation		
1 - 10 people	21	18%
11 - 25 people	5	4%
26 - 50 people	6	5%
51 - 100 people	3	3%
101 - 250 people	6	5%
251 - 500 people	10	8%
501 - 1000 people	8	7%
Over 1000 people	59	50%
Total	**118**	**100%**
For approximately how many years have you been using river hydrometric data?		
1 - 5 years	33	28%
6 - 10 years	37	31%
11 - 15 years	17	14%
16 - 20 years	9	8%
21 - 25 years	12	10%
26 - 30 years	4	3%
Over 30 years	6	5%
Total	**118**	**100%**

Model Estimation

Estimation Procedure

Two models were estimated using the choice data: a conditional logit model and a mixed logit model with main attributes. Estimations for both models were conducted using the package 'Mlogit' for R (Croissant, 2015), an open-source package available online from the Comprehensive R Archive Network (CRAN). The mixed logit model was simulated with 10,000 halton draws in light of the relatively small sample size; that is, 118 respondents making two valuations each yielding 236 choice occasions for analysis. This was in order to ensure that a global, and not local maximum was identified when seeking to maximise the value of the simulated maximum likelihood function (Train, 2003; Sarrias and Daziano, 2017). In addition, correlation was not permitted across the attributes as this multiplied the number of parameters for estimation considerably and, given the limited sample size, produced incongruous and exploding values in terms of estimated coefficients. Optimisation was conducted according to the 'Bfgs' method. Willingness-to-Pay and 95% confidence intervals based on the Krinsky-Robb method were calculated using the R package 'Support.CEs' (Aizaki, 2015). Both models were estimated relative to the opt-out alternative 'None', which represented the choices of participants who were either undecided or indifferent to the hydrometric alternatives on offer, or who may have had a preference for a river gauging option not available in the experiment. The choice might also be interpreted as a preference for no river gauging activity whatsoever. It is also possible that respondents choosing to opt-out were expressing resentment against the overall framework of the valuation exercise, and, by choosing 'None', were in effect choosing not to make trade-offs on the current facility thereby preferring to leave matters unaltered. Respondents may also have found that their effective decisions when consuming hydrometric data were not accurately reflected by the particular river gauging programmes presented in the experiment (Balcombe and Fraser, 2010). As shown in Table 7.3, 1.2% of respondents selected to opt-out. Setting this alternative as the reference option meant that the effects of constants specific to the two upgrades, the downgrade and the current facility could be interpreted relative to the combination of potential motives associated with the opt-out alternative.

The mixed logit model was also tested for the effects of respondent-specific characteristics on cost, stations and the alternative-specific constants. Variables included type of organisation (e.g. commercial vs. non-commercial); annual turnover; number of years for which hydrometric data has been used; number of employees; gender; higher degree (PhD); tenure and income level. However none of the interaction effects were significant or resulted in poor model fits in terms of Log-Likelihood or the AIC. This could be due to the limited number of choice occasions available for analysis, or the capturing of the most relevant sources of observed heterogeneity by the ten main non-monetary attributes in the model. Results of the two models are presented in Table 7.2.

Conditional Logit (CL) Model

The conditional logit was modelled with four Alternative-Specific Constants (ASCs). ASCs represent the effects of factors that are not accounted for by the modelled attributes, and as such capture residual or intrinsic preferences for an alternative. In this experiment the alternatives define competing states of the world for Scottish hydrometry, that is, whether the national river gauging programme ought to be delivered, and, if so, at what scale. The four possible programmes were a downgrade of the current facility operated at zero cost to the user; a continuation of the current facility that levied a positive charge on professional users based on the costs of the existing programme, and; two hypothetical upgrade configurations that would deliver major improvements in the present facility with correspondingly higher costs to the user. The estimated ASC coefficients showed that relative to a catchall 'None' gauging option, users had a mild but positive preference for a basic downgraded network. The coefficient value for this option was 12.393, significantly different from zero at the 90% level. Residual preferences for the current facility were also positive with an estimated coefficient of 4.938, but the effect was not statistically important. This meant that there was no significant difference in preferences between the opt-out alternative and the current facility. In contrast the upgrade alternatives were both estimated with negative but statistically insignificant effects; had the effects been important, then there would have been evidence that upgrades to the hydrometric system in Scotland were not generally welcomed. Figures for the main attributes showed that professional users received greater satisfaction from a larger number of river gauging stations, however the coefficient was small (0.005) and not statistically different from zero. Real-time views of the river channel were also welcomed. The coefficient for this attribute was estimated at 0.644 and significant at the 90% level. Similarly, professional data users preferred stations that were operated to collect discharge (flow) rather than just river level data and did not like wider error margins associated with hydrometric statistics. Of these however, only the estimate for data precision (-0.141) was significantly from zero at the 95% level. Users also disliked longer intervals between river level recordings as indicated by the estimated coefficient of -0.037 for the Frequency attribute but the effect was not significantly different from zero and therefore unimportant in explaining overall user preferences for hydrometric data. Enhanced metadata and advanced diagnostics both aim to provide more detailed insights, not just into the contents of river gauging data series but also into the bed, bank and cross-sectional profile of a river using advanced methods, instruments and visualisation technology. Although these services were viewed positively by users, they were also unimportant in adding any significant satisfaction to the user experience as demonstrated by the positive but statistically-insignificant coefficients estimated for these attributes. However one attribute which was identified as an important determinant of hydrometric utility was integrated provision – that is the amalgamation of river data provision with other types of environmental data collected by local and national authorities across Scotland. The coefficient estimated for this attribute was 0.732, significantly different from zero at the 95% level. By extension, it seems that users preferred to have access to the data online rather than having to request it in person, but yet again, the effect of this attribute was negligible. Finally, and as expected, users disliked having to wait longer to receive the data they had requested, and also disliked the prospect of having to pay more money in order to procure it. Neither attribute effect however was statistically different from zero.

Mixed Logit Model

The conditional logit model assumes that all respondents attach an identical level of importance to each of the hydrometric service attributes. This is not only unrealistic as individuals may rank attributes differently in order of personal preference priority but is also potentially misleading in terms of the claims, insights and predictions arising from the model. As a result, models which allow for heterogeneity in respondent preferences and characteristics have been developed. The random parameters or mixed logit model has some particularly appealing statistical properties which are discussed in Chapter 4. This method allows individual-specific parameter estimates to be obtained on the basis of random draws from a pre-specified population distribution. In order to account for potential heterogeneity among professional hydrometric users a mixed logit model was programmed on the choice data. Several competing distributions were tested on all the parameters in order to test for model fit and significance of estimates along the selection rationale provided by Hensher and Greene (2001). In particular, categorical variables such as real-time view, data type, enhanced metadata, advanced diagnostics, integrated supply and online access to data were tested with normal and uniform specifications while continuous variables, which included the total number of gauging stations, data precision, frequency, delivery time and cost, were tested with normal, log-normal and truncated normal specifications. Cost was additionally tested as a fixed parameter and with a triangular specification following Abdullah and Mariel (2010). However, in all cases the Normal distribution offered the best fit and convergence outcomes as benchmarked by the log-likelihood and AIC statistics, and also the most plausible coefficient estimates for the selected attributes. Estimates from this model are displayed in Table 7.2.

Alternative Specific Constants (ASCs) in the Mixed Logit model indicated that a Downgraded hydrometric option was much preferred to other alternatives outside of the choice experiment; i.e. to no gauging, or some other outcome. Its coefficient was estimated with a strong positive effect on utility of 233.42, which was highly statistically significant at the 99.99% level. At the same time intrinsic preferences for the current facility were not statistically different from the baseline alternative, reflecting similar findings from the CL model. On the other hand, estimates associated with network upgrades suggested that there were important drivers of unobserved disutility associated with these options, but were not captured by the model. These factors were important determinants of overall user preferences for national hydrometric programmes in Scotland. The coefficients for Upgrade One (-354.6) and Upgrade Two (-358.96) were both statistically different from zero at the 99.99% level. In terms of the main attributes, Mixed Logit estimates demonstrated highly significant effects, statistically important at the 99.99% level, for increased user utility from more river gauging stations (0.283); real-time river views (28.869); discharge instead of 'level-only' data (71.336); enhanced metadata (31.981); advanced diagnostics (30.268); integrated provision (36.895) and online provision (40.199). These findings are very much in line with prior expectations and user perspectives obtained during stakeholder consultations undertaken as part of this study. The relative magnitudes of the mean utility coefficients also provide meaningful information in that they identify a ranking of attributes as determinants of overall hydrometric utility. Using this knowledge it is straightforward to observe that users attach the highest level of value to discharge (flow) data collection, followed by online and integrated access to environmental data. The availability of enhanced metadata, which would provide improved contextual documentation to inform hydrometric data series, also improves the user experience considerably, and advanced diagnostics would be an equally useful analytics' service. Real-time views of the river channel would similarly attract high ratings of user approval. Additional gauging stations are perhaps seen as the most elementary aspects of national hydrometric programmes compared to other, higher-value services, but are nevertheless desired by professional users according to these estimates. The message that emerges from the findings is thus that the quality, rather than quantity of data is what professional users appear to value most of all. Estimates of other attributes are also noteworthy. A loss of data precision, measured by the size of the error margin associated with river gauging data, is not welcomed. Neither is a bigger time interval between consecutive readings of river levels. The coefficients associated with these effects are, respectively, -3.561 and -1.056, both highly significant at the 99.99% level. Higher costs of acquiring hydrometric data are similarly disliked. The cost coefficient is estimated at -0.659, significant at the 99.99% level. Delivery time, which marks the number days taken by hydrometric providers to supply gauging data to customers, is also unpopular, however the coefficient estimate for this attribute (-0.334) is not statistically different from zero. Of the factors whose increase leads to user discontent, it is interesting that users are less concerned by rising costs than by higher error margins and untimely data. 'Quality-over-Cost' is therefore a key finding communicated by these results.

In a mixed logit model, it is not just the mean parameter estimates which are important indicators of user preferences. The standard deviations associated with the means also provide useful and meaningful information. These estimates are presented in the last three sub-columns of Table 7.2. They demonstrate that mean preferences for stations, real-time river views, data precision, enhanced metadata, advanced diagnostics, integrated provision and cost are indeed heterogeneous across the user population and are symbolised by the highly statistically significant effects estimated at the 95% level and above. The comparative model fit statistics of the Conditional and Mixed Logit models also deserve attention. Of the two criteria used to assess model fit, the log-likelihood associated with the Conditional Logit is -271.2 compared with -263.4 for the Mixed Logit model. The latter thus seems to offer an improved specification as witnessed by the higher LL statistic for the Mixed Logit model. However the Akaike Information Criteria was not minimised for the Mixed Logit model (578.7) relative to the Conditional Logit model (572.4) suggesting that the improved model fit in the case of the Mixed Logit may be driven by an inflation in the number of model parameters (where standard deviations of mean parameters are also now included) rather than a genuine improvement in model capability. In either case, the absolute differences are small and, working with a relatively limited sample size, the best available results are presented here.

7.4. Welfare Analysis

Mean Willingness to Pay for Main Attributes

The mean and standard deviation parameters from mixed logit models do not have direct behavioural interpretations, as they represent the impacts of main attributes and respondent characteristics on an unobserved (or latent) dependent variable used as a proxy for indirect utility (Holmes, Adamowicz and Carlsson, 2017). As discussed above, analyses are therefore restricted to the signs and statistical significance associated with model estimates. However, these figures can be used to calculate the willingness-to-pay (WTP) for individual attributes. The mean willingness-to-pay is defined as the amount of money that a person is prepared to sacrifice in order to obtain one unit/level of an attribute (or, conversely, to prevent the loss of one unit/level of an attribute). In other cases, an individual may be willing to accept (WTA) compensation for the loss of a unit of a desired attribute, or equally, to tolerate an extra unit of an attribute that is otherwise undesirable. In order to calculate the willingness-to-pay for an attribute one must divide the marginal utility of an attribute (i.e. the change in total satisfaction received by a person when the amount or level of an attribute rises or falls by a single unit) by the marginal utility of income (which is the change in a person's satisfaction resulting from a one pound rise or fall in income).

The mean willingness to pay for all hydrometric attributes along with 95% confidence intervals are listed in Table 7.4. Confidence intervals were calculated according to the method proposed by Krinsky and Robb (1986). Given that the mixed logit model offers an improved statistical fit to the data in comparison with the conditional logit model it is more appropriate to examine the WTP estimates provided by the former, best-fitting model. Both the WTP and WTA figures refer to transfers made each time hydrometric data is requested. These results suggest that the average professional user of hydrometric data is prepared to spend about 43 pence per gauging station. However, user preferences vary within a range of this figure given by the upper and lower limits of the confidence intervals associated with the estimate. Thus some users might only be willing to contribute 37 pence while others would pay up to a maximum of 60 pence. Similarly, equipping stations to stream live views of the river channel from a web-enabled camera would attract contributions of around £43, up to a maximum of about £60. Most importantly, results show that organisations would be willing to pay an average of £108.31 in order to obtain discharge (flow) statistics from gauging stations rather than river level readings alone, with a minimum of around £90 to an upper limit of about £160. In terms of data precision, each percentage point of error associated with the 'true' hydrometric value is worth an average of £5.41 to users; the negative sign preceding this figure shows that organisations would need to be compensated by this amount in order to accept a worsening level of precision (that is, a higher error margin) associated with level and discharge statistics. Similarly, for each minute of lost frequency (i.e. every incremental minute in the interval between river level recordings), users would need to be compensated by £1.60. The availability of enhanced metadata and advanced diagnostics of the river channel would attract premiums of approximately £48 and £45 respectively from professional data users. Integrated and online provision of data is even more valuable, worth around £56 and £60 respectively. Although delivery time was not a statistically significant determinant of user satisfaction, its estimated value using the available coefficients indicates that customers would require a refund of around 51 pence for each day taken to deliver hydrometric data from the day of request.

