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Assessing the Value of Groundwater

Science Report – SC040016/SR1

SCHO0207BMBD-E-P

ea/br/e/sci/v1

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This report is the result of research commissioned and funded by the Environment Agency's Science Programme.

Published by:

Environment Agency, Rio House, Waterside Drive,
Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

ISBN: 978-1-84432-677-8

Further copies of this report are available from:
The Environment Agency's National Customer Contact Centre by emailing:
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Dissemination Status:
Publicly available

Keywords:
Groundwater, economic valuation

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Science Project Number:
SC040016/SR1

Product Code:
SCHO0207BMBD-E-P

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Steve Killeen

Head of Science

Executive summary

Purpose of the report

This report is intended to help non-economists working in the field of groundwater policy, protection and clean-up at the Environment Agency and other public or private sector organisations to assess the value of groundwater. The report aims to:

- develop a framework for the full range of groundwater benefits (following the ‘total economic value’ paradigm);
- collate and present existing groundwater benefit information in a form that can be readily used as part of a groundwater-related cost-benefit analysis (CBA) or another economic appraisal process;
- demonstrate the benefit assessment methodology through case studies.

Scientific and economic uncertainty in understanding the benefits of groundwater and the inherent complexity make it difficult to design policies to encapsulate all aspects of this essential resource. Policy developments are likely to increase the demand for a better understanding of groundwater as an economic resource, as well as for quantitative evidence of its importance. The main policy drivers are:

- implementation of the Water Framework Directive (groundwater is one of the types of water body covered by the Directive);
- remediation of contaminated land and/or groundwater;
- general prevention of groundwater pollution.

Including a better assessment of the benefits of groundwater in CBA will allow it to be more effectively performed and pollution prevention measures to be more effectively identified.

The starting point for a framework of groundwater benefits is to pose the fundamental questions of economic analysis:

- What is the environmental resource?
- What benefits does it provide?
- For whom are these benefits provided?
- What are the potential changes of concern in the quality and quantity of the resource (e.g. the impact of contamination, abstraction or a new protection policy)?
- How do these changes affect the benefits provided by the resource?

This study was designed to answer these fundamental questions.

The benefits of groundwater

Groundwater is a valuable resource primarily because:

- it provides a reservoir of clean fresh water, relatively free from chemical and microbiological contamination, which can be used for drinking water supply with minimal treatment and minimum infrastructure (if used *in situ*);

- it sustains river and stream flow during periods of dry weather, which dilutes discharges and maintains aquatic life, recreational use and visual appeal;
- it supports some wetlands where it discharges to surface (this can have enormous ecological importance as well as recreational opportunities);
- subsidence of the ground surface can result from lowering of groundwater levels from over-abstraction or land drainage.

The benefits that groundwater provides can be monetised, i.e. measured through the common numeraire of money in order to compare the magnitudes of different benefits and to compare them with the costs of controlling pollution or of enhancing the resource.

This process of economic valuation assumes that individuals hold preferences for resources that are not traded in markets as well as for those that are. It looks for evidence of individuals' preferences for environmental 'goods' through:

- **market prices proxies** – actual markets for the resource itself or for replacement resources;
- **revealed preference techniques** – other markets such as the housing market;
- **stated preference techniques** – asking individuals directly what they would be prepared to forgo to protect the resource or accept as compensation for its degradation.

Commonly used techniques for measuring value are:

- market prices;
- production function;
- preventive/avertive expenditure;
- opportunity cost;
- cost of alternatives;
- hedonic pricing;
- travel cost;
- contingent valuation;
- choice modelling.

Value evidence found for a resource in one context can often be transferred to another context through a technique called benefit transfer. But whether this is appropriate and likely to yield accurate results can be very case-specific.

Valuation of a resource usually relates to a specific change in its quality or quantity. The baseline – what would happen without a policy change or project – and the change from this baseline which the policy or project will create must be identified and described.

Illustration of the valuation methodology through case studies

The valuation methodology is illustrated through the use of case studies of groundwater bodies in Hampshire, Lincolnshire, Kent and Nottinghamshire.

The case studies are for illustration only. They are intended to show how an assessment of the value of a groundwater body might be structured, though they do provide some initial indication of the rough order of magnitude of the benefits that might be expected. But at this level there are some serious gaps in data and in the understanding of physical impacts. No groundwater body modelling has been undertaken for these case studies as would be expected for a full application of the methodology.

The case studies contain a general description of benefits. For most components of value, the change described is the change that would occur in the worst case scenario. In most realistic scenarios, the change in each benefit would be very much smaller than this. Assumptions about the time periods over which benefits occur are also simplified; they are either annual and continual, or one-off and immediate. In reality, the physical effects of a change in the groundwater body may take many years to appear or may vary over time.

The case studies show that, without much inclusion of non-use values, the economic value of a given groundwater body is likely to be significant. Groundwater bodies that provide a substantial contribution to surface water ecosystems, heavy industry and agriculture are likely to be the most valuable.

However, the case studies also show that benefits assessment can be complex and information-intensive due to the different spatial and temporal scales on which many of the benefits operate. Furthermore, information on populations is not always immediately available at the right spatial scale or resolution. A key recommendation from this study is to prioritise the effort to acquire information according to the likely magnitude of benefits.

Particular gaps in understanding of, or evidence on, scientific and economic components of the analysis are those relating to:

- carbon sequestration;
- regulation of flood flow;
- prevention of subsidence;
- ecological impacts.

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1 Introduction

1.1 Policy background

Scientific and economic uncertainty in understanding the benefits of groundwater and the inherent complexity make it difficult to design policies to encapsulate all aspects of this essential resource. Moreover, the lack of reliable quantitative information on the value of groundwater benefits is a barrier to the use of cost–benefit analysis (CBA) in the groundwater and contaminated land sectors and in assessing the impacts of policy drivers such as the Water Framework Directive (WFD).

Although the Environment Agency has published guidance on using CBA for cases of contaminated groundwater and land (Postle *et al.* 1999, Hardisty and Ozdemiroglu 2002), empirical applications have been limited in the UK. A larger literature is available in the USA due to the requirements of environmental policies such as Superfund[1] and the Natural Resource Damage Assessment and Restoration Program,[2] but site-specificity makes transfer of this literature to the UK difficult (Hardisty and Ozdemiroglu 2004).

Policy developments are likely to increase the demand for a better understanding of groundwater as an economic resource, as well as for quantitative evidence of its importance. The technical specification for this study identified the main policy drivers for this as:

- **Implementation of the Water Framework Directive.** Groundwater is one of the types of water body covered by the Directive. Evidence of the economic value of groundwater is required in assessing whether a given Programme of Measures to meet a given ecological objective impose disproportionate costs. This assessment could be qualitative or quantitative (this refers mainly to monetary in this context). In addition, the full cost pricing principle brought about by the Directive requires evidence on environmental costs and benefits of water supply to be quantified and incorporated in water pricing.

- **Remediation of contaminated land/groundwater**. The Environment Agency seeks to adopt a proportionate, risk-based and even-handed approach to regulating the remediation of contaminated land and groundwater. Part IIA of the Environmental Protection Act 1990 requires the regulator to ensure that any works within a Remediation Notice are cost-effective (part of the 'test for reasonableness'). Section 39 of the Environment Act 1995 requires the Environment Agency to ensure that any other Notice is served only after the likely costs and benefits of the works specified have been considered. These considerations may require greater use of economic tools such as CBA.

- **General prevention of groundwater pollution**. By working with industry, the Environment Agency can ensure that appropriate CBA is carried out on measures to prevent groundwater pollution (e.g. those relating to underground petrol storage tanks). Including a better assessment of the benefits of prevention in CBA will enable proportionate and cost-effective pollution prevention measures to be installed. Making different costs and

[1] See http://www.epa.gov/superfund/
[2] See http://restoration.doi.gov/

benefits more explicit (if not all in monetary terms) could also allow CBA to act as a negotiation tool between the polluters and the Environment Agency.

In response to the need to improve the policy-relevant understanding of the economic value of groundwater, the Environment Agency began a research programme called *Assessing the Value of Groundwater*. This programme included:

- description of groundwater as a resource and specification of its benefits;
- review of existing benefit valuation and gap analysis;
- illustrative benefit assessments in the form of case studies (but not original economic valuation work).

The programme was undertaken as an interdisciplinary work with inputs from hydrogeologists, policy-makers and economists. This report presents the research from the second and third items in the list above.

1.2 Target users and objectives

This report is aimed at non-economists working in the field of groundwater policy, protection and clean-up at the Environment Agency and other public or private sector organisations. It contains terminology and methods that may be new to the reader but endeavours to make them as reader-friendly as possible.

Economic analysis does not offer off-the-shelf monetary 'values for groundwater' *per se* (or indeed for any other environmental resource). The value is influenced by a number of factors including:

- physical characteristics of the water body;
- its current and future potential uses;
- alternative sources of the benefits it provides (i.e. the availability of suitable substitutes);
- characteristics and number of people affected.

This variety of factors means that separate analyses of each groundwater body are required.

Even taking all these factors into account, the economic value is not an absolute value but a relative one that shows the cost (or benefit) of a loss (or gain) in the quality and quantity of the groundwater body in question. Thus, the value also depends on the context of change.

The main objective of this report is not to state the value of groundwater, but to provide a framework of analysis that readers can use in describing, quantifying and comparing the costs and benefits of different investment and policy options which affect the quality and quantity of groundwater. Through this, the report is expected to help readers ensure better dialog with economists and other experts.

In attempting to achieve this overall objective, the report's specific tasks are to:

- develop a framework for the full range of groundwater benefits (following the 'total economic value' paradigm);
- collate and present existing groundwater benefit information in a form that can be readily used as part of a groundwater-related CBA or another economic appraisal process;

- demonstrate the benefit assessment methodology through case studies.

After the initial draft of this report, the focus of the case studies changed from CBA of individual remediation or abstraction cases (which would have considered only a sub-set of benefits provided by groundwater) to a demonstration of all the benefits of a number of groundwater bodies (some of which could be expressed in monetary terms). However, the case studies remained illustrative in nature.

1.3 Scope

The environmental scope of the study is limited to groundwater. This includes groundwater both as a resource in its own right and as contributor to surface waters.

The literature review is limited to economic valuation literature and, within that, to providing information necessary for a sufficient understanding of the studies with a view to using their valuation estimates in future assessments. All pertinent studies are listed (Annex 3), but only those relevant to the UK or important examples of their kind are summarised (Annex 4).

The discussion of groundwater benefits does not need to contain quantitative and/or monetary information to be useful. The overall framework of thinking in terms of economic benefits of an environmental resource has helped in other policy areas and will continue to do so in groundwater policy. The starting point for such a framework is to pose the fundamental questions of economic analysis:

1. What is the environmental resource?
2. What benefits does it provide?
3. For whom are these benefits provided?
4. What are the potential changes of concern in the quality and quantity of the resource (e.g. the impact of contamination, abstraction or a new protection policy)?
5. How do these changes affect the benefits provided by the resource?

The scope of the study and the resulting report are designed to answer these fundamental questions.

1.4 Report structure

This report is organised in five further sections:

- Section 2 presents the main characteristics of groundwater as a resource.
- Section 3 introduces the concept of economic value and applies it in the specific case of groundwater.
- Section 4 presents ways to use the information about economic value in decision-making.
- Section 5 presents the methodology used in the case studies and the application of this methodology to four groundwater bodies.
- Section 6 concludes with gaps and recommendations.

The main report is supported by annexes that provide additional technical information for interested readers. The main report can be read without them without loss of meaning. These annexes are as follows:

- Annex 1 explores the comparison of the terms ‘value’, ‘cost’ and ‘price’ in more detail than in Section 3 of the main report.
- Annex 2 presents a detailed discussion on the option (future use) value of groundwater.
- Annex 3 presents the reference list of the economic valuation literature in the context of groundwater.
- Annex 4 summarises some of these studies in some detail.
- Annex 5 (a separate Microsoft® Excel spreadsheet) shows the data on various groundwater bodies used as the basis of the case studies.

2 Overview of groundwater

This section explains:

- what groundwater is;
- what benefits it provides;
- what threats it faces.

These questions form the basis of understanding the economic value of groundwater and set the context for decision-making.

2.1 Definitions

Important definitions from the WFD are given in Table 2.1. The term 'groundwater body' is used throughout this report when referring to groundwater.

Table 2.1 Key definitions from the WFD

Term	**Definition**[1]
Groundwater	All water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil
Aquifer	A subsurface layer or layers of rock or other geological strata of sufficient porosity and permeability to allow either a significant flow of groundwater or the abstraction of significant quantities of groundwater
Groundwater body	A distinct volume of groundwater within an aquifer or aquifers

Notes: [1]Article 2 of the WFD (see http://ec.europa.eu/environment/water/water-framework/index_en.html)

2.2 Benefits

Groundwater is a valuable resource for the following reasons:

- Groundwater forms a reservoir of fresh water, which is typically recharged by winter rainfall. It is by far the largest source of fresh water in the UK and can be used during dry periods when surface waters may not yield reliable quantities; this is particularly important in the south and east where summer rainfall is limited in quantity. Groundwater is used extensively for public water supply. It provides about one-third of all UK drinking water; this proportion rises to about 80 per cent in some parts of southern and eastern England.
- Groundwater generally provides a clean, safe source of water, relatively free from chemical and microbiological contamination, which can be used for drinking water supply with minimal treatment.
- Groundwater for local use is often available at the point of use and therefore requires minimum infrastructure development in the form of pipes and service reservoirs (the groundwater body provides the storage). This is particularly important in rural areas, where access to mains water may not be available at reasonable cost. It also means that water distribution

networks can be of more limited extent in groundwater-supplied areas than elsewhere.

- The flow of groundwater to rivers and springs sustains flow during periods of dry weather. The continued flow of rivers and springs in dry weather is important in providing dilution of discharges and maintaining aquatic life, recreational use and visual appeal. The relative importance of groundwater to the overall flow in a river can be deduced from the base flow index, which relates the quantity of flow contributed by direct runoff to that provided by groundwater. A high base flow index (close to one) indicates that groundwater provides a significant proportion of the flow, while a low value indicates a limited contribution from groundwater.

- Where it discharges to surface, the flow of groundwater supports some wetlands. Some wetlands are almost completely dependent upon groundwater for their water supply, while groundwater makes up part of the water requirements of others. However, some wetlands do not receive groundwater inflows and are entirely fed by surface water and rainfall.

- Groundwater supports the levels of some lakes, preventing them drying out or suffering large or erratic changes in seasonal water levels.

- Groundwater provides a sink for atmospheric carbon dioxide (CO_2), which is dissolved in rainwater and enters groundwater as carbonic acid. This reacts with the mineral components of groundwater bodies to produce carbonate. Carbon dioxide is a greenhouse gas, making sinks for it important in limiting increases in its concentration in the atmosphere.

- Groundwater contributes to the protection of transitional waters (estuaries) by maintaining an input of fresh water necessary to help create the valuable brackish water environment found at such locations.

- Groundwater contributes to habitats in coastal areas such as dune environments and retreating cliffs.

- Groundwater provides dilution of contaminants and nutrients that enter a groundwater body, thus reducing their impact at the location of groundwater discharge. Land spreading of sewage sludge, landfill sites and mines are examples of activities whose effect may be reduced by groundwater dilution.

- Lowering of groundwater levels as a result of over-abstraction or land drainage can result in subsidence of the ground surface causing structural problems to buildings, changes in the falls of drainage systems and local depressions prone to flooding;

- The relatively long travel times of groundwater mean that pollutants (chemical and microbiological) that enter a groundwater body may be attenuated before they reach a receptor. This means, for example, that septic tank discharges to ground can be made without causing permanent damage to parts of groundwater bodies provided there is sufficient distance between the point of entry and any receptors.

- Groundwater provides a sink and/or source of energy (heat) for space heating (ground storage of building energy schemes).

- In areas where the water table is close to the surface, groundwater sustains deep-rooted crops reducing the need for irrigation. It can also sustain wet woodlands and grasslands. Lowering the water table in arable areas with a shallow water table would require a switch to irrigation or a change in agricultural practice. Lowering the water table in non-arable areas is likely to lead to stressing or loss of that particular habitat.

- Groundwater provides a habitat for hypogean species (e.g. cave fish, stygobites etc., particularly in karst environments).
- Groundwater provides a refuge (in shallow alluvial groundwater bodies) for insect larvae and other stygofauna.

The uses of groundwater listed above are based on expert judgment and consider the following factors:

- human health and wellbeing;
- commercial activity;
- the environment;
- aesthetic factors.

This prioritisation does not necessarily reflect Government or Environment Agency policy or evidence found in the economic literature. The full list of services does not apply to all groundwater bodies universally and some are very site-specific.

Within the framework of the economic analysis, some of the above benefits are in fact 'processes' that lead to 'outcomes' such as water as a commodity (or a good) and support to ecosystem services such as the ecological functions of wetlands. Because economic analysis focuses on the outcomes, not all the above can be valued separately (in quantitative or monetary terms). How the list above list fits within the typology of economic value is discussed in Sections 3 and 4.

2.3 Threats to groundwater

As mentioned in Section 1, the economic value of the benefits of groundwater is also influenced by any change in its quality and quantity. It is therefore important to establish at the start of an economic analysis those threats to groundwater likely to lead to quality and quantity changes.

Groundwater resources can be damaged by a reduction in the quantity of water and/or by contamination affecting its natural quality (usually very high).

Reductions in quantity can occur as a result of:

- over-abstraction;
- reduction in available recharge due to an increase in impermeable surfaces (which also divert rainfall to surface water courses) as part of the built environment;
- land drainage measures lowering the water table;
- climate change altering previously established historical rainfall and recharge patterns.

A reduction in quantity will reduce the available groundwater resource and result in:

- reduced flows to rivers;
- drying up of wetlands and lakes;

- reduced availability of groundwater for abstraction for household, public, agricultural and industrial use.