Marginal Willingness-to-Pay for Main Attributes

Building on mean willingness-to-pay estimates, an interesting question focuses on how much professional data users are prepared to contribute (or receive) in order to secure or endure a change in the levels of hydrometric attributes. In terms of the qualitative attributes (real-time views, enhanced metadata, advanced diagnostics, integrated and online provision), a marginal change simply refers to a conversion in the attribute's obtainability, for example, from becoming available following circumstances in which they were not originally provided. These figures are the same as the mean WTP estimates given in Table 7.4 and discussed above. In contrast to the qualitative attributes, the continuous attributes (number of stations, frequency, data precision, type and delivery time) can be further analysed in order to reveal the value of each intermediate or marginal level of provision. These are explained in further detail below.

Stations

Table 7.5 displays the impact on mean willingness-to-pay if the gauging station network were expanded or downgraded. Starting with a baseline willingness-to-pay value of 43 pence per station professional users would be willing to pay (£0.43 x 392=) £168.60 for the current network which hosts 392 river gauging stations. From this basic level, they would then be willing to contribute an additional £16.77 for expanding the gauging network by 10%, which would deliver 39 new stations. The total value per organisation of a gauging network comprising 431 stations, rather than the current 392, is thus (£168.60+ £16.77 =) £185.37. Similarly, each organisation would be willing to pay an additional £42.15 for a 25% expansion in the number of gauging stations; £84.30 for a 50% expansion and £168.60 for a doubling of the current network, from 392 to a total of 784 stations. All along, the reader should be mindful of the variation in each of these figures, presented as confidence intervals associated with each estimate. The table also shows that organisations would not welcome a downgrade of current river gauging facilities. In order to live with this change, the average household would require compensation to the tune of £82.58 for a 50% reduction in the number of stations, such that only 200 stations were now available across the network rather than the current 392. This reduces their net willingness-to-pay to (£168.60 – 82.58=) £86.02.

Frequency

Table 7.6 presents a similar set of estimates for the value of time, or frequency of river level readings. An organisation would be willing to *accept* (£1.60 x 15mins =) £24.04 for a basic delay of 15 mins between successive river level readings. A further delay of 15 mins would require compensation of an additional £24.04, bringing the total willingness to accept a 30-minute time interval to (£24.04+24.04=) £48.08. A single hourly collection would increase this compensation figure to £96.17. Similarly, an organisation would be willing to pay an extra £8.01 for a 10-min saving or 8 more readings of river level per hour. Reducing the time-interval between river level readings even further to a 1-min frequency (60 observations per hour) would thus reduce the total willingness-to-accept value from £24.04 to (£-24.04+22.44=) £1.60.

Precision

Table 7.7 presents estimates for the value of precision or the error associated with river level and discharge data. An organisation would be willing to *accept* (£5.41 x 25 percentage points =) £135.16 for a basic error margin of 25 percentage points, such that the hydrometric observations provided to users are within 25% of the true value. An increase in the error margin by a further 25 percentage points would require compensation of an additional £135.16, bringing the total willingness to accept a 50% error margin to (£135.16+135.16=) £270.32. Similarly, the value of lowering the error margin associated with hydrometric observations to a level of 5 percentage points, such that data estimates are within 5% of the true river level or discharge value, is calculated as (£-135.16+108.12=) £27.04. In other words organisations would still require this amount for agreeing to use data at a 5% level of error.

Delivery Time

Table 7.8 displays the impact on mean willingness-to-pay of delivering hydrometric data more quickly to customers. Starting with a baseline willingness-to-accept value of 51 pence per day's delay from the point of request, users would be willing to accept (£0.51 x 14=) £7.11 for a standard waiting time of two weeks. From this basic level, they would then be willing to contribute an additional £3.55 for acquiring the data up to a week earlier, bringing the necessary compensation down to (£-7.11+3.55=) £3.56. By the same formula, acquiring the requested data on the same day would mean that the necessary compensation value is (£-7.11 + £7.11=) £0. In contrast, a waiting time of 30 days would increase professional users' requirement for compensation to (£-7.11 + £-8.12=) £15.23.

Data Type

In the choice experiment, the Data Type attribute was coded as a simple qualitative scale representing a ratio of river level-to-discharge operated stations in the network. The lower limit of the scale consisted of all stations operated to collect river level data only (coded as Grade 0.0), while at the upper limit, all stations were defined entirely as 'Flow-Only' facilities (coded as Grade 2.0). The mid-point of the scale (Grade 1.0) represented a network consisting of a combination of both facilities, with the interval 1 to 2 consisting of an increasing proportion of Flow compared to Level-Only stations. This scale is shown in greater detail in Table 7.9. Using this gradation, it becomes possible to examine the marginal willingness-to-pay for changing combinations of flow-to-level facilities in the national hydrometric network. For example, starting with a mean willingness-to-pay of £108.31 for data grade 1.0, where 50% of stations are 'level-only' and the remainder are full stage-discharge facilities, users would be willing-to-pay £5.42 for securing a 5% increase in Flow-to-Level facilities. The total value of increasing flow data facilities by 5% is thus (£108.31+5.42=) £113.73 per organisation. Similarly, in order to realise a national gauging programme consisting entirely of discharge-only facilities, users would be willing to pay £54.16 in addition to the baseline average. This would bring the total value of a full-discharge grade network to (£108.31+£54.16=) £162.47 per organisation. In contrast reducing the number of flow gauging stations relative to the number of 'level-only' facilities would detract from users' utility, and they would require compensation against the baseline in order to accept incremental levels of this transformation. This means that if national hydrometric capabilities were scaled back from a combination of flow and level facilities to one where only river level data was collected at all stations, then this would reduce users' willingness-to-pay by £54.16, to a total of (£108.31 - £54.16 =) £54.15. Note that in this analysis users are assumed to attach an equal weight to transformations in both data types; however, it is much more likely that gains and losses in discharge-grade facilities are felt more keenly than changes in 'level-only' facilities. Also note that a river gauging network operated entirely to a downgraded, 'level-only' policy still attracts a net positive willingness-to-pay from users, suggesting that even basic hydrometric data is a valuable commodity adding to the satisfaction and wellbeing of professional data consumers.

Aggregate Willingness-to-Pay

Aggregate willingness-to-pay estimates provide insights into the value of changes in levels of hydrometric attributes across all organisations. These are presented for the mixed logit model in Table 7.10. The figures for mean willingness to pay were aggregated across 384, 864 organisations in Scotland as detailed by Scottish Government statistics (SG, 2014). An example of how to read and interpret the figures is provided in the notes section at the bottom of the table. For example the baseline value for stations is (£0.43 x 392 stations x 384,864 organisations =) £64,887,762.51. Installing ninety-eight more stations add £16,221,940.63 to this figure. For data type, the baseline value is represented by Grade 1.0 where the distribution of level-to-flow stations is 50% to 50%. However, since the current network configuration is more like 15% (level-only) to 85% (flow), the table shows that the current aggregate value of data type at Grade 1.7 is (£41,684,619.84 + £14,589,616.94 =) £56,274,236.78. Marginal estimates are useful in order to assess the value of changes to the current network based on the sensitivity of users to particular attributes. However, in order to determine the average current value of the hydrometric service to all professional users, a summing of the attributes' baseline estimates is required. If only the core effective attributes are selected, that is the number of stations, frequency, data type (at Grade 1.7), precision and delivery time, then this yields a total gross value of £57,157,769.07. Net of operating costs of £3,427,414 (costs for financial year 2014-15), this indicates a residual non-market benefit of £53,730,355.07 arising from the standard provision of hydrometric data to professional users. The net non-market benefit-to-cost ratio for standard data provision is thus £15.68 in economic benefits to every £1 of costs, or about 16:1. At the same time, if a range of additional facilities were provided – for example, enhanced metadata, advanced diagnostics, real-time river views, integrated and online provision of data – then this would increase the net benefit value to £152,022,811.81. The additional features would therefore increase the net benefit to cost ratio to 44:1.

7.5. Conclusion

This chapter analysed the results from two models aiming to explain the preferences of professional data users for competing hydrometric aspects. It showed that a mixed logit specification in which selected attributes were allowed to vary randomly offered an improved model fit over a conditional logit model and also captured the heterogeneity inherent among respondents. The marginal willingness to pay or accept for each of the attributes was calculated and potential implications of these findings for the design of hydrometric networks were discussed. Although findings were limited by the number of available choice occasions (n = 236), results showed clear and positive valuations for the number of stations and for operating these facilities to collect river discharge rather than level statistics alone. In addition, businesses and other organisations were willing to pay significant premiums for extra hydrometric services and features such as enhanced metadata, advanced diagnostics, real-time views of the river channel, integrated and the online provision of data. Simultaneously, it was seen that data precision and the time interval between detections of changing river levels would require quality-related reimbursements to users, most probably owing to the onward risks posed by data observations of uncertain quality to the circumstances and issues in which the information was applied. A discussion and conclusion of the thesis follows in the next chapter.

Table 7.2: Conditional Logit and Mixed Logit Main Effects Models

Alternatives & Attributes	Conditional Logit Model: Mean Beta	S.E.	T-St.	Mixed Logit Model: Mean Beta	S.E.	T-St.	Std. Deviation Beta	S.E.	T-St.
ASC: Downgrade	12.393	6.852*	1.809	233.420	30.933****	7.546	-	-	-
ASC: Current Facility	4.938	4.082	1.210	-53.079	50.432	-1.053	-	-	-
ASC: Upgrade One	-0.423	5.451	-0.078	-354.600	84.476****	-4.198	-	-	-
ASC: Upgrade Two	-0.800	5.472	-0.146	-358.960	84.864****	-4.230	-	-	-
STATIONS	0.005	0.003	1.440	0.283	0.044****	6.502	-0.123	0.008****	-14.470
REAL-TIME VIEWS	0.644	0.349*	1.842	28.869	5.619****	5.137	-46.019	3.496****	-13.165
DATA TYPE	1.015	0.664	1.528	71.336	9.993****	7.139	-2.792	11.700	-0.239
DATA PRECISION	-0.141	0.063**	-2.227	-3.561	0.285****	-12.477	0.908	0.351***	2.585
FREQUENCY	-0.037	0.035	-1.052	-1.056	0.155****	-6.827	0.287	0.230	1.248
ENHANCED METADATA	0.469	0.301	1.559	31.981	5.707****	5.604	78.393	3.870****	20.259
ADVANCED DIAGNOSTICS	0.524	0.322	1.629	30.268	7.346****	4.120	73.265	6.070****	12.069
INTEGRATED PROVISION	0.732	0.332**	2.208	36.895	4.157****	8.876	86.277	4.431****	19.469
ONLINE PROVISION	0.212	0.822	0.258	40.199	8.702****	4.619	-14.856	10.200	-1.456
DELIVERY TIME	-0.071	0.070	-1.019	-0.334	0.614	-0.544	-0.180	0.448	-0.402
COST	-0.001	0.010	-0.110	-0.659	0.169****	-3.903	0.200	0.079**	2.519
LL: -271.2 AIC: 572.4				LL: -263.4 AIC: 578.7					

Significance Levels: **** 0.01 per cent *** 1 per cent ** 5 per cent * 10 per cent

Table 7.3: Frequency of Alternatives

Current Facility	Upgrade 1	Upgrade 2	Downgrade	None
14%	42%	34%	8.8%	1.2%

Table 7.4: Random Parameter Distribution for the Mixed Logit Model

Attributes	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
STATIONS	-Inf	0.12	0.20	0.20	0.28	Inf
REAL-TIME VIEWS	-Inf	5.52	20.34	20.34	35.16	Inf
DATA TYPE	-Inf	46.74	47.61	47.61	48.48	Inf
DATA PRECISION	-Inf	-3.15	-2.66	-2.66	-2.18	Inf
FREQUENCY	-Inf	-0.85	-0.71	-0.71	-0.57	Inf
ENHANCED METADATA	-Inf	2.66	23.16	23.16	43.66	Inf
ADVANCED DIAGNOSTICS	-Inf	-33.63	21.66	21.66	76.95	Inf
INTEGRATED PROVISION	-Inf	-5.66	25.37	25.37	56.40	Inf
ONLINE PROVISION	-Inf	-0.32	24.95	24.95	50.22	Inf
DELIVERY TIME	-Inf	-0.77	-0.62	-0.62	-0.46	Inf
COST	-Inf	-0.54	-0.46	-0.46	-0.38	Inf

Table 7.4: Mean Willingness-to-Pay for All Attributes

Attributes	Mean Willingness to Pay in GBP (£)	
	[1]. Conditional Logit Model	**[2]. Mixed Logit Model**
STATIONS	4.33 (-5.86 to 7.04)	£0.43 (0.37 to 0.60)
REAL-TIME VIEWS	576.67 (-824.62 to 991.76)	£43.83 (36.30 to 59.47)
DATA TYPE	909.02 (-1300.19 to 1459.93)	£108.31 (90.77 to 157.45)
DATA PRECISION	-126.39 (-198.61 to 193.00)	£-5.41 (-10.24 to -3.59)
FREQUENCY	-33.10 (-60.27 to 56.15)	£-1.60 (-2.79 to -1.09)
ENHANCED METADATA	419.79 (-596.04 to 693.02)	£48.56 (33.55 to 82.19)
ADVANCED DIAGNOSTICS	469.42 (-697.35 to 758.07)	£45.96 (37.97 to 57.31)
INTEGRATED PROVISION	655.91 (-1018.11 to 1078.44)	£56.02 (41.34 to 95.09)
ONLINE PROVISION	189.92 (-907.26 to 1041.35)	£61.03 (46.84 to 87.03)
DELIVERY TIME	-63.96 (-113.16 to 128.87)	£-0.51 (-3.86 to 1.03)

Notes: (1). Figures in brackets represent 95% confidence intervals for Willingness-to-Pay estimates. (2). Confidence intervals calculated using the Krinsky-Robb method. (3). Negatively-valenced figures imply that users would be willing to accept compensation for a change in the level of the attribute. (4). All figures are in GBP (£).

Table 7.5: Willingness-to-Pay for Hydrometric Stations

Total Number of Stations	Additional Stations	Hydrometric Network Adjustment	Mean Willingness-to-Pay
200	-192	-50% (approx.)	£-82.58 (£-70.54 to -115.91)
392	**0**	**0**	**£168.60 (£144.02 to 236.65)**
431	+39	+10%	+ £16.77 (£14.33 to £23.54)
490	+98	+25%	+ £42.15 (£36.01 to £59.16)
588	+196	+50%	+ £84.30 (£72.01 to 118.33)
686	+294	+75%	+ £126.45 (£108.02 to 177.49)
784	+392	+100%	+ £168.60 (£144.02 to 236.65)

Notes: (1). 95% confidence intervals for mean willingness-to-pay (wtp) estimates are shown in brackets in column four. (2). Estimates are relative to a baseline of 392 stations which approximates the size of the current river gauging network in Scotland. (3). A reduction of approx. 50% in the current gauging network, or 192 fewer stations overall, would not be welcomed; the average professional user would require compensation of £82.58 in order to accept the change. This is represented by the negative sign preceding the wtp estimate in column four.

Table 7.6: Willingness-to-Pay for Hydrometric Frequency

Frequency of River Level Measurement	Time Loss	Total Observations Recorded	Additional Observations Recorded	Mean Willingness-to-Pay
Every 1 min	-14 mins	60	+56	+ £22.44 (£39.11 to £15.28)
Every 5 mins	-10 mins	12	+8	+ £8.01 (£13.97 to £5.46)
Every 15 mins	**0**	**4**	**0**	**£-24.04 (£-41.90 to £-16.37)**
Every 30 mins	+15 mins	2	-2	£-24.04 (£-41.90 to £-16.37)
Every 60 mins	+45 mins	1	-3	£-72.13 (£-125.71 to £-49.12)

Notes: (1). 95% confidence intervals for mean willingness-to-pay (wtp) estimates are shown in brackets in column four. (2). Estimates are relative to a frequency baseline of 15 mins (4 river level measurements per hour) which approximates the temporal resolution of the current river gauging network in Scotland. (3). The average professional user would require compensation of at least £24.04 in order to accept a time loss of 15 mins (or two fewer data readings per hour than the four observations currently made). This is shown by the negative sign preceding the wtp estimate in column four.

Table 7.7: Willingness-to-Pay for Hydrometric Precision

Precision Margins	Precision Loss (in percentage points)	Mean Willingness-to-Pay
True Value (0% error)	-25 pts	+ £135.16 (£256.05 to £89.85)
Within 5% of True Value	-20 pts	+ £108.12 (£204.84 to £71.88)
Within 10% of True Value	-15 pts	+ £81.09 (£153.63 to £53.91)
Within 15% of True Value	-10 pts	+ £54.06 (£102.42 to £35.94)
Within 25% of True Value	**0 pts**	**-£135.16 (-£256.05 to -£89.85)**
Within 50% of True Value	+25 pts	-£135.16 (-£256.05 to -£89.85)
Full Error (100% error)	+75% pts	-£405.47 (-£768.16 to -£269.54)

Notes: (1). Comparison baseline is 25% error margin. (2). True Value and Full Error represent idealised upper and lower bounds for illustrative purposes only; they were not presented as choices to respondents. (3).The average professional data user would require compensation of at least £135.16 if the measurement error associated with hydrometric data observations were to increase by an additional 25 percentage points. This is shown by the negative sign preceding the wtp estimate associated with a 50% error margin in column three.

Table 7.8: Willingness-to-Pay for Hydrometric Delivery

Delivery Time from Date of Request	Additional Days Taken	Mean Willingness-to-Pay
0 (Same Day)	-14	+ £7.11(£53.99 to -£14.38)
7 days	-7	+ £3.55 (£26.99 to -£7.19)
14 days	**0**	**-£7.11(-£53.99 to £14.38)**
21 days	+7	-£3.55 (-£26.99 to £7.19)
30 days	+16	-£8.12 (-£61.70 to £16.43)

Notes: (1). Comparison baseline is an average of 14 days taken to service a request for hydrometric data from a customer or service user. (2). A further week's delay in supplying hydrometric data is not welcomed. The average professional users would require at least £3.55 to accept the change. This is shown by the negative sign preceding the wtp estimate associated with a 21-day versus 14 day request turnaround in column three.

Table 7.9: Marginal Willingness to Pay for Data Type by Network Grade

Data Type (Grade)	Percentage of Stations in Network that are Level Only (%)	Percentage of Stations in Network that are Flow Only (%)	Additional Level Only Stns in Network (%)	Additional Flow Stns in Network (%)	Marginal WTP (£) for more Flow Grade data
0.0	**100**	**0**	**+0.50**	**-0.50**	-£54.16 (-£45.39 to -£78.73)
0.1	95	5	+0.45	-0.45	-£48.74 (-£40.85 to -£70.85)
0.2	90	10	+0.40	-0.40	-£43.32 (-£36.31 to -£62.98)
0.3	85	15	+0.35	-0.35	-£37.91 (-£31.77 to -£55.11)
0.4	80	20	+0.30	-0.30	-£32.49 (-£27.23 to -£47.24)
0.5	75	25	+0.25	-0.25	-£27.08 (-£22.69 to -£39.36)
0.6	70	30	+0.20	-0.20	-£21.66 (-£18.15 to -£31.49)
0.7	65	35	+0.15	-0.15	-£16.25 (-£13.62 to -£23.62)
0.8	60	40	+0.10	-0.10	-£10.83 (-£9.08 to -£15.75)
0.9	55	45	+0.05	-0.05	-£5.42 (-£4.54 to -£7.87)
1.0	**50**	**50**	**0**	**0**	**£108.31 (90.77 to 157.45)**
1.1	45	55	-0.05	+0.05	£5.42 (£4.54 to £7.87)
1.2	40	60	-0.10	+0.10	£10.83 (£9.08 to £15.75)
1.3	35	65	-0.15	+0.15	£16.25 (£13.62 to £23.62)
1.4	30	70	-0.20	+0.20	£21.66 (£18.15 to £31.49)
1.5	25	75	-0.25	+0.25	£27.08 (£22.69 to £39.36)
1.6	20	80	-0.30	+0.30	£32.49 (£27.23 to £47.24)
1.7	15	85	-0.35	+0.35	£37.91 (£31.77 to £55.11)
1.8	10	90	-0.40	+0.40	£43.32 (£36.31 to £62.98)
1.9	5	95	-0.45	+0.45	£48.74 (£40.85 to £70.85)
2.0	**0**	**100**	**-0.50**	**+0.50**	£54.16 (£45.39 to £78.73)

Notes: (1). Marginal willingness to pay for more Discharge data is relative to a baseline of Grade 1.0 which represents an idealised and equally-apportioned network configuration of 50% between level-only and flow-operated stations. The value of providing additional flow data over-and-above Grade 1.0 is ranked by sub-levels from Grade to 1.1 to Grade 2.0, where the latter represents a gauging network comprising 100% flow-operated stations and no 'level only' stations. Conversely the economic loss of reducing the ratio of flow-operated stations in the network to a predominance of level-only stations is ranked by sub-levels 0.9 to 0.0, where Grade 0.0 means that the entire gauging network comprises level-only stations, and no flow-operated stations. Intermediate levels provide useful information on the impact of altering the ratio of flow-to-level-only stations relative to a 50-50 mix. (2). A more realistic reflection of the current network is represented by Grade 1.7 where approximately 15% of gauging stations are 'level-only' and the balance of 85% are operated to produce Discharge data. The value per organisation of this network grade is thus (£108.31 + £37.91 =) £146.22.

Table 7.10: Aggregate Willingness to Pay for Continuous Hydrometric Attributes

Attribute	Level of Change in Attribute relative to Current Provision	Aggregate Willingness-to-Pay
STATIONS [Baseline=392 Stns].	**392 stns**	**£64,887,762.51 (£55,428,421.17 to £91,078,219.55)**
	+39 stns	£6,455,670.25 (£5,514,562.31 to £9,061,353.48)
	+98 stns	£16,221,940.63 (£13,857,105.29 to £22,769,554.89)
	+196 stns	£32,443,881.25 (£27,714,210.59 to £45,539,109.77)
	+294 stns	£48,665,821.88 (£41,571,315.88 to £68,308,664.66)
	+392 stns	£64,887,762.51 (£55,428,421.17 to £91,078,219.55)
	-192 stns	-£31,781,761.23 (-£27,148,614.45 to -£44,609,740.19)
FREQUENCY [Baseline=Every 15 Mins].	**15 mins**	**-£9,253,477.58 (-£16,127,341.06 to -£6,301,763.14)**
	-14 mins	£8,636,579.08 (£5,881,645.59 to £15,052,184.99)
	-5 mins	£3,084,492.53 (£2,100,587.71 to £5,375,780.35)
	+15 mins	-£9,253,477.58 (-£16,127,341.06 to -£6,301,763.14)
	+45 mins	-£27,760,432.75 (-£48,382,023.17 to -£18,905,289.41)
PRECISION ERROR [Baseline=Within 25% of True Value].	**25 pts**	**£-52,016,293.92 (-£98,545,389.36 to -£34,578,106.08)**
	-20 pts	£41,613,035.14 (£27,662,484.86 to £78,836,311.49)
	-15 pts	£31,209,776.35 (£20,746,863.65 to £59,127,233.62)
	-10 pts	£20,806,517.57 (£13,831,242.43 to £39,418,155.74)
	+25 pts	£-52,016,293.92 (-£98,545,389.36 to -£34,578,106.08)
DELIVERY TIME [Baseline=14 days].	**14 days**	**-£2,734,458.72 (£5,534,113.40 to -£20,777,036.99)**
	-14 days	£2,734,458.72 (-£5,534,113.40 to £20,777,036.99)
	-7 days	£1,367,229.36 (-£2,767,056.70 to £10,388,518.49)
	+7 days	-£1,367,229.36 (-£10,388,518.49 to £2,767,056.70)
	+16 days	-£3,125,095.68 (-£23,745,185.13 to £6,324,701.03)
DATA TYPE (GRADED) [Baseline Index = Grade 1.0 where 50% of Gauging Stations are 'Level Only' and 50% are Flow Stations].	**Grade 1.0**	**£41,684,619.84 (£34,934,105.28 to £60,581,442.24)**
	-1 (All Level)	-£20,842,309.92 (-£17,467,052.64 to -£30,298,418.40)
	+0.1	£2,084,230.99 (£1,746,705.26 to £3,029,841.84)
	+0.2	£4,168,461.98 (£3,493,410.53 to £6,059,683.68)
	+0.3	£6,252,692.98 (£5,240,115.79 to £9,089,525.52)
	+0.4	£8,336,923.97 (£6,986,821.06 to £12,119,367.36)
	+0.5	£10,421,154.96 (£8,733,526.32 to £15,149,209.20)
	+0.6	£12,505,385.95 (£10,480,231.58 to £18,179,051.04)
	+0.7	£14,589,616.94 (£12,226,936.85 to £21,208,892.88)
	+0.8	£16,673,847.94 (£13,973,642.11 to £24,238,734.72)
	+0.9	£18,758,078.93 (£15,720,347.38 to £27,268,576.56)
	+1 (All Flow)	£20,842,309.92 (£17,467,052.64 to £30,298,418.40)

Notes: (1). Aggregate values refer to willingness-to-pay (wtp) across all registered non-governmental organisations in Scotland. This was calculated at 384,864 including charities, private-sector enterprises and higher education institutions. (2). Confidence intervals for wtp estimates shown in brackets. (3). Attribute level changes which represent a worsening scenario relative to current provision are displayed in italics. Society would require compensation to accept this level of change so wtp estimates are preceded a negative sign. (4). All figures above represent marginal values and should be added/subtracted from the baseline value to arrive at the net value for a given change in attribute level. For example the baseline value for stations is (£0.43 x 392 stations x 384,864 organisations =) £64,887,762.51. Installing ninety-eight more stations adds £16,221,940.63 to this figure.