Many contamination sources can reduce the quality of groundwater. These can be categorised as follows:

- **Diffuse sources of contamination.** These result from activities that take place over an area (e.g. use of nitrate fertilisers in farming). Common diffuse contaminants include nitrates and pesticides.

- **Point sources of contamination**. These result from activities taking place at discrete locations (e.g. petrol stations, gas works) or sites of accidental spill. There are many potential groundwater contaminants, used at a large number of locations. Common point source contaminants include hydrocarbons and chlorinated solvents.

Once introduced into groundwater, many contaminants persist for many years and can spread over large areas. Some contaminants may also evolve chemically into other forms more toxic than their precursors.

3 Economic value of groundwater

This section discusses:

- conceptual background to economic value (Section 3.1);
- factors likely to affect the economic value of groundwater (Section 3.2);
- methods for estimating economic value (Section 3.3);
- the valuation literature (Section 3.4).

3.1 Concepts

3.1.1 Individuals' preferences count

The economic value of a resource such as groundwater is based on individuals' preferences for that resource. Individuals are assumed to have preferences for or against the changes in the quality and quantity of goods and services, regardless of whether these are traded in markets.

While related, economic value is distinct from the concept of price. The worth, or value, of a resource is defined in terms of the quantity of other resources, or money, someone is willing to give up to acquire it. In modern economies, money is typically the unit used for this exchange. This value could be more or less than the market price (if it exists).[3]

In actual markets, people can express their preferences through their selling and purchasing behaviour. The perfect market price is the maximum amount buyers are willing to pay and the minimum price sellers are willing to accept. When markets are not perfect (they rarely are for various reasons), there is said to be a 'consumer surplus' – when what buyers are willing to pay to purchase a resource exceeds what they have to pay (market price).

Economics assumes that individuals hold preferences for resources that are not traded (or at least not directly or wholly traded) as well as for those that are. Most environmental resources, including groundwater, are prime examples of 'non-market' resources. While there is a market for the groundwater abstracted (e.g. public supply), there is no market for many of the other benefits of groundwater (see Section 2.2). Therefore, groundwater can be said to have an incomplete market.

The same measures of preference apply to non-market or incomplete market resources as to those traded in markets. Individuals are assumed to have a willingness to pay (WTP) to secure gains or to avoid losses in the quality and quantity of the resource. Alternatively, they are assumed to have willingness to accept (WTA) compensation to forgo gains or to tolerate losses. Here, a gain (or a benefit) is any change that increases human welfare, and a loss (or a cost) is any change that decreases human welfare. Similarly, 'an avoided cost' becomes a benefit and a

[3] Economic value is also related to cost in so far as the cost of, say, an investment would be worth incurring if it was less than the economic value (or benefit) of that investment. Annex 1 provides further detail on the differences between the terms value, cost and price which are – often mistakenly – used interchangeably.

'forgone benefit' becomes an opportunity cost.[4] This interchangeability of the notions of cost and benefit is particularly important in cost–benefit analysis (see Section 4.2).

Two important aspects of economic value need to be emphasised here:

- Economic value is defined by human preferences. Therefore any notion that cannot be expressed by people (e.g. the 'intrinsic' value of the environment) is not included in the economic value.
- Economic value is about changes (gains or losses) in the quality and quantity of environmental resources. It is not a statement about the absolute value of the environment.

3.1.2 Total economic value

But why should individuals have preferences for environmental resources such as groundwater? The typology of likely reasons is known as the 'total economic value' (TEV). TEV is the principal typology in environmental economics used to understand preferences both for resources that are bought and sold in markets, and those that are not.[5]

TEV has two main components:

- **Use value**. This involves some physical interaction with the resource, either directly or indirectly.
- **Non-use value**. This is associated with benefits derived simply from the knowledge that the resource is maintained, either for one's own satisfaction or that of others.

Use value

Use value can be further described in relation to the degree of use:

- **Direct use value***.* This involves human interaction with the resource itself. It may be consumptive or extractive use (e.g. fisheries, timber) or it may be non-consumptive, as with some recreational and educational activities.

  The consumptive use value of water is its use for domestic, public, commercial, agricultural and industrial supply. Provided the quantity and quality (composition, taste, etc.) of water is the same, the welfare of individuals with respect to this value category is unlikely to be affected by the source of water (surface or ground). This is the component of groundwater benefits that is, to some extent, directly traded and the part of TEV that may be quantifiable using data from the market.

- **Indirect use value.** This derives from the ecological services provided by the resource. Possible examples include:

  - removal of nutrients;
  - providing cleaner water to those downstream;

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[4] The opportunity cost is the benefits society would receive from the best option of a resource that is not selected net of the benefits from the option that is selected.

[5] As well as being used in the context of groundwater (e.g. US EPA 1995, Bergstrom *et al.* 1996), TEV (and the associated 'economic valuation methods' mentioned in Section 3.3) is also used in the *Green Book* (HM Treasury 2003) (the Government's main appraisal guidance), several reports published by the Department for Environment, Food and Rural Affairs (Defra) and other research. See Defra (2006) for a review.

- prevention of downstream flooding and diseases;
- climate regulation;
- provision of information.

As outlined in Section 2.2, groundwater recharges surface waters, enables natural attenuation of contamination, etc. (see Table 3.1 for a complete list).

Non-use value

By definition, non-use value is not associated with any use of the resource or tangible benefit derived from it by the holder, though users of a resource might also attribute non-use value to it.

Non-use value can be split into three basic components:

- **Existence value**. This is derived simply from the satisfaction of knowing that the resource continues to exist, whether or not this might also benefit others. Groundwater as a resource on its own and through its recharge of surface water is likely to attract existence values.
- **Bequest value**. This is associated with the knowledge that the resource will be passed on – in suitable quantity and quality – to descendants and other members of future generations. Groundwater is likely to generate bequest value both as a resource (i.e. ensuring that future generations have access to sufficient water supply) and through its contribution to surface water bodies and other ecological services (see Table 3.1).
- **Altruistic value**. This is derived from knowing that contemporaries can enjoy the benefits the resource provides. Again groundwater is likely to attract altruistic values for others' use of the resource and as a provider of wider ecological services.

Option value

Another category not immediately associated with the initial distinction between use values and non-use value is option value (OV).

This is the benefit derived by individuals from ensuring that the resource will be available for their own use in the future. In this sense it is a form of use value, although it can be regarded as a form of insurance to provide for possible future use.

While many economic valuation studies capture option value, it is difficult to disaggregate it from other types of value. Annex 2 discusses option value in terms of what it is and why it is so difficult to measure on its own.

The ability of a groundwater body to store water for future use (regardless of whether it is used currently) leads to option value.

3.1.3 Whose preferences matter?

The preferences of everyone affected by the change in the resource of concern should be counted. However, this simple statement hides a complex definition. 'Affected' parties could be those who make use of groundwater directly or indirectly, and the change can either diminish or enhance the opportunities for such use. Using the TEV terminology, these are 'the users'. But since individuals could hold preferences for environmental resources they do not use now or plan to use in the future, they could also be affected by the changes in this 'non-use' way. Again, using the TEV terminology, these are 'the non-users'.

Users may have both use and non-use values, while non-users hold only non-use values. In most cases, users are relatively easier to identify and quantify. However, there is limited evidence as to what type of individual is likely to hold non-use values for a given environmental resource. Theoretically anyone (regardless of their current use of a given resource or how far away they reside from it) could hold non-use values.

In practice, the very few studies that search for geographical boundaries for such populations have found what can be called a 'distance–decay' relationship. In other words, the number of those who hold positive non-use values for a given resource declines with the distance from the resource. Unfortunately, no studies to date have looked at such a relationship for groundwater (or in fact whether individuals hold non-use values for groundwater bodies). The ongoing benefit assessment research within the Collaborative Research Programme for implementing the Water Framework Directive could shed some light on this issue.[6]

3.1.4 Summary

Table 3.1 shows how the benefits of groundwater discussion can fit within the TEV typology. Some of the benefits listed in Section 2.2 have been merged, as they lead to the same type of economic value and affect the same general categories of beneficiaries. The table is not intended to imply that separate quantification of these components is possible, or indeed always necessary.

Table 3.1 provides the full list of benefits that could potentially be provided by a groundwater body. Not all groundwater bodies provide all of these benefits. In some cases, groundwater delivers all of the benefits of one type; in others it is responsible for a proportion. For example, if groundwater is the only source of water supply in an area, then 100 per cent of the value of water supply is attributable to groundwater. Actual ecological relationships (especially in assessing the contribution of groundwater to other ecosystems) are likely to be much more complex, but such impact assessment is not within the scope of this study. And, in practice, time and budget limitations mean that most cost–benefit analyses are based on simplifying assumptions.

[6] Study by JacobsGIBB, RPA, ADAS and eftec as WFD Collaborative Research Programme Contract Number CRP/SG PROJECT 3 (Guidance on the evidence required to justify disproportionate cost decisions under the Water Framework Directive). See http://www.defra.gov.uk/Environment/water/wfd/economics/research.htm

Table 3.1 Benefits and total economic value of groundwater

BENEFITS	Use value		Non-use value			OV	Who benefits?
	DUV	IUV	EX	ALT	BQ		
Water supply							
Public supply							Water users (all affected) and non-users may hold ALT, BQ and OP.
Private supply							Water users (household users) and non-users may hold ALT, BQ and OP.
Agriculture							Farmers and non-users may hold ALT, BQ and OP.
Industrial abstractions							Industrial customers and non-users may hold ALT, BQ and OP.
Recharge to surface waters (rivers, lakes, springs, wetlands[1], transitional waters)							Direct users: consumptive (e.g. for fishing) and non-consumptive for recreation (in and along surface water bodies). Indirect users: sustaining these habitats and their ecosystem services. Non-users: EV of the habitats (not of the groundwater itself); ALT and BQ as they apply to all.
Flood risk regulation							Indirect users: reduced risk of flooding. Non-users: possible with regards to others and future generations facing lowered risk of flooding.
Sink for atmospheric carbon dioxide							Users: Since climate change to which CO_2 contributes is a global issue, the beneficiary is the global population, so theoretically there are no 'non-users'.
Dilution and attenuation of pollutants							Users: water users – overlap with the benefits and beneficiaries of 'water supply' benefit. Users: residents local to the affected area – avoided contamination and hence related blight. Non-users: most relevant through ensuring clean water supply and support to other ecosystems rather than directly for groundwater itself.
Prevents subsidence							Users benefit from continued maintenance of ground levels. While in theory, non-users may hold ALT, BQ and OP, it is not clear how this would manifest itself in practice.
Sustaining habitats							
Deep-rooted crops, trees							Users: farmers, recreational visitors and local population.

BENEFITS	Use value		Non-use value			OV	Who benefits?
	DUV	IUV	EX	ALT	BQ		
(wet woodlands) and grasslands, other terrestrial ecosystems and wet natural habitats and riparian zones							Non-users may hold ALT, BQ and OV for the ecosystems that are supported by groundwater (i.e. not directly for groundwater but attributable to it).
Other 'wet' habitats: wet dunes, tufa springs, eroding sea-cliffs							Users: recreational visitors and local population. Non-users may hold ALT, BQ and OP for the ecosystems that are supported by groundwater.
Provides sink and/or source of energy (heat)							Users of energy: from cost savings compared with alternatives. Local/regional/global population: from emissions savings compared with alternative sources of energy.
Provides habitat for hypogean species and refuge for insect larvae and other stygofauna							There are no users as the species are not used directly or indirectly. There could be, in theory, non-use values attached to these species but, in practice, this is unlikely due to lack of knowledge about them. Thus, non-use value is likely to be limited to specialist researchers.

Notes: [1] groundwater-dependant wetlands
ALT = altruistic value
BQ = bequest value
DUV = direct use value
EX = existence value
IUV = indirect use value
OP = option price (see Annex 2)

3.2 Factors influencing the economic value of groundwater

Before describing the methods that can help to define the economic value of groundwater in monetary terms, it is useful to examine the factors that influence the economic value. Economic valuation methods are designed to gather or generate data on these factors and analyse such data to estimate the economic value. Therefore, understanding the factors that influence economic value of groundwater helps to understand the valuation methods (see Section 3.3) and make the selection of the most relevant method(s) easier.

The various factors influencing the total economic value of groundwater can be grouped into:

- those relating to the characteristics of the groundwater body and the ecosystems which it affects (see Section 3.2.1);
- the characteristics of the individuals (user and non-user) whose preferences or behaviour are analysed (see Section 3.2.2).

3.2.1 Characteristics of the groundwater body

Water quality

Once treated, the water from groundwater usually has the same value to the customer as any other potable source,[7] but the costs could be different.

The higher the quality of water prior to any treatment, the higher its economic value would be before that treatment. The higher the treatment requirement, the higher the cost of water supply will be.

The value of lower quality water (e.g. high total dissolved solids groundwater) can also be inferred as being the same as that of high quality water, but minus the added expense of required treatment (all other things being equal).

Timing and permanence

The value of water, as with any other asset, is affected by:

- the timing of when it is available for use;
- the duration over which it is available.

Water assured continually and/or indefinitely will command a higher economic value than water available only during a limited period either due to natural uncertainty or licensing processes.

Likewise, water available for use a decade or more into the future is less valuable (other things being equal) than water available today as the same rules of discounting (see Section 4.2) apply as they would to any other commodity.

[7] In practice, this may not always be true. There may be 'stigma' effects associated with water that was once highly contaminated but is now clean.

Availability and cost of substitutes

The value of water provided by groundwater (or any other source) also depends on the availability and cost of substitutes, i.e. other sources. The same is also valid for recreational and other uses of surface water supported by groundwater.

The more substitutes there are and the cheaper they are, the less the value attached to a particular source is likely to be. This is also likely to apply to non-use values as well as to use values. Unique resources attract higher non-use values (both in that they may be held by more people and may generate higher per person values *per* se) than those that are commonly found or easy to replace.

However, availability of substitutes may change over time. The planning time frames for water are rather long due to the long construction periods necessary for water supply and treatment infrastructure. This also applies to groundwater due to inherent latency (e.g. contamination could take a long time to detect and even longer to clear up).

Benefit assessments and cost–benefit analysis usually take place at the beginning of this time horizon. But since the change in the availability and cost of substitutes is unlikely to be known, cost and benefit assessments either use the current values at the time of the assessment or make simplifying assumptions about future trends.

The uncertainty about future availability of substitutes stems from scientific uncertainty (e.g. the effect of climate change on water resources) and uncertainty about human behaviour (e.g. change in demand) – even though some projections for both exist.

The nature of the change

As mentioned in Section 3.1, economic value is about the change in the quality and quantity of a resource and the related changes in the benefits it provides.

Changes in the quantity of groundwater available could have very different effects on the different benefits compared with changes in the quality of groundwater. Therefore, quality and quantity changes cause different changes in economic value.

The value of the groundwater body cannot be divorced from the pressures or threat causing the change.

What replaces the lost benefit?

Particularly with ecological benefits, an impact on a benefit will not necessarily result in a total absence of any similar benefit. For example, a groundwater body might provide water to a particular ecosystem such as a wet woodland. If the groundwater is lost, there will be a different type of ecosystem where the wet woodland once was and not ‘no ecosystem’. It may be that people prefer the new ecosystem compared with the wet woodland. Hence, the economic value of the lost benefit is the net value (value attached to the lost ecosystem minus the value attached to the new ecosystem).

3.2.2 Characteristics of the affected population

Ultimately, economic value is an expression of individuals’ preferences. Any factor that influences the preferences of affected individuals will therefore also influence the economic value of groundwater.

Research shows that a number of factors affect individuals' preferences and hence their willingness to pay or willingness to accept compensation. These factors are as follows:

- socio-economic characteristics such as age, gender, education, household size, occupation and income;
- opinions and attitudes towards the environment, etc;
- personal tastes so that, for example, some households may value improved taste and odour of their tap water, and may reveal their value through ancillary purchases they make (e.g. buying bottled water or an in-home filter device), whereas others may not see sufficient value in these alternatives to motivate such purchases;
- personal interests so that, for example, those who undertake near or on-water recreational activities may value the quality and quantity of surface water (and hence indirectly the benefit of groundwater in recharging surface waters) more than those who do not. Similarly, the frequency with which such recreational activities take place is also found to be an important factor in determining value; all else being equal, those who visit water bodies more frequently may be willing to pay more for their protection.

3.3 Economic valuation methods

There are three main categories of economic valuation methods depending on what type of data are used:

- If there are actual markets in which an environmental resource is traded, valuation methods that collate and analyse the price, purchase and sale data are used. In the case of groundwater, the most obvious market data are:
  - the price of water (public supply and bottled water);
  - the cost of water supply and treatment infrastructure and spending on water filters and storage system by users.

  These can all indicate the value of changes in water quality and quantity. Economic valuation methods that use market data are generally known as **market price proxies** (see Section 3.3.1).
- While many environmental resources are not (at least not fully) traded in actual markets, it is possible to analyse how consumer behaviour in actual markets for other goods and services is affected by their preferences for environmental resources. In the case of groundwater, property values can give clues about the value of reliable and good quality water supply (and groundwater's contribution to this). In the case of groundwater's recharge of surface water, spending on relevant recreational activities can be used as evidence of economic value. Economic valuation methods that use this type of data are known as **revealed preference methods** (see Section 3.3.2).
- Where there are no markets in which the environmental resource of concern is traded, the data necessary to estimate economic value have to be generated through hypothetical markets in which individuals can express their preferences (or WTP) directly. This is done by asking a series of questions to a representative sample of the affected population. Economic valuation methods that help design and analyse such

questionnaires are known as **stated preference methods** (see Section 3.3.3).

Each method category has different time, cost and expertise requirements, which it is not always feasible to meet for each and every economic analysis case. In other words, conducting a primary study is usually relatively expensive compared with looking at literature that may be relevant to the valuation question at hand. Therefore, an approach known as **benefits transfer** (see Section 3.3.4) has been developed to aid consistent and transparent borrowing of economic value estimates from the literature to use for the analysis in hand.