Table 7.11: Aggregate Willingness-to-Pay for Qualitative Hydrometric Attributes

Attribute	Change in Level of Provision	Aggregate Willingness-to-Pay relative to a baseline of No Provision
REAL-TIME VIEWS	Becomes available	£16,869,089.44 (£14,085,560.56 to £22,887,169.32)
ENHANCED METADATA	Becomes available	£18,687,725.79 (£12,910,955.64 to £31,632,741.89)
ADVANCED DIAGNOSTICS	Becomes available	£17,686,579.07 (£14,614,248.24 to £22,055,555.19)
INTEGRATED PROVISION	Becomes available	£21,559,350.04 (£15,909,854.41 to £36,597,333.54)
ONLINE PROVISION	Becomes available	£23,489,712.40 (£18,025,297.87 to £33,493,674.79)

Table 7.12: Ranking of Attributes by Respondents

Attributes	Most Important	Second-Most Important	Third-Most Important	Fourth-Most Important	Fifth-Most Important
Stations	21%	17%	16%	11%	8%
Real-Time Views	1%	5%	5%	6%	2%
Data Type	30%	23%	16%	10%	22%
Data Precision	17%	24%	17%	9%	8%
Frequency	2%	10%	11%	19%	8%
Enhanced Metadata	0%	1%	2%	4%	4%
Advanced Diagnostics	0%	1%	1%	3%	6%
Integrated Provision	1%	1%	3%	3%	3%
Online Provision	8%	6%	12%	10%	14%
Delivery Time	8%	5%	9%	16%	12%
Cost	12%	9%	9%	10%	14%

Table 7.13: Net Non-Market Benefits of providing Hydrometric Data to Professional Users

Benefits of Data Provision		Cost of Data Provision	Net Benefits	Net Benefit-Cost Ratio
Core Attributes	£	£	£	
Stations	£64,887,762.51	-	-	-
Data Type	£56,274,236.78	-	-	-
Precision	-£52,016,293.92	-	-	-
Frequency	-£9,253,477.58	-	-	-
Delivery Time	-£2,734,458.72	-	-	-
Total	**57,157,769.07**	£3,427,414.00	53,730,355.07	**15.68 to 1**
Additional Attributes				
Real Time Views	16,869,089.44	-	-	-
Enhanced Metadata	18,687,725.79	-	-	-
Advanced Diagnostics	17,686,579.07	-	-	-
Integrated Provision	21,559,350.04	-	-	-
Online Provision	23,489,712.40	-	-	-
Total	**155,450,225.81**	£3,427,414.00	£152,022,811.81	**44.35 to 1**

Notes: (1). Costs refer to annual operating costs of the Hydrometry Unit advised by the Scottish Environment Protection Agency (SEPA) for financial year 2014-15. (2). Benefit value for Data Type is evaluated at Grade 1.7 rather than baseline Grade 1.0 in order to reflect the actual network configuration in Scotland at the time of study where the proportion of 'level-only' to flow stations was about 15% to 85% rather than the baseline assumption of 50:50.

Chapter 8

Discussion and Conclusion

8.1. Introduction

The role of 'big' data, open data and Public Sector Information has received considerable attention as a driver of social mobility, economic development and political accountability in recent years (Cukier and Mayer-Schonenberger, 2013; Hey et al. 2009). More data about individuals and the environment has been generated in the last year than in the last 7000 years of human history (Gurin, 2013; Henke et al., 2016). Environmental data forms a distinctive class of information and entails the detection and recording of changes in structural components of the earth and its atmosphere with the use of bespoke measuring instrumentation. In the case of freshwater bodies such as inland rivers, which serve a range of functions to support human, animal and aquatic life by storing, processing and transporting freshwater across vast landscapes, modern river gauging stations have been designed in order to quantify changes in the elevation of water above the river bed and its discharge at specific locations across river catchments. Data collected from these stations provide a means for assessing available water quantity to society and serve a critical purpose in protecting water resources from over-exploitation by the competing demands of households, agriculture, industry and ecology.

In the UK, both public and private organisations install and manage singular or small networks of river gauging stations. However, it is environmental regulators who are specifically charged with the responsibility to operate gauges that collect continuous, consistent and quality-controlled data over long periods of time in the public environmental interest. The data from gauging stations in Scotland informs a wide range of purposes and applications and is available to the public at little or no cost. At the same time, the infrastructure used to collect this data competes with alternative candidate programmes and policy areas which also require public investment. During periods of government spending retrenchments, funding for operating and maintaining river gauging stations is often reduced, with stations having to be suspended, closed or downgraded. Reasons why such closures may be undesirable include the loss of continuity in data time series, the length of which provides important insights into river trends over time; the loss of capability in addressing specific freshwater management challenges, as river gauges may be useful one purpose (say, flood warnings) but not another (say, stage-discharge conversion); loss of insights into the behaviour of rivers at specific locations and in particular catchments; and a loss of scientific material for tracing the effects of longer term phenomena such as climate change.

In order to justify public investment into river hydrometric networks, it is important to understand the three-way link between river gauging infrastructure, uses of hydrometric data and the value that is placed on both stations and information by members of a given society. The objective of this study was to explore this triangulation in further detail. By using non-market valuation methods to quantify the economic value of hydrometric data in Scottish settings, it aimed to systematically examine the trade-offs that citizens benefiting from the data were willing to make between competing attributes of the hydrometric system in Scotland. It is important to note that the economic value is additional to the market value generated by applications of hydrometric data to specific functions, infrastructures, projects and products. The latter is a form of financial value accruing private returns to individuals and organisations, while the economic aspect is concerned with societal benefits accruing public returns. Without an estimation of the economic value, financial quantifications by themselves are insufficient indicators of the full value of data and consequently the wider benefit provided by river gauging infrastructure remains under-valued. This places hydrometric networks reliant on public funding at a distinct disadvantage when competing for scarce government resources relative to alternative programmes and policies.

In this thesis, choice experiments were conducted in order to elicit the value of hydrometric infrastructure from the perspectives of households and professional users of gauging data. Four hundred and thirty-four Scottish residents and one-hundred and eighteen professionals were surveyed in 2017. Both cohorts were presented with a set of four hydrometric alternatives with a view to measuring their preferences for not just the competing alternatives but also for competing attributes characterising the alternatives. The hydrometric alternatives in both experiments included choices for the current facility, a downgrade of the current facility, and two upgrade scenarios which would deliver improvements to the current hydrometric infrastructure. These findings were analysed in chapters 5, 6 and 7.

8.2. Overview of Findings from Household and Professional Surveys

In the first of these analyses, household preferences were modelled using conditional and mixed logit specifications. In both models five main attributes were defined as component characteristics of the Scottish gauging network. These included the number of river gauging stations, the number of river level observations collected per hour based on the time interval between consecutive river level readings; the operation of stations to collect discharge data in addition to stage-readings alone, and; the provision of a web-enabled camera facility that would allow residents to view the river channel at the station site in real-time via the internet. An operating cost associated with each combination of these attributes was also included as a common trade-off denominator against which preferences for the other main attributes could be evaluated. The mixed logit model, which demonstrated a significant improvement on the conditional logit specification, was further refined to test for the effects of socio-economic and demographic variables such as gender, age, income, education and employment status on household valuations of hydrometric networks. These factors significantly improved the model. In a further iteration, an additional set of variables designed to capture the effects of individual attitudes, beliefs, values and levels of awareness were also included and seen to improve the model's findings.

In the second analysis, (Chapter 6), latent class specifications were used in order to get a different perspective on the distribution of household preferences within the population. Three models were initially estimated here; one where only the main attributes were included as determinants of household utility, and two further iterations which, like the Mixed Logit specification, accounted for the socio-economic, demographic and cognitive characteristics of respondents. The latent class approach allowed the identification of two distinct groups within the household cohort, each with similar, in-group preferences, but who displayed divergent preferences when compared with members of the alternate group. An assumption underlying all the standard latent class specifications was that members of a group attached equal weight to all of the attributes of any given alternative. The only variation within the sample was therefore considered to occur only between groups. However, it was reasonable to assume that intra-group preferences were also likely to vary, and on this basis a more flexible model specification known as the Latent Class with Random Parameter model was estimated. This model combined the flexibilities of both the Mixed Logit and standard Latent Class specifications, yielding further improvements to the modelling capability applied to household preferences.

The final set of results analysed professional users' preferences for hydrometric alternatives and attributes. As with the households, four major hydrometric alternatives were presented for consideration; namely a downgrade and two upgrades in addition to the current facility. In terms of attributes, the competing alternatives comprised the same five hydrometric features as included in the household survey. However, an additional six attributes were also included. These were designed to test for the importance of data precision on user valuations along with the level of customer demand for enhanced metadata, advanced diagnostics, integrated and online provision of gauging data, as well as the delivery time taken by collecting authorities to provide the data. Two models were estimated, that is, a conditional logit and mixed logit model. As with households, modelling outcomes were markedly improved using the second specification. Unlike the households, however, in the case of the professionals, none of the organisation- or respondent-specific variables such as annual turnover, salary level and years of professional experience had any stable impacts on either model fit or attribute-based utility. These factors were therefore excluded from the estimation and only main effects models comprising eleven hydrometric attributes were analysed.

8.3. Household Preferences: A Comparison of Findings from the Mixed Logit and Latent Class Models

Results from the household cohort demonstrated consistent preference profiles across both the Mixed Logit and Latent Class analyses. In comparing these findings the 'best fit' models are selected for discussion, that is, the Mixed Logit Model incorporating sociodemographic and cognitive effects and the corresponding latent class model which allowed parameters to vary randomly within classes.

Preferences for the Scale of River Activity in Scotland

The first interesting finding was that even though most households selected upgrade options (64% of the cohort) instead of the current facility (26%) or a downgrade (4%), Mixed Logit estimations revealed a residual preference on the part of the average household to leave the state of hydrometry in Scotland unchanged. The Alternative-Specific Constants for both upgrades, which were negatively-valenced and carried highly significant statistical effects, showed that preference drivers left uncaptured by the model were substantially at work in drawing mean household favour towards the current facility. At one level, this could be evidence for a *status quo* bias, where respondents who are relatively unfamiliar with a good tend to avoid alternatives that entail a change from the present state of affairs. However, the option selection distribution highlighted above, as well as the availability of opt-out and downgrade options suggested that the size of such a bias was likely to be small. These seemingly conflicting indications received clarification from the Latent Class analysis. The estimates from this model suggest that it was members of Class Two (Hydrometric Maximisers) who welcomed network upgrades, while members of Class One (Satisficers) did not and preferred to continue with the current facility. Within each class, members also demonstrated significant differences in preferences for network upgrades. This was indicated by the statistically important standard deviation effects associated with upgrade alternatives. The Latent Class estimates went further in showing that when group-based preferences were considered, both classes demonstrated very strong loss aversion effects. Neither Maximisers nor Satisficers desired a scaling back of current facilities or favoured alternatives such as say, autonomous gauging arrangements or some other outcome which may exist outside the option set in the experiment. Thus the Latent Class model was effective in uncovering further insights that remain concealed in the case of corresponding mixed logit estimates. Taken together these figures suggested that although most households cautiously welcomed gauging network upgrades (recall that Maximisers comprise about 70% of the population), about a third of the population still remained to be convinced about the overall benefits of improved hydrometric facilities in Scotland.

Stations

Weak preferences for hydrometric upgrades were reflected in correspondingly low utility estimates for the total number of gauging stations in the hydrometric network. Willingness-to-Pay estimates from the Mixed Logit model showed that households were prepared to sacrifice relatively small amounts, about 6 pence on average, for new stations, up to a maximum of 10 pence. When examined in light of group-specific preferences, Latent Class estimates showed that Maximisers were prepared to pay between 9 pence and 17 pence for additional stations, but Satisficers would instead require an average compensation of 5 pence to convince them that expenditure on new gauging stations was a worthwhile use of public resources. Nevertheless, the fact remains that more gauging stations displayed statistically valid increases in societal wellbeing on average. According to the insights of the Mixed Logit model, the current gauging network, which hosts about 392 stations, was worth £24.92 on average to every household. The Latent Class model moderated this figure with the insights that while Maximisers would pay up to £35.03 for the present network, Satisficers would require compensation of £19.28 per household, with a weighted average of these figures yielding a net willingness-to-pay of £19.09. Similarly, aggregate figures showed that the present network was valued at £59,806,656 by households on the basis of 392 network stations (Mixed Logit figures). In comparison, taking the two-class average of station-based preferences from the Latent Class model, where the total is weighted by the size of each class, produced a lower total estimate of £45,804,914.75 for 392 stations. This is a significantly lower estimate than the Mixed Logit Model, and, in practical terms would usually be chosen in order to control for optimism bias. However, the Mixed Logit model (log-likelihood: -1353.4) offered a better fit to the data compared with the Latent Class Random Parameter model (log-likelihood -1421.2) so estimates of the former were chosen as the benchmark for discussion.