Each economic valuation method has advantages and disadvantages, which are relevant in the different contexts of environmental change or different policy or investment decisions. With the exception of some applications of stated preference methods, they can also provide only partial estimates of TEV. Market price proxies and revealed preference methods provide only parts of use value, while stated preference methods provide both use and non-use values.

The commonest criteria for selecting the most appropriate valuation method for an economic value analysis are presented in Section 3.3.5.

Annex 1 provides further explanation of the differences between value, cost and price.

3.3.1 Market price proxies

In this report, market price means the market price of:

- water;
- goods and services that are used to maintain good quality and sufficient quantity of water;
- goods and services that are affected by the quality and quantity of water.

Market price for water

One of the most direct methods for estimating the value of water is to look at the market price for water. Although a market price may be observed for water, the simple single observation of what people pay for water, or the price it is sold at, does not allow an estimate for the overall value of water to be developed.

To use the market price to estimate the value of water to consumers, market transactions for water must be observed across a number of different price levels and demand situations. By tracing the relative amount of water demanded at different prices, it is possible to map out the demand curve for water. This demand curve is the consumers' willingness to pay (i.e. value), which can then be used to calculate the change in consumer surplus which results from a policy that changes the demand curve. In practice, most analyses use the simple calculation of price per unit of water multiplied by the amount of water (gained or lost) (see Annex 1). However, this is, at most, a lower bound estimate of value.

Production function

This is a common method used to measure the value of inputs (e.g. in agriculture) by evaluating the benefit the input provides to the overall product. This approach defines water as one of the necessary inputs to produce crops along with seeds, land, labour and other factors of production.

The approach calculates the marginal value of water in the overall crop production process by estimating:

- the marginal unit of crop production per unit of water;
- the value of the marginal crop yield using the market price for that crop.

For example, if adding another megalitre (ML)[8] of water increases crop production by 5 per cent and thus increases crop revenue by £100, the value of that extra megalitre of water is said to be £100.

Similar production functions can, in principle, be estimated for other uses of water in the industrial and commercial sectors. In practice, it is difficult to assess the response of production to changes in water input. In addition, a number of considerations underline the complexity of analysis including:

- nature of production (single or multi-product companies);
- market structure (e.g. vertically linked markets);
- presence of market distortions (e.g. monopoly power, price subsidies, etc.).

When impact assessment is not possible, simplifying assumptions are made about the relationship between water input and crop or other output.

Opportunity cost

This approach estimates the benefits that are forgone when a particular action is taken. For example, if a groundwater body is contaminated, the economic value that water would have generated would be forgone. In the strictest sense, opportunity cost should be viewed as the next best alternative use of a particular resource, i.e. the answer to the question of what the lost water would be used for. This could be the value of the current use of water if alternative supply is not possible.

Mitigation behaviour/preventive or avertive expenditure

Such approaches analyse the cost incurred in defending against the negative impacts of environmental degradation. In the context of groundwater, the most common examples are spending on bottled water and water filters. The benefits estimated in this way would include reliable quantity and quality of water, but also more intangible benefits like improved taste of water.

Substitute goods/cost of alternatives

These approaches involve estimating the cost of provision of an alternative resource that provides the benefit of concern. A wetland service that provides protection against flooding could, for example, at the very least be valued on the basis of the cost of building man-made flood defences of equal effectiveness. Another example might be the cost of supplying the current quantity and quality of water from an alternative source if a groundwater body is lost due to contamination or over-abstraction.

[8] I megalitre = 1 million litres

3.3.2 Revealed preference methods

Hedonic property pricing method

This method is based on the notion that the price at which a property sells is determined, in part, by the environmental characteristics of the surrounding location among others such as size.

The economic value of the environmental characteristics is estimated by regressing the sale price against all factors thought to affect the price. The method is generally used for localised and site-specific impacts including:

- ‘goods’ such as pleasant views (and related increases in property price);
- ‘bads’ such as traffic noise, disamenity due to proximity of landfills, etc.

The scope of these studies is limited to environmental characteristics that are observable by individuals and are likely to have an impact over the period of occupancy. By definition, this excludes changes that are yet to occur.

In the context of groundwater, the value of reliable and good quality water supply can be estimated based on its contribution to property price. Similarly, the effect on property prices of the presence of water bodies (which may be partly fed by groundwater) in close proximity to housing can also be estimated using this method.

Travel cost method

This is a survey-based technique that uses the cost incurred by individuals travelling to and gaining access to a recreation site as a proxy for the value of that site. Costs considered are travel expenditures, entrance fees and the value of time.

Typically the method is limited to valuing environmental goods and services that have explicit recreational uses such as woodlands, wetlands, rivers and lakes, national parks and coastal areas. The method is not able to account for environmental ‘goods’ (or ‘bads’) that are imperceptible to visitors. In the context of groundwater, the recreational benefit of the recharge of surface waters can be used. However, it is limited to recreational use value of surface water alone and cannot, by definition, estimate the economic value of changes that are yet to occur.

3.3.3 Stated preference methods

Contingent valuation

Questionnaires using the contingent valuation (CV) method ask a sample of affected individuals their WTP or WTA for specified changes in the quality or quantity of the environmental resource of concern. An example might be the protection of groundwater from nitrate contamination.

A typical questionnaire will develop a clear and focused discussion on the specific ‘good’ to be valued. The responses are analysed to develop an estimate of the demand curve for the ‘good’ in question and thus its value. There may, however, be a danger of respondents overstating their WTP because they do not think they will really have to pay. Good practice in survey technique tries to reduce this possibility.

Choice modelling

Choice modelling (CM) is similar to contingent valuation except that, instead of expressing preferences for a single change, survey respondents are given a set of choices. The surveys describe a set of characteristics of the resource of concern and then vary these across the choices. Respondents are asked to either rank the choices or choose their most preferred. One of the characteristics is always price or cost, so that by ranking the alternatives or choosing their most preferred, respondents implicitly trade resources against money. Hence their WTP or WTA can be inferred through their choices.

As it allows more flexibility in the scenarios presented in a questionnaire, choice modelling is often better than contingent valuation at handling future uncertainty. This reduces the burden on the researcher to get the scenario exactly right in the questionnaire – a risk with contingent valuation.

3.3.4 Benefits transfer

Benefits transfer is an approach in which the results of previous economic valuation studies are applied to new policy or decision-making contexts. It is commonly defined as the transposition of monetary economic values estimated at one site (the study site) to another (the policy site). The study site is the location at which the original study took place, while the policy site is a new site where information is needed about the economic value of similar benefits. The main reason for using previous research results in new policy contexts is that this saves considerable time and money.

Several approaches to benefits transfer can be distinguished which differ in their degree of complexity and data requirements, and the reliability of their results. In principle, these approaches are all related to the use of either average WTP values or WTP functions and can be grouped into three categories:

- **Using the unadjusted mean WTP estimate from another study site** to predict the economic value of the benefits involved at the policy site. Ideally, the study had focused on the same environmental resource, but was carried out at a different location or at the same location but at a different point in time. As well as an unadjusted mean WTP from a single study, the average of the unadjusted mean WTP estimates from more than one study (if available) can also be used.
- **Using one or more mean WTP estimates adjusted for one or more factors influencing the WTP estimate**, which are often based on expert judgment. For instance, mean WTP is sometimes adjusted for differences in income levels at the study and policy sites, based on existing information about the income elasticity of WTP for the resource in question. This information is usually taken from the estimated WTP function in the original study.
- **Using the entire WTP function that shows all factors** has two common forms:
    - The entire WTP function from an original study can be used to predict mean WTP at the policy site. The estimated coefficients in the WTP function are multiplied by the average values of the explanatory factors at the policy site to predict an adjusted average WTP value. It has been argued that the transfer of values based on estimated functions is more robust than the transfer of unadjusted average unit values because effectively more information can be transferred (Pearce *et al*. 1994).

However, this approach is usually more data intensive than the first two as information about all the relevant factors must be available.

- A WTP function estimated based on the results of various similar valuation studies can be used. The difference between this approach and the one above is that the WTP function here is estimated on the basis of either the summary statistics of more than one study or the individual data from these studies. In the literature, this approach is usually referred to as meta-analysis. Formally, meta-analysis is defined as the statistical analysis and evaluation of the results and findings of empirical studies (e.g. Wolf 1986).

Although the application of benefits transfer is common, as with the other methods, caution should be used when developing estimates of value. The accuracy of the values transferred depends on a number of factors specific to the original study and to the new policy question. These factors include issues such as how comparable the policy site is to the study sites.

In the case of groundwater, the main factors that need to be kept in mind when selecting appropriate studies from the literature are:

- groundwater body – characteristics and definition;
- the benefits the asset provides in the baseline (see Table 3.1);
- environmental change to be valued – type (quality or quantity) and magnitude of change;
- affected population – both in terms of the type of population (i.e. user or non-user) and geographical location of the population.

All these factors should be 'sufficiently similar' between the study site and the site of the environmental asset to be valued to justify use of the results from a given study. The definition of what is 'sufficient' is generally based on expert judgment as the services that groundwater provides can be highly complex and case-specific.