Frequency

The value of hydrometric frequency was estimated at about 53 pence per minute's delay per household, according to the Mixed Logit model. Comparatively, group-based preferences identified by the Latent Class model showed that for Satisficers, this was reduced to 18 pence per household, while Maximisers would require an average of 79 pence per household. It is important to note that these are willingness-to-accept figures; the prospect of longer time intervals between river level readings were not welcomed by households, and each additional minute would require a transfer from the data supplier to the user in order to maintain the latter's satisfaction with the service. Thus a standard frequency of 15 minutes between water stage readings was worth £7.98 to the average household according to Mixed Logit figures. In comparison, the underlying distribution of willingness-to-accept revealed by Latent Class figures showed that Satisficers would be prepared to settle for much less at £2.67 while Maximisers would demand £11.83, thereby bringing the weighted average across both groups to £9.14 for a standard gauging frequency of four observations per hour.

Real-time River Views

The potential usefulness of installing web-enabled cameras at station sites was included in the household choice experiment for a number of reasons. One is that several river users may wish to obtain a visual assessment of water level and flow conditions before undertaking a trip to the river for recreational purposes. The websites of several angling clubs in Scotland for example now provide a live feed to a web-enabled camera that allows members to view general river, bank and weather conditions; when river levels are high, it is likely that fishing conditions are also favourable. Second, the ability to view key stretches of river may offer peace of mind to some residents who have experienced flooding in the past or where flood alerts are currently in place. Local information in these circumstances can be valuable for planning and response to a potential emergency. In one focus group for instance several flood victims mentioned that personal levels of anxiety are elevated during periods of high rainfall when the river has been known to show a relatively flashy response in the past. One participant reported that this causes sleepless nights for several affected residents, many of whom walk to the river side in person during the night in order to assess the potential risk arising from the local river to their homes. Third, the ability to connect with nature and a riverine environment with the help of a webcam may provide health and wellbeing benefits to some householders. Of course whether a webcam installed at a particular gauging site would provide any meaningful information is open to question; it may be that users prefer views of river stretches that are not gauged. All the same, the ability to engage visually with a river close to a gauging site was included as a potential driver of hydrometric utility. Findings from the experiment showed that households were willing to pay £12.72 on average for a webcam facility (Mixed Logit estimates). Evaluated on the basis of group preferences, Latent Class estimates demonstrated that Satisficers would contribute around £5.34, while Maximisers were willing to go further and pay £18.84. The weighted Latent Class average, in comparison to the Mixed Logit average, was thus slightly higher at £14.93 per household. At an aggregate level, the potential value added to national hydrometry from providing real-time river views was £30,519,024 according to Mixed Logit estimates and £35,705,562.09 according to weighted average estimates from the Latent Class model.

Data Type

The fourth hydrometric feature tested in this study, and which held the highest level of utility for households, was operating stations to collect discharge data rather than observations of river level alone. The Mixed Logit model demonstrated a mean willingness to pay of £19.75 per household for stage-discharge stations, and when this figure was deconstructed by the group typologies identified in the Latent Class model, it was seen that, although Satisficers were prepared to pay only £1.43 for discharge-grade data, Maximisers were far keener on this feature and were willing to pay £39.65 for flow data. The weighted average across classes in the Latent Class estimation was therefore £28.57, almost £8 higher than the estimate yielded by the Mixed Logit model. At an aggregate level, the added value arising from operating river gauging stations to collect discharge data rather than river level readings alone is £47,400,480 according to Mixed Logit figures and up to £68,231,913 by Latent Class estimates. These figures are very much in line with views expressed at focus groups and in pilot versions of the choice questionnaire. Even where respondents were not fully aware of hydrometric data applications and knew the significantly higher costs and effort required to collect stage-discharge readings, it was considered to be much more cost effective to operate stations at their full capacity rather than to a minimal, 'level-only' specification.

Socio-Economic and Demographic Effects

Further insights into preferences for the state of river hydrometry in Scotland were obtained when taking account of individual respondent characteristics. In the Mixed Logit model, these characteristics were interacted with the Alternative Specific Constants of each hydrometric programme. Estimates of these interactions provided insights into whether specific demographic groups or those with particular belief structures were likely to have any different preferences for competing hydrometric programmes even after the individual attributes in each alternative had been considered, relative to a comparator, baseline group. For example, the figures obtained allowed an analysis of whether low income individuals, relative to higher earners, gained significantly more or less satisfaction from proposals to upgrade or downgrade the river gauging network.

In the Latent Class model these features were entered as determinants of class membership rather than ASC or main attribute interactions as this offered improved modelling capability, convergence and coefficient estimates. Of the two identified groups, Hydrometric Maximisers, accounting for about 70% of the population, were willing to pay significantly more for new gauging stations, discharge data and real-time river views, and, simultaneously, required higher rates of compensation for a loss of temporal resolution in river level readings in comparison with Hydrometric Satisficers. The latter group comprised about 30% of the population and received significant disutility from expanding continuous river gauging activity to new locations. Compared with Maximisers, they were willing to pay less for discharge data and real-time river views, and were also less concerned by a loss of hourly river level readings.

The effects of socio-economic and cognitive characteristics on household utility revealed the following preference profiles for hydrometric alternatives, shown in Table 8.1. Females, who formed about 50% of the sampled population, were significantly more likely to prefer an upgrade of hydrometric facilities in Scotland relative to men, and were identified clearly as Hydrometric Maximisers according to the typologies traced out in the Latent Class analysis. Other statistically important Maximisers were flood victims (6% of sampled households) and those living at greater distances from the river (self-reported, approximate distances), however no significant effects were found for these groups in the final mixed logit model. Additional population markers which were good predictors of positive preferences for hydrometric upgrades included active data consumption, living in a family household comprising three or more members, education to degree level, being aged sixty-five and above, and a high certainty level about one’s environmental choices. In the Latent Class model however none of these characteristics were important determinants of membership of any particular group probably due to a more even distribution of the same markers across the entire sampled population. In contrast, owner occupants, self-employed individuals, those who were more environmentally-conscious in general and hydrometrically-informed in particular were more likely to vote for network upgrades and also more likely to be Maximisers.

On the other hand, four population characteristics were shown to detract significantly from hydrometric upgrades. These included low income status, those in employment, environmentally-passive belief holders and those who may have felt that alternative policy areas were more important for the government to address than the environment in general. The latter two were identified, in line with expectations, as Hydrometric Satisficers. Interestingly, employed individuals were classified as Maximisers in spite of their overall aversion to gauging network upgrades, again revealing significant heterogeneity in preferences across the entire cohort. Low income earners received significant disutility from river gauging upgrades but their preferences were not statistically important in explaining membership of either hydrometric group as distinguished by the Latent Class model.

Table 8.1: Comparison of Socio-Economic and Cognitive Effects between Mixed Logit and Latent Class Models

Socio-Economic and Cognitive Characteristics	**Mixed Logit Model**	**Latent Class Random Parameter Model**
Variable	**Hydrometric Preference Characteristics**	**Group Membership Assignment**
Females	Prefer hydrometric upgrades compared to men.	Group 2: Maximisers
Low-Income Households	Dislike hydrometric upgrades compared to higher income earners.	No significant effect
Distance to River (Perceived)	No significant effect.	Group 2: Maximisers
Dwelling Flooded	No significant effect.	Group 2: Maximisers
Data Users	Prefer hydrometric upgrades compared to non-users.	No significant effect
Family Households	Prefer hydrometric upgrades compared to single and two-person households.	No significant effect
Degree Holders	Prefer hydrometric upgrades and dislike downgrades compared with less educated individuals.	No significant effect
Owner Occupants	Prefer hydrometric upgrades compared to tenant occupiers.	Group 2: Maximisers
Senior Citizens	Prefer hydrometric upgrades and dislike downgrades relative to younger age groups.	No significant effect
In Work	Dislike hydrometric upgrades compared to unemployed, self-employed, home duties, students and retired individuals.	Group 2: Maximisers
Business Owners/Self-Employed	Prefer hydrometric upgrades and dislike downgrades relative to unemployed, employed, home duties, students and retired individuals.	Group 2: Maximisers
Environmental Beliefs: Pro-Action	Prefer hydrometric upgrades relative to pro-inaction individuals.	Group 2: Maximisers
Environmental Beliefs: Pro-Inaction	Dislike hydrometric upgrades relative to pro-action individuals.	Group 1: Satisficers
Hydrometric Awareness Level	Prefer hydrometric upgrades relative to less aware/informed individuals.	Group 2: Maximisers
Decision Certainty Level	Prefer hydrometric upgrades relative to less certain individuals.	No significant effect
Public Policy Priorities	Dislike hydrometric upgrades compared with individuals who rank the environment more highly as a public policy priority.	Group 1: Satisficers

8.4. Professional Users' Preferences: Comparison with Household Findings.

Results from the professional users' survey revealed interesting parallels with household preferences. As active stakeholders in the state of the national hydrometric system, professional respondents made higher consumption valuations for all common hydrometric attributes shared with the household experiment. However, readers should also be mindful of key structural differences between the professional and household surveys. First, a set of six additional attributes were presented for consideration by professionals, over and above the five core attributes shared with the household survey. This means that the valuation scenario, density of trade-offs and overall task complexity was much higher for professionals compared with households. Second, professional users are likely to have a much higher awareness of hydrometric uses and applications, and also to have more specific and more developed requirements from hydrometric data than household users. Third, the financial instrument for professional users required payment each time hydrometric data was requested (payment per transaction), while for households, payment referred to a one-off contribution through their household water bill. Thus the comparative figures below are effectively normalised to a single transaction by both households and organisations. Fourth, while households were expressing value relative to the marginal utility of their own income, professionals were expressing value relative to their organisation's income. Fifth, professionals were asked to consider the value of hydrometric alternatives for their work and contractual requirements while households were asked to consider value of river gauging data for future societal needs and challenges. Finally, the total number of households was taken at 2.4 million (ONS, 2014) while the total number of organisations was taken at 384,864 in 2016 (SG, 2016).

Core Attributes

Comparing mean willingness-to-pay results from the Mixed Logit specifications, professionals were prepared to spend, on average, 43 pence per station compared to 6 pence per household. The current gauging network, consisting of 392 stations, was therefore worth £168.60 to each organisation compared with £24.92 to a domestic user. At the aggregate level, this translated to a current station value of £59,806,656 across households and £64,887,762.51 across all organisations. In terms of hydrometric frequency, a larger number of stage observations is known to improve the reliability of discharge statistics. Household choices revealed an implicit value of 53 pence per minute's delay between consecutive stage readings, while for professionals, the value of each additional minute was

£1.60. A standard 15-min data collection frequency was therefore evaluated at £7.98 for households and £24.04 for organisations (willingness to accept). At the aggregate level, these figures translated to a total required compensation of £19,154,160 for all households and £9,253,477.58 across all organisations. For operating gauging stations to generally collect discharge as well as stage readings, households were willing to pay £19.75, while organisations were willing to spend £108.31 for a network comprising 50% stage-only and 50% stage-discharge stations. For professionals, the current network ratio of approx. 15% stage to 85% discharge (grade 1.7) was therefore worth £146.22 per organisation. At an aggregate level, discharge-operated stations were worth £47,400,480.00 to households, while for professionals this sum was £56,274,236.78. These findings closely corroborate views received during the stakeholder consultations undertaken at the questionnaire design phase of this study. Several professional users emphasised the importance of discharge statistics, as without these figures, independent flow gauging may become necessary which would incur its own time, insurance, equipment, staff time, health and safety costs and procedures, all without the relative quality and credibility of such readings being sourced from an official agency. Finally, river views in real time, which might be useful tools providing visual assessments of out-of-bank flows, channel changes and blockages during flood events, were valued at £12.72 per household versus £43.83 per organisation. In the aggregate, this yielded a collective webcam value of £30,519,024.00 for all households in comparison with £16,869,089.44 across organisations.

Additional Attributes

In addition to the core, shared attributes across both surveys, the professional users' choice experiment also evaluated preferences for data precision, enhanced metadata, advanced diagnostics, integrated and online provision and delivery time.

<u>Data Precision</u>

Data precision was highlighted as a major, if not paramount issue during some stakeholder interviews, particularly by commercial users as, without accurate estimates of river level and discharge, the true usefulness of a set of hydrometric statistics was not known. This could have significantly adverse costs and impacts on the predictions and recommendations made on the basis of such data. Some hydrologists have suggested that poor quality, low accuracy data is counter-productive rather than simply an inconvenience as it may provide indications of catchment behaviours and characteristics that are not true (Hamilton, 2017). Several users also mentioned in focus groups and correspondence that often the quality and usefulness of hydrometric data only became known after it was received and analysed. This made it difficult to assess whether a given series of observations pertaining to one or more stations offered any value for money at the point of payment. Another user made a related observation, that in a commercial project, costs below £100 could typically be recovered from clients, however, where the data precision and thus data utility was unknown, then making a business case for such expenditure could prove challenging. Furthermore, user charges above this amount could come to constitute a significant proportion of the total project value in the case of relatively small jobs; consequently, the costs and benefits of acquiring hydrometric data would have to be much more carefully evaluated when taking on new business. The sensitivity of professional users to data precision yielded a willingness-to-accept value of £5.41 for each percentage point of error associated with hydrometric data. Although the level of data precision is likely to be highly variable from station to station, estimates suggested that for a standard error margin of 25% (that is, river gauging estimates are within 25% of the true hydrometric value), stakeholders would require a basic compensation of £135. These findings underline the critical role of data precision for the user experience of organisational stakeholders.