3.3.5 Selecting the most relevant valuation method

Four main criteria inform the selection of appropriate valuation methods. These are:

- type of benefit provided by groundwater – whether it is reflected in actual markets or not;
- expected response of the affected population to the change in the quality and quantity of groundwater;
- inherent characteristics of the valuation methods;
- needs of the policy appraisal or decision analysis.

These criteria are illustrated below with examples taken from the context of water and other environmental assets.

Type of benefit

As shown above, some of the benefits of groundwater are reflected in actual markets (e.g. water supply for various uses). These 'market' benefits can be valued using market prices. Benefits of groundwater that are reflected in markets other than that for water (e.g. groundwater recharging surface waters) may be estimable using revealed preference methods (Section 3.3.2). Benefits that are not reflected in any market (e.g. informal recreation and non-use values) can only be estimated by stated preference methods (Section 3.3.3).

Where a benefit is partially captured by actual markets, different methods can be used and the results can be aggregated. For example, the value of water purification services includes both the financial value of the service provided to water companies (which would otherwise have to spend more to treat the water) and the value of the contribution to water quality to informal recreational users.

Double counting should be avoided. For example, if avoided treatment costs to water companies are used as the measure of value, these cannot be added to the WTP of households to avoid contamination, since both approaches address the same change.

The legislative context

The economic valuation method used depends partly on what actions are needed to address the change (e.g. decline in quality or quantity of groundwater). Here, the cost of such action becomes either the cost of quality or quantity decline, or the benefit of continued good quality or quantity. To give an extreme example, the benefit of groundwater providing good quality water for public supply could be considered in different legislative contexts.

Where water companies are legally required to take on the extra burden of water treatment for supply when a groundwater body is degraded or lost, the cost to the water companies of increased treatment effort would be a valid measure.

Where no legal requirement exists and extra treatment does not take place, the result would be increased illness from consuming poorer quality drinking water. Alternatively, we may expect that, in the absence of increased treatment effort, people would purchase bottled water, in which case the appropriate technique would be avertive expenditure.[9] These techniques do not estimate the total economic value of clean water, only the economic cost of losing one of the benefits of groundwater.

Inherent characteristics of valuation methods

Although stated preference methods can in principle be applied to any context, they are often limited by what scientific data exists and the ability of respondents to understand the nature of the change being valued. Many benefits of groundwater are generally unobserved by individuals and, as such, would rarely enter into their set of preferences. However, some argue that many economic decisions (including purchasing of traded goods and services) are made on the basis of little information but that this does not make them less valid.

There are also ways in which changes in groundwater quality and quantity (with associated uncertainties) can be made more 'digestible' and relevant for individuals. For example, the implications of a decrease in groundwater available for water level in the local river and its recreational uses can be described clearly. The changed benefits may be so complex that they may each merit a separate valuation study so as not to

[9] Pricing techniques need not be mutually exclusive and several can be employed to evaluate the different outcomes of changes in groundwater quality or quantity. A mix of avertive expenditure techniques, production function, replacement cost and opportunity cost may be employed. The important point is to avoid double counting in defining the benefits and impacts of change.

overburden respondents. In such situations it may become practical to use benefits transfer for some impacts and new valuation work for others.

Data availability in general is a concern for all valuation methods. For example, in the absence of data on house prices, hedonic pricing is not possible. The travel cost method requires data to be collected through a survey of visitors, increasing the cost and time requirement. Although one of the benefits of stated preference work is that it serves to collect economic data, it relies on accurate representations of the impacts of change for its own validity.

While revealed and stated preference methods have a greater theoretical appeal compared with market price proxies, there are certain cases where it may be more practical and relevant to use the latter to estimate economic value. Market prices are less controversial in the sense that market data reflect the preferences as actually demonstrated in the market. Therefore they do not suffer from some of the uncertainties that are inherent in the hypothetical markets created through stated preference questionnaires. However, all methods employing market data will be underestimates of actual willingness to pay as they provide partial indications of use value and cannot detect non-use value at all. In addition, market data are not without their own problems including distortion through taxes and subsidies, and market failures.

Given sufficient scientific impact data, another consideration is the time and resources required for different methods. Benefits transfer can be applied in a matter of weeks, but is constrained by the limited coverage of the literature and site-specific nature of some environmental changes. Stated and revealed preference studies can take from six months to more than a year to implement, at much greater cost. The cost and resource requirements of any valuation method should not, however, be assessed in isolation from the needs of the policy appraisal and decision context, which is the next criterion.

The needs of the policy appraisal or decision context

The more important the groundwater body and the more significant the changes in quality and quantity, the greater is the need for as comprehensive an analysis as possible. Benefits transfer can be used to indicate the magnitude and direction of a benefit. But depending on the sophistication of the benefits transfer technique employed, a more detailed assessment, involving at least some original valuation work, is required when significant policy decisions are to be taken.

While conceptually desirable, it may not always be necessary to estimate the economic value of all the benefits of groundwater (or, in other words, the entirety of the total economic value). So long as a 'benefit threshold' (where benefits are at least equal to costs) is exceeded, a valuation exercise does not always need to go any further. The main purpose of valuing the benefits of groundwater is not necessarily to have a complete estimate (even if this was possible), but to show whether the benefits of protecting or improving groundwater quality and quantity exceed the costs.

3.3.6 Summary

Table 3.2 shows the categories of groundwater benefits and which valuation methods are generally more appropriate for each. The table also shows the data needs for designing the studies and aggregating the results and coverage of economic value and caveats. The two main rules are that:

- market prices can only be a weak and lower limit indicator of the entirety of direct use values alone;

- non-use values can only be elicited through stated preference methods.

3.4 Literature

Annex 3 presents the list of groundwater studies identified in a review of the academic and grey literature. Not all these studies are relevant in the context of groundwater valuation in the UK, but they are listed for completeness. The list also incorporates groundwater-related studies reported originally in the Benefit Assessment Guidance (BAG) database used during the last Periodic Review.

Some other studies that focus on surface water are also relevant for the analysis of the economic value of groundwater since groundwater recharges surface water. However, they are already contained in the BAG database and its update for WFD benefits (see Section 3.1.3). With the exception of those that are used in the case studies (Section 5), these are not reported here.

Annex 4 presents in-depth summaries of a selection of these studies. The summary sub-headings represent the information needed for an extensive benefits transfer exercise. Table 3.3 provides an overview of these studies.

The literature concentrates on changes in the quality of groundwater and the studies are mostly from the USA and continental Europe rather than the UK. This literature focuses on the value of the public water supply estimated through market proxies and willingness to pay for reliable and safe drinking water. Only four studies explicitly make the link between groundwater and surface water.

Given this geographical and context coverage of the literature, benefits transfer is likely to be limited for a particular groundwater policy decision.

Table 3.2 Relevance of pricing and valuation techniques for groundwater benefits

BENEFITS	Relevant valuation methods	Data needs	Coverage of economic value and caveats
Water supply			
Public and private supply	**Market price proxy:** Market price of water	Quantity of water supplied and (real) market price	Direct use value only
	Market price proxy: Cost of alternatives	Changes in quantity and/or quality of water to be supplied Definition of alternatives (e.g. infrastructure for supply from another source) Cost (financial + environmental) of alternatives	Direct use value only
	Market price proxy: Substitute good	Changes in quantity and/or quality of water Definition of alternatives (e.g. bottled water) Market price of alternatives Affected population	Direct use value only
	Market price proxy: Avertive/mitigation behaviour	Changes in quantity and/or quality of water Definition of the alternatives (e.g. water filters, water tanks) Affected population	Direct use value only
	Non-market methods: Stated preference (CV and CM)	Changes in quantity and/or quality of water supply Description of how these affect human welfare Affected population	Use and non-use values
	Non-market methods: Hedonic property pricing	Panel data on the changes in quantity and/or quality of water Panel data on house purchase transactions Socio-economic characteristics of the affected population	Direct use value only Could be data-intensive.
Agriculture and industrial abstractions	**Market price proxy:** Production function in addition to market price and cost of alternatives	Changes in quantity and/or quality of water supplied Impact of this change in crop yields and output production Cost structures (if more sophisticated version of the technique is used) Market price of the goods (crops, products)	Direct use value only At the simplest level, analysis has to assume that cost and price structures in the market are not changed by changing quantity and quality of water.