Enhanced Metadata

During stakeholder consultations, it was suggested that one key attribute likely to shed further light on the overall usefulness of a set of hydrometric observations is what this study conceptualised as enhanced metadata. This term refers to extra contextual information on the environmental and institutional circumstances and limitations under which river stage readings were collected, and the computational assumptions and statistical decisions on which discharge estimates and other data series were derived. Although such information is qualitative in nature and time-consuming for measuring authorities to provide, results from the choice experiment showed that professional users were willing to pay significant premiums of around £48 for enhanced metadata documentation to accompany river level and flow statistics as a way of improving the usability of the data. In the aggregate, providing enhanced metadata had the potential to add £18,687,725.79 worth of non-market benefits to the national economy.

Advanced Diagnostics

The choice experiment also tested for the effects of providing users with advanced diagnostics in addition to regular river level and flow data by measuring authorities. This referred to the use of advanced equipment, software, computational methods and visualisation techniques in order to provide more detailed and focused insights of bed, bank and channel profile. As a natural monopoly in the market for hydrometric data supply, measuring authorities were considered to possess a unique advantage in the provision of such information, which could significantly improve the quality of evidence available for user decisions. Results from the valuation exercise showed that users were willing-to-pay an additional £46 per data request for the recourse to such facilities in order to better meet their current work and contractual requirements. At an aggregate level, this attribute had the potential to add value worth £17,686,579.07 from organisational stakeholders alone.

Integrated Provision, Online Provision and Delivery Time

During interviews and focus groups conducted for this study, a key set of factors arising from the workflows of professional data users included the convenience of obtaining environmental data in general, and hydrometric data in particular. Participants mentioned that, in the context of a given project, hydrometric data was only one of several different classes of environmental information required, and river measuring authorities only one of several public suppliers who needed to be engaged in order to acquire all the relevant data for a project. For example, flood risk studies pertaining to certain locations required not just river gauging data, but also rain gauge and traffic flow data. This entailed separate data requests for all the relevant information, not just to river gauging authorities, and also to other local and national providers. Necessary procedures and the length of time taken were both unstandardised and highly variable across organisations which incurred significant costs in terms of time and effort for professional stakeholders.

Accordingly, several participants suggested that a single, preferably online, portal for obtaining environmental data would prove helpful. In order to test for the individual effects of distinct elements of such a system, three attributes were included in the choice experiment, namely, integrated provision, online provision and delivery time. Valuations of integrated provision showed that unified access to different sources of public data was highly preferred with a mean willingness-to-pay per organisation of £56. If the information was available for direct download, then this would be worth an additional £61 to professional users. Estimates for these attributes at an aggregate level showed that approximately £45 million worth of potential societal benefits were potentially forthcoming from the provision of these facilities. In terms of delivery time, the Mixed Logit model of professional user preferences showed that this was not a statistically important attribute in improving the user experience. Nevertheless, welfare analysis conducted using the attribute's utility estimates suggested that each extra day taken to deliver data to users from the day of request was worth 51 pence. In other words, users would be would be willing to wait an extra day if this amount was refunded to them. For a standard two-week waiting time this amounted to an average compensation per organisation of £7.11. Aggregating this figure across all organisations in Scotland yielded a potential loss of £2,734,458.72 for a two-week delay in delivering hydrometric data to customers.

8.5. Benefit Cost Analyses

Figures obtained from the choice experiments in this study can be used to calculate the total non-market benefits arising from river hydrometry by subtracting willingness-to-accept compensation transfers from willingness-to-pay receipts. These figures can then be compared with costs of operating and maintaining the hydrometric network as a way of computing the aggregate net benefits in monetary terms with each pound spent on river gauging activity. However, it is important to note that the comparative figures obtained separately from both choice analyses are not directly comparable owing to the very different purposes and valuation tasks which the household and professional users were asked to consider. These have already been discussed. In addition, it seems from responses to the household survey that a small number of participants may have been more informed data users than the average household; in other words, that they may have been professional data users. Thus a risk exists that a double-counting may occur if the two survey estimates are directly compared. In light of the larger and more representative sample of the household survey, the choice estimates are also likely to be more reliable indicators of general population preferences than valuations arising from the more specialist frame of decisions facing professional users. Accordingly, figures from the residents' cohort are adopted as the benchmark indicators of societal preferences for hydrometric data. These results show that taking account of the three core attributes that currently characterise the hydrometric network (that is, stations, data type and frequency) produces total non-market benefits to society of £88,052,976. Subtracting the operating and maintenance costs associated with river hydrometry, one obtains a net benefit of £84,625,562. This yields a non-market benefit-to-cost ratio of £24.69 for each £1 spent on river hydrometry in Scotland. Note that this comparison does not account for the market (i.e. financial or private) benefits conferred by the use of hydrometric data, and is therefore only a minimum estimate based on household valuations – in other words, it is the bottom-line value of river gauging activity to society. Taking account of value adding activities, such as the provision of real-time river views, the net household benefits increase to £118,572,000 yielding a non-market benefit-to-cost ratio of £33.60 for each £1 spent on river gauging activity in Scotland. Comparatively, professional user valuations yield lower net benefits, considering core attributes only, with a non-market benefit to cost ratio of £15.68 for every £1 spent on river gauging activity. These figures are likely to be a reflection of the more specialist requirements from hydrometric data held by organisational stakeholders and also a larger volume of (notional) two-way transfers comprising both payments and compensations between stakeholder and supplier. This group's valuations also showed that considerable premiums would be forthcoming if value-adding hydrometric services were offered to customers, for example, real-time river views, enhanced metadata, advanced diagnostics, integrated and online provision. These facilities are worth a potential £155,450,225.81, and capable of increasing the total non-market benefit-to-cost ratio to £44.35 for each £1 spent on river gauging activity in Scotland. The implications of these results for public policy purposes are now discussed in the following section.

8.6. Policy Implications

1. User Engagement

   Results from the choice experiments, including both utility estimates and willingness-to-pay figures, show that there are significant returns to be made from awareness-raising activities on the role of river gauging activity for inland freshwater management. Particular households and individuals would benefit significantly from such information, for example, women, large families, owner-occupants, recreational river users and flood survivors. Information should be tailored to both general audiences (those with a low level of awareness) and those with specific needs but limited knowledge of alternative hydrometric data applications. Other stakeholders, such as environmental groups and outdoor activity groups would also be useful to engage. A separate campaign to engage sceptical citizens (Hydrometric Satisficers) who constitute about 30% of the population would also deliver good value for money.

2. Fundraising

Findings from an analysis of household preferences showed that a large proportion of Scottish households are willing to make relatively large, one-off contributions to upgrade the river gauging network. This fact could be leveraged to establish an independent gauging trust which could raise, save and manage funding for extra gauging activity, and for stepping-in to 'save' stations at risk during times of economic downturn when pressure on public funds are high. Results also suggest that some economic actors, for example, microbusinesses and small-to-medium-sized enterprises, are likely to make contributions towards river gauging activity if suitably engaged.

3. Investment

Results of the household survey suggest that long-term plans to upgrade and expand national river gauging facilities would be welcomed by most sections of society, however in the short-term, priorities should be to improve existing facilities by upgrading 'level-only' sites to full stage-discharge facilities and for increasing the frequency of river level readings for specific purposes such as flood warnings. Additional investment into equipping stations with web-enabled cameras would increase the health and wellbeing of households generally, and particularly of those vulnerable to flooding who may experience elevated levels of anxiety during periods of high flooding risk.

4. Quality Assurance

The professional survey showed clear user preferences for and significant returns to improving the quality of data. Measuring authorities should increase departmental efforts aimed at quality-control in order to reduce error margins associated with data observations (higher precision). They should also devote a higher level of resources to metadata documentation in order to contextualise the limitations inherent in the data and thereby to improve its usability across a wider range of applications. Where possible, river gauging data should be provided online for immediate download, and diverse sources of additional gauging and environmental information should be unified and delivered via a single portal conforming to common, interoperable data standards.

5. Value-Added Services

Organisational stakeholders revealed a substantial loss to society arising from an unmet demand for advanced diagnostic services designed to inform complex decisions. Measuring authorities should leverage their unique position as data collectors and develop new and innovative services to provide finer, more detailed insights in to river bed, bank and channel profiles using state-of-the-art equipment, software and visualisation techniques. These services could be provided at a relatively cost effective rate due to the economies of scale enjoyed by measuring authorities, the large number of gauging stations under their operation, and the unique assemblage of highly skilled scientists already working within the organisation.

8.7. Conclusion

In this thesis we set out to quantify the value of data obtained from Scottish river gauging stations. The research required the bridging of several literatures and disciplines spanning river hydrometry, the economics of utility and non-market valuation, open government data, environmental psychology and information systems. In Chapter One an overview of the context and proposed methodological approach was provided. Chapter Two went into further detail by explaining key concepts underlying the measurement, role and importance of stream flow data. It also canvassed different approaches used in the evaluation of hydrometric networks in both Scotland and other settings. Chapter 3 discussed in greater detail the two main stated preference methods for valuing environmental goods; that is, contingent valuation and choice experiments. An insight in to their historical development was provided in order to contextualise both the intellectual and practical approaches to valuing non-market-traded goods and services. The review in this chapter also provided an outline of how CE and CV studies are typically conducted and looked at some of the caveats, sources of bias and design issues which have been theorised and developed within the literature. Chapter 4 proceeded to explain the research design including how participants were engaged for both the qualitative and quantitative branches of the study and derived the theoretical models for the conditional, random parameters (mixed logit) and latent class models. The first two modelling frameworks were used to analyse household choice data, and the results were presented and discussed in Chapters 5 and 6 respectively. These demonstrated that increasing the number of stations, providing opportunities for real-time river views using a web-enabled camera, and operating stations to collect data on river flows rather than just river levels were welcomed by respondents. In contrast, reducing the frequency of hourly river level readings (fewer observations per hour) and higher costs associated with hydrometric activity were disliked. In Chapter 6, we observed that consumer preferences for hydrometric data could be classified according to two user types; Hydrometric Satisficers who expressed a low value for new stations and who would require little compensation for losing sub-hourly data readings, but who were willing to make higher one-off contributions towards securing visual apparatus to view river conditions (web camera) and for the peace of mind that data on river flows (rather than simply river levels) was being collected. In contrast, Hydrometric Maximisers comprised a group of data users who were keen to see an expansion in the number of stations, and who considered that real-time river views were desirable. They also laid significant weight on the loss of sub-hourly data readings and strongly preferred that Discharge data was collected at stations rather than just readings on river levels alone. In Chapter 7, findings from a choice experiment conducted with professional users of hydrometric data were presented. The results showed a high level of priority attached to data precision and to the operation of gauging stations to collect Discharge data. Losing precision of level and flow estimates and longer delays to receiving requested data would typically require some compensation to be paid to business users. On the other hand, integrated and online data supply river flow statistics were likely to attract considerable premiums from professional consumers willing to pay for hydrometric data.

8.8. Extensions

Two key extensions of the work in this thesis are underway: (i) exploring the effects of scale on user valuations (Fiebig et al., 2010) using a generalised multinomial logit model. Scale refers to the effect of different levels of certainty among the sample population based on the variable levels of individual knowledge when making environmental valuations, and; (ii) exploring the effects of space on user valuations (Schaafsma et al., 2013). This refers to the effect of location and distance on user valuations; a review of relevant literature has been provided in Chapter 3.

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APPENDICES

Appendix 1: Key policy areas and issues investigated using non-market valuation methods.

Agriculture
Johnston & Duke (2007) – Farmland Preservation. Kapaj et. al (2011) – Preferences for milk attributes. Llewellyn and Kragt (2014) – Demand for decision-support tools for weed and herbicide resistance management. Barton et al (2002) – Value of irrigation water for farming. Huber et al (2011) – Preferences of decision-makers for future land use scenarios. Liljenstolpe (2011) – Demand for improved animal welfare standards by pork fillet consumers.

Biodiversity
Birol et al (2006) – Value of biodiversity in Hungarian home gardens. Do & Bennett (2007) – Value of wetland biodiversity in Vietnam's Mekong delta. La Notte (2012) – Value of habitat services in forests and wetlands. Czajkowski & Hanley (2012) – Effects of information on preferences for biodiversity conservation.

Climate Change
Rothman et al (2003) – Benefits of climate change policies. Longo et. al. (2012) – WTP for climate change mitigation.

Coastal and Marine
Frau (2010) – Value of the marine environment to coastal dwellers in Wales. Barr & Mourato (2014) – Fishers' preferences for design of marine PES (payment-for-environmental services) schemes. Philcox (2007) – Review of nonmarket benefits from ocean and marine coastal resources in British Columbia, Canada. Liu and Wirtz (2009) – Value of oil spill management practices in a German coastal region. Halsall & Associates (2001) – Non-market values of the Australian SE marine region. Ostberg et al (2012) – Value of improving water quality in Swedish coastal regions. Hoyos et al (2012) – Environmental benefits of coastal developments in Spain.

Ecosystem Services
Logsdon & Chaubey (2013) – Quantification of benefits from ecosystem functions. Bateman et al (2013) – Economic value of alternative land use scenarios for ecosystem services. Salojarvi (2014) – Valuation of ecosystem services in the Gulf of Finland. Whitehead et al (2008) – Nonmarket value of ecological services. Barral et al (2012) – Value of ecosystem goods and services in changing complex production landscapes. Maltby et. al (2013) – Economic assessment of freshwater, wetland and floodplain ecosystems.

Energy
Gunatilake et al (2012) – Benefits of electricity provision in Madhya Pradesh, India. Pepermans (2011) – Value of continuous power supply for Flemish households. Klinglmair et al (2012) – Benefits to households of a new hydropower station in Graz, Austria. Kwak et al (2010) – Value of energy saving measures in residential buildings.

Natural Resources
Mazur & Bennett (2008) – Comparing benefits of alternative natural resource management strategies in NSW, Australia. Schuhmann (2015) – Economic valuation of marine ecosystem goods in the Caribbean.

River Systems
Doherty et al (2014) – Valuing ecosystem services across water bodies in Ireland. Rolfe & Brouwer (2012) – Value of river health in Australia. Hanley et al (2006) – Economic value of river ecology improvements in the UK. Bliem et al (2012) – Value of river restoration in Austria. Farber & Griner (2000) – Value of multiple stream quality improvements in an acid-mine degraded watershed.

Wildlife
Moro et al (2012) – Value of options for reducing illegal bushmeat hunting in the Serengeti.

Groundwater
Hasler et al (2005) – Valuing groundwater protection vs water treatment policies in Denmark.

Wastewater
Birol & Das (2010) – Value of improved wastewater treatment services in India.

Housing

Timmermans et al (1994) – Valued attributes in selection of housing choice. Sirgy et al (2005) – Consumer responses to new housing.	

Land Use
Ma (2013) – Valuing Brownfield remediation. Allin et al (2010) – Value of attractive landscapes in the urban economy.

Transportation
Koundouri et al (2012) – Value of a highway construction project in Greece. Hoen & Koetse (2012) – Private car owner preferences for Alternative Fuel Vehicles (AFV). Roman et al (2009) – Competition between high speed trains and alternatives in Spain. Khademi & Timmermans (2012) – Preferences for transport charging schemes. Outwater et al (2009) – Evaluation of high speed rail alternatives in California. Catalano et al (2008) – Demand for car-sharing in Palermo, Italy. Hensher & King (1998) – Establishing fares for urban passenger transport modes. Collins et al (2012) – Air travel behaviour. Nkurunziza et al (2012) – Commuter preferences for rapid bus transport in Tanzania. Yang (2010) - Preferences for innovative modes and services in Lisbon. Bhat and Sardesai (2005) – Effects of time travel reliability on value of public transport mdoes. Thanos et al (2011) – Valuing aircraft noise. Phanikumar and Maitra (2006) – Valuing urban bus attributes. Pereira et al. (2007) – WTP for airline service attributes. Senbil & Kitamura (2007) – WTP and WTA for expressway services.

Employment and Human Resources
Lagarde & Blaauw (2009) – Preferences for job attributes in health care work. Vujicic et al (2010) – Preferences for medical work in rural healthcare settings. Gibson (2016) – Valuation of drinking water quality preferences in developing countries: Willingness-to-work approaches. Anderson et al (2012) – How to design compensation packages.

Legal
Thompson (2002) – Non-market valuation of natural resource damage assessments for the courtroom.

Knowledge
Rijnsoever and Kempkes (2014) – Value of competing knowledge acquisition strategies to drive innovation in firms. Awatere (2008) – Costs and benefits of environmental changes for indigenous societies in New Zealand.

Appendix 2: Ethical Approval Obtained for Study.

Dr Kathy Burrell

School of Environmental Sciences

Roxby Building
Liverpool

L69 7ZT

E k.burrell@liverpool.ac.uk

Mr. Kush Thakar
Geography and Planning
University of Liverpool

13th August 2015

Dear Mr Thakar,

RE: Quantifying the Data obtained from River Gauging Stations in Scotland: A Users' Perspective

FoSEETH/SOES ethics reference number: 054

Thank you for your application requesting ethical approval from the University of Liverpool, Faculty of Science and Engineering Research Ethics Committee.

Your application has been reviewed by two reviewers, and the application and reviewers' comments subsequently considered by the Chair of the committee.

On behalf of the committee, I am pleased to confirm that the procedures set out in your application form and the supporting documentation are sufficient to ensure ethical practice for your research project.

This confirmation is given provided that you comply with the conditions outlined in your application. Please ensure that all staff and students working on the project are aware of these procedures. If any additional staff or students (not named on your application form) undertake research related to this project, please ensure their names are passed to Artemis Mermigki (mermigki@liverpool.ac.uk)

If there are any major changes to the research methods that affect the ethical considerations of your project, you are required to complete an amendment form. Details of this procedure are available here:

http://www.liv.ac.uk/researchethics/application/guidance_on_the_application_process/after_approval/

If you have any further questions about ethical approval, please don't hesitate to contact me.

Yours sincerely

Dr. Kathy Burrell
Senior Lecturer in Social & Cultural Geography
Chair, Faculty of Science and Engineering Ethics Committee

Appendix 3: Choice Set Matrices for Household and Professional Users' Surveys.

Household Survey Choice Sets

Scenario	Downgrade (Alt 1)					Status Quo (Alt 2)					Upgrade 1 (Alt 3)					Upgrade 2 (Alt 4)					Block
Choice situation	Freq	Stns	Wbcm	Dtyp	Cost	Freq	Stns	Wbcm	Dtyp	Cost	Freq	Stns	Wbcm	Dtyp	Cost	Freq	Stns	Wbcm	Dtyp	Cost	Block
1	1	200	0	1	0	3	192	0	0	27	29	231	1	0	47	29	486	0	1	63	5
2	1	200	0	1	0	3	192	0	0	27	11	486	1	1	63	29	290	0	0	55	4
3	1	200	0	1	0	1	192	0	0	32	11	486	0	1	63	59	231	1	1	35	2
4	1	200	0	1	0	1	192	0	1	32	59	486	0	0	35	11	388	1	1	63	1
5	1	200	0	1	0	1	192	0	0	32	11	486	0	1	63	59	231	1	1	40	4
6	1	200	0	1	0	3	192	0	1	27	29	290	0	0	55	11	486	1	0	40	4
7	1	200	0	1	0	1	192	0	1	32	59	486	0	0	35	11	388	1	1	55	6
8	1	200	0	1	0	1	192	0	1	32	11	388	1	1	63	59	584	0	0	35	3
9	1	200	0	1	0	1	192	0	1	27	59	290	0	1	55	11	486	1	0	40	2
10	1	200	0	1	0	1	192	0	1	32	29	388	0	1	63	59	486	1	0	35	5
11	1	200	0	1	0	1	192	0	0	27	11	486	0	1	63	59	231	1	1	35	1
12	1	200	0	1	0	3	192	0	1	27	29	388	0	1	63	29	290	1	0	47	3
13	1	200	0	1	0	1	192	0	0	27	59	231	1	1	40	11	486	0	1	63	6
14	1	200	0	1	0	3	192	0	0	27	29	231	1	0	47	11	486	0	1	63	2
15	1	200	0	1	0	1	192	0	0	27	29	290	1	0	55	59	486	0	1	63	5
16	1	200	0	1	0	3	192	0	0	32	11	584	1	1	40	59	231	0	0	40	3
17	1	200	0	1	0	1	192	0	1	32	29	290	1	0	47	59	584	0	0	35	3
18	1	200	0	1	0	3	192	0	1	27	29	290	1	0	47	29	388	0	0	63	3
19	1	200	0	1	0	1	192	0	1	32	59	584	0	0	35	29	231	1	0	47	1
20	1	200	0	1	0	3	192	0	1	27	29	388	0	0	55	29	290	1	0	47	4
21	1	200	0	1	0	3	192	0	0	32	59	231	1	1	35	11	584	0	1	55	2
22	1	200	0	1	0	1	192	0	0	27	59	231	1	1	40	29	388	0	0	55	1
23	1	200	0	1	0	3	192	0	1	27	29	290	1	0	47	29	388	0	0	47	6
24	1	200	0	1	0	1	192	0	0	32	11	290	1	0	40	59	584	0	1	35	3
25	1	200	0	1	0	1	192	0	0	27	11	388	0	0	55	59	231	1	1	40	5
26	1	200	0	1	0	1	192	0	1	27	29	388	0	0	55	29	290	1	0	47	4
27	1	200	0	1	0	3	192	0	0	32	59	231	0	1	47	11	584	1	1	35	4
28	1	200	0	1	0	3	192	0	0	32	11	584	1	1	35	59	231	0	1	40	6
29	1	200	0	1	0	3	192	0	1	32	11	584	1	0	35	59	290	0	1	55	2
30	1	200	0	1	0	3	192	0	1	27	29	388	0	0	55	11	388	1	0	47	1
31	1	200	0	1	0	3	192	0	1	32	59	231	0	1	47	11	584	1	0	35	6
32	1	200	0	1	0	3	192	0	0	32	59	231	1	1	40	11	584	0	1	40	1
33	1	200	0	1	0	3	192	0	1	27	11	486	1	0	40	29	388	0	1	63	2
34	1	200	0	1	0	1	192	0	0	32	59	584	0	1	35	29	231	1	0	47	6
35	1	200	0	1	0	3	192	0	0	27	11	584	1	1	40	29	290	0	0	55	5
36	1	200	0	1	0	1	192	0	1	32	59	584	0	0	35	11	290	1	1	55	5

Notes: A pivot design was used to generate the choice sets and levels are relative to the quantities specified in the pivot option. For example the number of stations in the current facility and upgrades were specified relative to a pivot level of 200 stations in the downgrade alternative so the actual levels for this attribute, as produced in the choice cards, were totalled across alternatives as 200+192; 200+231; 200+290 and so on for the current facility and upgrade alternatives. Only the disaggregated levels are specified in the matrix above.