BENEFITS	Relevant valuation methods	Data needs	Coverage of economic value and caveats
Recharge to surface waters (rivers, lakes, springs, wetlands, transitional waters)	**Non-market methods:** Stated preference (CV and CM)	Changes in the quality and/or quantity of surface water Share of groundwater in this change Likely impacts of this on welfare Affected population	Use and non-use values Determining the role of groundwater in the change could be difficult.
	Non-market methods: Travel cost method	Changes in the quality and/or quantity of surface water Share of groundwater in this change Impact of recreational opportunities Affected population	Recreational use value only Determining the role of groundwater in the change could be difficult.
Flood risk regulation	**Market price proxy:** Avertive/mitigation behaviour or cost of alternative	Changes to flood risk management investments to make up for the loss of flow regulation provided by groundwater Mitigate (or replace) the lost property if the flooding does increase (and in the absence of extra spending on flood risk management)	Use values (tangible costs only)
	Non-market methods: Stated preference (CV and CM)	Changes in the risk of flooding and associated impacts	Use (better for intangible costs such as loss of personal items, stress, anxiety, etc.) and non-use values
Sink for atmospheric carbon dioxide	Benefits transfer[1]	(Change in) the quantity of CO_2 stored	Use and non-use values Since contribution of CO_2 to climate change is a global issue; it is better to use the existing literature. An original study is not warranted here.
Dilution and attenuation of pollutants	This benefit contributes to water supply, recharge to surface waters and sustaining habitats. See relevant parts of the table. Avoid double counting with those benefits.		
Prevents subsidence	**Market price proxy:** Market price	Changes in quantity and/or quality of soil stability Quantity of properties damaged Market price of properties	Direct use value only

BENEFITS	Relevant valuation methods	Data needs	Coverage of economic value and caveats
	Market price proxy: Avertive/mitigation behaviour	Changes in quantity and/or quality of soil stability Definition of the alternatives (e.g. supportive construction) Affected population	Direct use value only
	Non-market methods: Hedonic property pricing	Panel data on the changes in soil stability Panel data on house purchase transactions Socio-economic characteristics of the affected population	Direct use value only (affect of soil stability on house prices). If soil stability affects other land uses, then these may need to be treated separately. Could be data-intensive. Determining the role of groundwater in the change could be difficult.
Sustaining habitats			
Deep-rooted crops, trees (wet woodlands) and grasslands (wet natural habitats and riparian zones) and other 'wet' habitats: wet dunes, tufa springs, eroding sea-cliffs, etc.	**Market price proxy:** Production function	Changes in quantity and/or quality of water supplied Added value of water in production Cost structures (if more sophisticated version of the technique is used) Market price of the goods (crops, products)	Direct use value only Valid if presence of groundwater has impact on crop yields.
	Market price proxy: Avertive/mitigation behaviour	Changes in quantity and/or quality of habitat Proportion of groundwater's contribution to that change Definition of mitigation actions (e.g. alternative source of recharge) Affected population	Strictly not TEV, but a minimum expression of it Determining the role of groundwater in the change could be difficult.
	Market price proxy: Cost of alternatives	Changes in quantity and quality of habitat Cost of creating the same habitat elsewhere (if feasible)	Strictly not TEV, but a minimum expression of it Determining the role of groundwater in the change could be difficult.

BENEFITS	Relevant valuation methods	Data needs	Coverage of economic value and caveats
	Non-market methods: Stated preference (CV and CM)	Changes in quantity and/or quality of the habitat Proportion of groundwater's contribution to the habitat Affected population	Use, non-use and option values Determining the role of groundwater in the change could be difficult.
	Non-market methods: Travel cost method	Changes in the quality and/or quantity of surface water Share of groundwater in this change Impact of recreational opportunities Affected population	Recreational use value only Determining the role of groundwater in the change could be difficult.
Provides sink and/or source of energy (heat)	Need to understand this service better before assessing the relevance of different pricing and/or valuation techniques.		
Provides habitat for hypogean species and refuge for insect larvae and other stygofauna	If the assessment in Table 3.1 is correct and there are no users, pricing and valuation methods will not be relevant. The assumption that non-users will not be aware of these habitats and species and hence are unlikely to hold values for them is just that, an assumption. This benefit alone is unlikely to have sufficient priority to warrant an original study to explore the existence of non-use values. However, it may be possible to include it among other benefits in a stated preference study.		

Notes: [1]Benefits transfer applies to all other benefit categories (subject to availability of relevant literature). It is explicitly mentioned here because the application of other techniques is not necessary.

Table 3.3 Literature summary

Reference	Name and location of groundwater resource	Valuation context	Methodology and WTP definition	Mean WTP	Sample for SP/travel cost etc., data source and other relevant information	Year of data
Studies directly valuing groundwater body or bodies						
Rinaudo *et al*. 2005	Diffuse groundwater pollution in Upper Rhine Valley aquifer, France	Values past costs of diffuse groundwater pollution by nitrates and pesticides in Upper Rhine valley between 1988 and 2000	Uses avoidance costs method to assess pollution costs for water companies and households. A geostatistical method used to model the likely evolution of nitrate concentrations. The resulting estimates of groundwater pollution costs are compared with an earlier CV study.	Estimated pollution costs for DWUs: €1.8 million/year (constant 2001 euros) or a total of €26.4 million in expenditures for DWUs between 1988 and 2002. Household avoidance costs estimated to be €20 million/year.	Sampled 28 DWUs. Household avoidance costs aggregated from other studies.	2001
Bergstrom *et al.* 2004	Groundwater supplies in Maine and Georgia, USA	Valuing household WTP to protect groundwater quality from potential nitrate contamination	CV study using split sample to test effect of different payment vehicles: special tax and tax reallocation	Mean WTP per hh per year for pooled samples: Special tax: US$69.04 Tax reallocation: US$130.40	Pooled *n* for WTP scenario = 661	2004
Travisi and Nijkamp 2004	Effects of pesticide use on soil and groundwater, Milan, Italy	Valuing public WTP to avoid harmful effects of pesticide use including soil and groundwater contamination	Uses CE and CV to assess preferences for lowering the pesticide use in agriculture. CE uses: (1) reduction in farmlands biodiversity; (2) reduced contamination of soil and groundwater; (3) reduced health effects of pesticide use on general public; and (4) a monetary attribute specified as an increase in monthly household food expenditure. CV values WTP for	CE implicit prices (€/month/hh) Avoid loss of one farmland bird species: €23.01–24.57 Avoid contamination of 1 per cent of farmland and soil aquifer: €12.28–16.21 Avoid one case per year of human ill-health: €2.5–3.14 CV WTP to reduce all environmental impacts: LB €14.54/month/hh	302 completed surveys	2003

Reference	Name and location of groundwater resource	Valuation context	Methodology and WTP definition	Mean WTP	Sample for SP/travel cost etc., data source and other relevant information	Year of data
			eliminating 'all' risks.			
Brox *et al.* 2003	Grand River watershed in south-western Ontario, Canada	Valuing residential WTP (WTA) for water quality improvements (deterioration) following hypothetical pollution incidents.	CV study exploring WTP(WTA) an improvement in water quality under three different scenarios: (1) WTP following a [major] pollution incident; (2) WTP following a [minor] pollution incident affecting taste and odour of water supplies; (3) WTA compensation for decreased water quality.	Mean monthly WTP per hh (C$): Major incident: C$8.29; Minor C$4.56; Major WTA: C$9.42	Sampled 3070 residents Total *n* for WTP = 899–1,003	1994
Epp and Delavan, 2001	Nitrate pollution in groundwater south-eastern Pennsylvania, US.	Valuing WTP for reduced nitrate contamination in groundwater	CV study using two different valuation question in split sample design: (1) dichotomous choice with OE and (2) informed OE	WTP per hh per year for 10 years: DC (open ended): $74 Informed open ended: $51	Surveyed 1,000 households – received 617 useable returns	2001
Randall *et al*. 2001	Maumee River basin in north-western Ohio, USA	Valuing three different protection programmes for the Maumee River Basin aimed at protecting: (1) groundwater;(2) surface water; and (3) wetland areas	CV study using split sample design to value either one, two or all three protection programmes: (1) reduction and stabilisation of nitrate levels between 0.5–1 mg/litre; (2) reduction of volume of sediment entering the Maumee River by 15 per cent; (3) protection and improvement of existing wetlands, restoration of 3,000 additional acres of wetlands and provide 20 per cent more wildlife habitat for migrating.	LB mean WTP (one-time) per hh based on referendum data: Groundwater: US$52.78 Surface water: US$78.38 Wetlands: US$62.57 All programmes: US$91.41 Mean WTP based on OE data (one-time/hh): Range US$32–47	427 residents	2001
Garrod *et al.*	Hardham	Valuing public	Choice experiments using five	Marginal WTP per hh per year	412 households	2000