Appendix 3: Professional Users' Survey: Choice Sets

	Downgrade											Current Facility											Upgrade Option 1											Upgrade Option 2											
Choice situation	Stations	Real-Time Views	Data Type	Precision	Frequency	Enhanced Metadata	Advanced Diagnostics	Integrated Provision	Online Provision	Delivery Time	Cost	Stations	Real-Time Views	Data Type	Precision	Frequency	Enhanced Metadata	Advanced Diagnostics	Integrated Provision	Online Provision	Delivery Time	Cost	Stations	Real-Time Views	Data Type	Precision	Frequency	Enhanced Metadata	Advanced Diagnostics	Integrated Provision	Online Provision	Delivery Time	Cost	Stations	Real-Time Views	Data Type	Precision	Frequency	Enhanced Metadata	Advanced Diagnostics	Integrated Provision	Online Provision	Delivery Time	Cost	Block
1	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	231	1	2	-40	-59	1	1	0	0	-16	182	584	0	1	-40	-55	0	0	1	1	-30	182	32
2	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	486	0	1	-40	-45	0	0	1	0	-23	243	290	1	2	-40	-55	1	1	0	1	-30	133	17
3	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	486	1	2	-35	-59	1	0	0	0	-23	133	290	0	1	-45	-45	0	1	1	1	-30	243	7
4	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	290	0	1	-35	-59	1	1	1	1	-30	212	486	1	2	-45	-45	0	0	0	0	-16	152	13
5	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	290	0	2	-45	-45	0	1	1	0	-16	182	486	1	1	-35	-59	1	0	0	1	-30	182	3
6	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	584	1	1	-45	-45	0	1	0	1	-30	152	231	0	2	-35	-55	1	0	1	0	-23	212	16
7	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	388	0	2	-35	-59	1	1	0	1	-30	133	290	1	1	-45	-55	0	0	1	0	-16	243	6
8	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	388	1	1	-45	-45	0	0	0	1	-30	243	388	0	2	-35	-55	1	1	1	0	-23	152	15
9	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	231	0	2	-45	-45	0	0	1	1	-30	243	584	1	1	-35	-59	1	1	0	0	-23	152	35
10	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	486	1	1	-45	-55	0	1	1	0	-16	152	290	0	2	-35	-59	1	0	0	1	-30	212	5
11	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	388	0	1	-45	-45	1	0	1	0	-16	212	388	1	2	-35	-59	0	1	0	1	-30	152	11
12	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	486	0	2	-45	-55	1	1	0	0	-16	133	290	1	1	-35	-59	0	0	1	1	-30	212	29
13	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	584	0	2	-40	-45	0	1	0	0	-23	133	231	1	1	-35	-59	1	0	1	1	-30	243	21
14	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	486	1	2	-35	-55	0	0	1	0	-23	133	290	0	1	-40	-45	1	1	0	1	-30	243	33
15	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	388	0	2	-40	-55	1	0	0	1	-30	152	388	1	1	-40	-59	0	1	1	0	-16	182	19
16	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	290	0	2	-45	-55	1	1	1	0	-16	152	486	1	1	-35	-59	0	0	0	1	-30	212	20
17	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	584	0	2	-40	-45	0	0	1	0	-23	152	231	1	1	-40	-55	1	1	0	1	-30	243	7
18	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	486	0	1	-40	-55	0	0	0	1	-30	212	290	1	2	-40	-59	1	1	1	0	-16	133	26
19	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	231	0	1	-40	-55	0	1	1	1	-30	243	584	1	2	-40	-45	1	0	0	0	-23	133	33
20	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	290	1	1	-45	-55	0	0	1	0	-16	243	486	0	2	-35	-59	1	1	0	1	-30	133	11
21	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	584	0	1	-40	-55	0	0	1	1	-30	152	231	1	2	-40	-45	1	1	0	0	-23	212	18
22	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	231	0	2	-40	-55	1	1	0	1	-30	212	584	1	1	-40	-59	0	0	1	0	-16	152	27
23	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	584	1	1	-40	-45	1	0	0	0	-23	182	231	0	2	-40	-55	0	1	1	1	-30	182	4
24	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	486	0	1	-35	-59	1	0	0	1	-30	212	290	1	2	-45	-55	0	1	1	0	-16	152	1
25	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	388	1	2	-40	-55	1	0	1	1	-30	133	388	0	1	-40	-45	0	1	0	0	-23	243	14
26	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	231	1	1	-40	-55	0	1	0	1	-30	243	584	0	2	-40	-45	1	0	1	0	-23	133	3
27	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	584	0	1	-35	-59	1	1	0	0	-23	182	290	1	2	-45	-45	0	0	1	1	-30	182	19
28	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	584	1	1	-35	-59	0	0	0	1	-30	152	231	0	2	-45	-45	1	1	1	0	-16	182	26
29	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	584	1	1	-35	-59	0	1	1	0	-23	152	231	0	2	-45	-45	1	0	0	1	-30	243	16
30	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	231	1	2	-35	-55	1	0	0	0	-23	243	584	0	1	-45	-45	0	1	1	1	-30	152	5
31	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	388	0	2	-35	-59	0	1	1	1	-30	133	388	1	1	-45	-45	1	0	0	0	-16	212	1
32	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-9	121	584	1	1	-35	-59	0	1	0	0	-23	182	231	0	2	-45	-45	1	0	1	1	-30	182	9
33	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	388	0	2	-45	-45	1	0	0	0	-16	182	388	1	1	-35	-59	0	1	1	1	-30	182	2
34	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	290	0	1	-35	-59	1	1	0	0	-23	243	486	1	2	-45	-45	0	0	1	1	-30	133	31
35	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	290	1	1	-40	-59	1	0	1	0	-16	212	486	0	2	-40	-55	0	1	0	1	-30	133	34
36	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	231	1	2	-35	-59	0	0	1	1	-30	182	584	0	1	-45	-55	1	1	0	0	-16	152	8
37	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	290	0	1	-45	-45	1	1	1	0	-16	243	486	1	2	-35	-59	0	0	0	1	-30	133	13
38	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	290	1	2	-35	-59	1	0	1	1	-30	152	486	0	1	-45	-55	0	1	0	0	-16	212	12
39	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	388	1	1	-40	-59	1	0	0	0	-16	212	388	0	2	-40	-55	0	1	1	1	-30	133	32
40	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	486	1	1	-45	-45	1	1	0	1	-30	152	290	0	2	-35	-55	0	0	1	0	-23	243	22
41	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	290	1	2	-35	-55	0	1	1	0	-23	182	584	0	1	-45	-45	1	0	0	1	-30	182	18
42	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	231	1	1	-40	-55	1	0	1	0	-16	243	486	0	2	-40	-55	0	1	0	1	-30	133	25
43	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	290	1	2	-45	-45	1	1	0	1	-30	133	486	0	1	-35	-59	0	0	1	0	-23	243	9
44	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	486	1	2	-40	-55	0	0	0	1	-30	133	290	0	1	-40	-59	1	1	1	0	-16	212	31
45	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	584	0	1	-35	-59	1	0	1	1	-30	152	231	1	2	-45	-45	0	1	0	0	-16	212	20
46	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	486	1	2	-40	-45	0	0	1	1	-30	133	290	0	1	-40	-59	1	1	0	0	-16	243	28
47	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	584	0	1	-45	-55	0	0	1	0	-16	182	231	1	2	-35	-59	1	1	0	1	-30	182	25
48	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	486	1	2	-35	-59	1	0	1	0	-23	133	388	0	1	-45	-45	0	1	0	1	-30	243	14
49	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	231	1	2	-35	-59	0	1	0	1	-30	212	584	0	1	-45	-55	1	0	1	0	-16	152	22
50	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	231	0	2	-35	-59	0	1	1	1	-30	212	584	1	1	-45	-55	1	0	0	0	-16	133	30
51	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	231	1	2	-45	-45	1	0	0	0	-16	212	584	0	1	-40	-59	0	1	1	1	-30	133	34
52	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	584	0	1	-45	-45	0	1	0	1	-30	152	231	1	2	-35	-55	1	0	1	0	-23	212	29
53	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	486	0	2	-45	-45	1	0	1	1	-30	133	290	1	1	-35	-55	0	1	0	0	-23	243	23
54	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	290	1	1	-45	-45	0	1	0	0	-16	243	486	0	2	-35	-59	1	0	1	1	-30	133	10
55	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	584	1	1	-35	-59	0	1	0	0	-23	182	231	0	2	-45	-45	1	0	1	1	-30	182	28
56	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	231	0	2	-35	-59	0	1	1	1	-30	212	584	1	1	-45	-55	1	0	0	0	-16	152	2
57	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	584	0	1	-45	-45	1	0	0	1	-30	182	231	1	2	-35	-55	0	1	1	0	-23	212	6
58	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	290	1	2	-40	-45	1	0	1	0	-23	182	486	0	1	-40	-55	0	1	0	1	-30	182	35
59	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	388	0	2	-45	-45	0	0	0	1	-30	182	388	1	1	-35	-59	1	1	1	0	-23	182	23
60	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	388	1	2	-45	-55	0	1	0	0	-16	152	388	0	1	-35	-59	1	0	1	1	-30	212	24
61	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	388	0	1	-35	-59	1	1	0	1	-30	212	388	1	2	-45	-45	0	0	1	0	-16	152	30
62	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	290	0	1	-35	-55	1	1	1	0	-23	243	486	1	2	-45	-45	0	0	0	1	-30	133	21
63	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	388	1	1	-40	-55	0	0	1	1	-30	212	388	0	2	-40	-45	1	1	0	0	-23	182	27
64	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	231	1	2	-45	-45	0	0	0	1	-30	212	584	0	1	-35	-55	1	1	1	0	-23	152	4
65	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-30	0	0	0	0	-16	121	486	0	1	-40	-59	1	1	1	0	-16	152	231	1	2	-40	-55	0	0	0	1	-30	212	15
66	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	486	0	2	-35	-55	0	1	1	0	-23	133	290	1	1	-45	-45	1	0	0	1	-30	243	24
67	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	290	0	1	-40	-55	1	0	1	1	-30	243	486	1	2	-40	-45	0	1	0	0	-23	152	10
68	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	231	1	2	-40	-55	1	1	0	1	-30	182	584	0	1	-40	-45	0	0	1	0	-23	212	17
69	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-9	105	388	1	1	-40	-45	0	1	0	0	-23	243	388	0	2	-35	-59	1	0	1	1	-30	152	8
70	200	0	0	50	60	0	0	0	0	30	0	192	0	1	-25	-45	0	0	0	0	-16	105	388	0	2	-45	-45	1	1	1	0	-16	133	388	1	1	-35	-59	0	0	0	1	-30	243	12

Notes: A pivot design was used to generate the choice sets and levels are relative to the quantities specified in the pivot option. For example the number of stations in the current facility and upgrades were specified relative to a pivot level of 200 stations in the downgrade alternative so the actual levels for this attribute, as produced in the choice cards, were totalled across alternatives as 200+192; 200+231; 200+290 and so on for the current facility and upgrade alternatives. Only the disaggregated levels are specified in the matrix above.

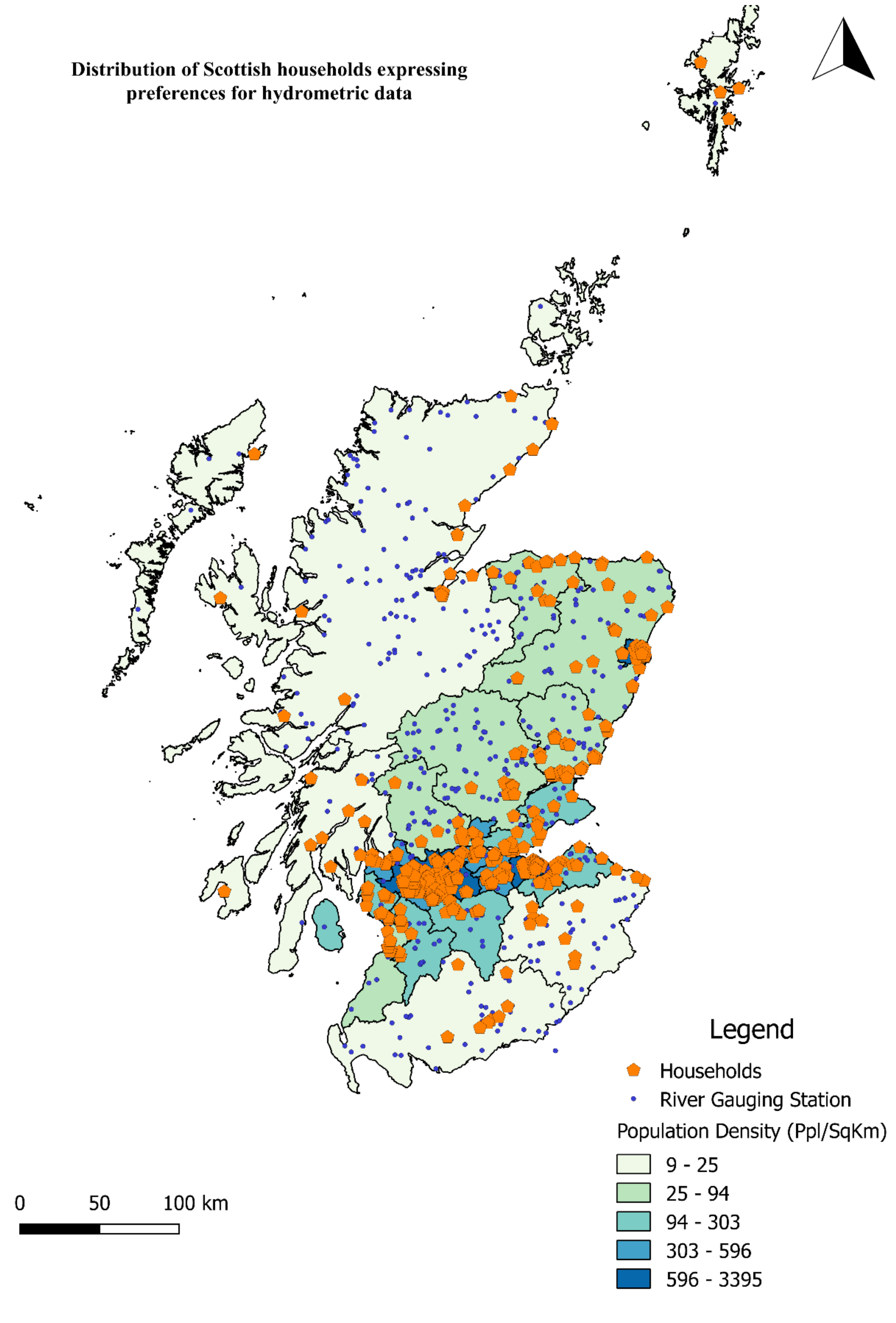
Appendix 4: Number of Responses per Block for Household Users' Survey

Block N umber	**Responses**
Block1	70
Block2	79
Block3	74
Block4	81
Block5	78
Block6	71
Total	**453**

Appendix 4: Number of Responses per Block for Professional Users' Survey

Block Number	Responses	Block Number	Responses	Block Number	Responses
1	2	13	5	25	2
2	7	14	2	26	4
3	4	15	3	27	4
4	2	16	1	28	4
5	6	17	2	29	2
6	4	18	5	30	3
7	3	19	1	31	2
8	6	20	6	32	3
9	3	21	3	33	1
10	6	22	4	34	2
11	3	23	2	35	3
12	4	24	4	**Total**	**118**

Appendix 5: Map of Responses from Household Survey



Data Sources: (1). Scottish Index of Multiple Deprivation (SG, 2016); (2). Scottish Environment Protection Agency.