Reference	Name and location of groundwater resource	Valuation context	Methodology and WTP definition	Mean WTP	Sample for SP/travel cost etc., data source and other relevant information	Year of data
2000	Aquifer, UK	preferences for main impacts of the Hardham Artificial Recharge scheme	attributes: two environmental, two relating to water supply and a cost attribute. Used both contingent ranking and preferred alternative.	(2001) for attributes: Avoid 1 per cent decrease in no. of birds: £1.52 Avoid small decrease in river flows: £4.25 Avoid a decrease of up to 10 per cent of no. of birds and plant species: £21.24 Increase of up to 5 per cent in no. of birds and diversity of plants found: £5.06	interviewed	
Lichtenberg and Zimmerman 1999	Groundwater resources in Maryland, New York, Pennsylvania	Valuing farmers WTP to prevent leaching of pesticides into groundwater	CV study to estimate farmers WTP to prevent leaching of pesticides into groundwater using a dichotomous choice question.	WTP to prevent pesticide leaching per acre: US$35.35–17.37 Corn acreage: US$1,112–2,256 Total acreage: US$3,475–7,050	Sampled 2,700 farmers; received 1,611 usable returns	1995
Stevens and Krug 1995	Groundwater reserves in Massachusetts, USA.	Valuing residents WTP for groundwater protection in form of a town-wide special aquifer protection district	CV study using payment card. Payment vehicles differed depending on the household water supply; for households on public water supplies, the payment vehicle was an increase in water utility bills and, for households served by private wells, an increase in property taxes.	Average WTP: US$63/hh/year Average WTP declined with the perceived groundwater safety level, ranging from US$48.62/hh/year where safety level was perceived to be 'absolutely secure' to US$129.67 where respondents considered safety levels to be presently contaminated.	397 residents	1995
Hasler *et al.* 2005	Groundwater resources in Denmark	Valuing consumers WTP for: (1) increased protection of groundwater quality; and (2)	CV to estimate household WTP per year to move from status quo (uncertain groundwater quality) to (1) increased protection meaning naturally clean water; and (2) water purification of polluted	CV results: Mean WTP: 711 DKr/hh/year for naturally clean groundwater Mean WTP: 529 DKr/hh/year for purified water.	CV: *n* = 663 hh CE: *n* = 584 hh	2004

Reference	Name and location of groundwater resource	Valuation context	Methodology and WTP definition	Mean WTP	Sample for SP/travel cost etc., data source and other relevant information	Year of data
		water purification	groundwater. CE: respondents chose between three options consisting of the status quo option and two alternatives described by three attributes: (1) Drinking water quality; (2) conditions for plant and animal life in watercourses; and (3) price: annual increase in water bill per household.	CE implicit prices: WTP to move from uncertain drinking water quality to naturally clean groundwater: 1,899 DKr/hh/year WTP to move from uncertain drinking water quality to purified groundwater: 912 DKr/hh/year WTP to move from less good conditions for animal and plant life to very good conditions: 1,204 DKr/hh/year WTP to move from less good conditions of animal and plant life to bad conditions: –1,759 DKr/hh/year CE results approx. 2–4 times higher than CV.		
Valuation studies concerning surface water bodies used in the case studies in Section 5 (for others see the BAG database and forthcoming update)						
Willis and Garrod 1995	River Darent and all 40 other low flow rivers	Two scenarios were tested in the study: (1) improve upon flow levels in the Darent River; and (2) maintain or improve upon flow levels in all 40 low flow rivers in England	CV: open ended WTP question; Survey: one-to-one interviews	River Darent (per hh per year) (2001 prices): Residents: £11.68 Visitors: £8.20 General public: £4.41 All low flow rivers (per hh per year): Residents: £21.14 Visitors: £17.26 Non-users: £14.23	Sample size/population: 325 residents and 335 visitors; 758 households	1995

CE = choice experiment; DC = dichotomous choice; DWU = drinking water utility; hh = household; LB = lower bound; SP = stated preference

4 Using evidence on the economic value of groundwater

The ultimate aim of defining and quantifying the economic value of groundwater is to inform decision-making. In turn, the main purpose of decision-making is to allocate available limited resources between the competing wants and needs of society.

In the context of groundwater, this may take the form of a choice between spending to protect or improve groundwater bodies versus spending on other environmental issues. It could also take the form of a choice between the revenues from an activity that threatens a groundwater body versus the loss of this revenue if the activity is reduced or stopped. 'Resource' could equally be money or a physical resource such as the groundwater itself. Here, the allocation issue could be between abstraction for different purposes as well as between abstraction and leaving the water in the environment.

In all these decision cases, knowledge of the pros and cons of alternative decisions is required to compare them. Evidence on economic value allows this to be performed subject to uncertainty and data availability. It can tell us:

- what the benefit of protecting or improving groundwater is likely to be (which can be compared to the cost of action);
- what the costs of using or polluting groundwater are (which can be compared to the benefit of action).

Thus, there are two principal inter-related uses for the evidence on the economic value of groundwater. These are:

- demonstrating the economic importance of groundwater as a resource (benefits of its protection and improvement or cost of its degradation), or in other words, benefit assessment (Section 4.1);
- cost–benefit analysis of policies, programmes or projects[10] to compare the pros and cons of decisions (Section 4.2).

As the case studies in Section 5 illustrate, benefit assessment is far from complete, and is generally surrounded with uncertainty and incompleteness in scientific and economic data. But this should not stop efforts to gather and analyse evidence on economic value, since the alternative could be groundwater being given zero value when decisions are made – which can only be detrimental to the protection of groundwater.

4.1 Benefit assessment

The benefits, or value, of groundwater can be expressed in qualitative, quantitative and monetary terms. Which one is more appropriate and/or sufficient depends on:

- the purpose for which the evidence is needed;

[10] There are other uses of economic value evidence including: the determination of appropriate levels for environmental pricing and taxation; setting priorities within a sector plan or across different sectors; green national and corporate accounting; and determining compensation in environmental litigation. They also require the same type of economic value evidence, with small differences in approach to valuation. Since these uses are of secondary importance to the scope of this report, they are not discussed further.

- the availability of the necessary information.

Economic evidence in monetary terms is the final stage of a benefit assessment and first requires the collation of qualitative and quantitative information. There could be occasions when qualitative and quantitative information on benefits would be sufficient to make a case for the protection or clean-up of a groundwater body, in which case there would no need for monetary expressions of economic value. This is why the main purpose of this study is to provide a framework for the analysis of the value of groundwater and expand the concept of ‘value’, rather than generate off-the-shelf values (even if this were possible) (Section 1.2).

Benefit assessment starts with the definition of the resource to be valued. In the context of this study, this is a groundwater body. The starting point should be descriptions of the physical parameters of the groundwater body such as its geographical location, hydrology, geology and hydrogeology. The assessment should then identity those benefits in Table 3.1 that apply to the groundwater body.

As mentioned in Section 3, economic valuation is not about the absolute value of an environmental resource but about the cost or benefit of a change – small or large – in the quality or quantity of that resource. At one end of the scale, the total loss of a given groundwater body might be considered; at the other end, a small change in its quality or quantity. The change could be positive (e.g. improving the baseline conditions to meet good ecological status) or negative (e.g. allowing further contamination or draw down of the groundwater body).

Caution is required in using a value determined when the resource is relatively plentiful or in a good state in another context. This is illustrated in Figure 4.1, which shows how the marginal benefit (the benefit provided by an additional unit) provided by a resource might increase as it becomes less plentiful. A change in the level of the resource from R_0 to R_t results in a loss of value that is relatively small. Using this to estimate changes in value as the resource is depleted (i.e. as the level of the resource gets lower), and perhaps even basic uses of the resource are no longer possible, would give an underestimate of the total value of the resource.

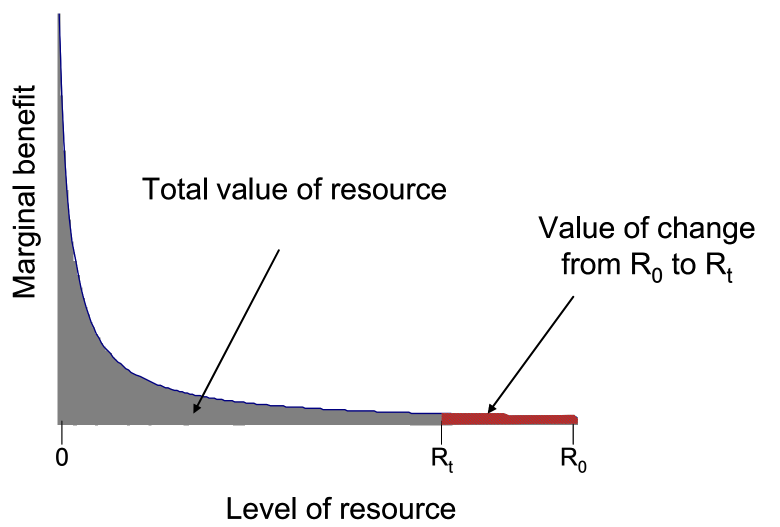

Figure 4.1 How the marginal benefit of a resource might change with scarcity

The area under the curve between two points represents the value lost or gained from the change.

Here, 'change' refers not only to the physical and chemical changes to the quality and quantity of the groundwater body, but also to the resulting changes in the provision of the benefits which the body provides and the impacts these have on the affected population.

Two crucial steps in benefit assessment are thus the definition of:

- the baseline;
- the change which may be brought about by a policy or action.

The baseline refers to the current situation ('without the change') of the groundwater body extrapolated into the future, including all the benefits it provides and the pressures it is under.

The assessment of the baseline and changed states of the groundwater body is an interdisciplinary venture requiring input from:

- hydrogeologists;
- specialists in the sectors or habitats benefiting from groundwater;
- economists.

The type of quantitative information provided is crucial, since information that is used in scientific research or environmental impact assessment may differ from that necessary for an economic assessment. Therefore, there is usually a 'translation' step between the two types of information. For example, while the change in the concentration of a particular pollutant or the change in the flow level may be the result of a scientific assessment, the economic analysis needs to know what this means in terms of how people make use of the water (or how it affects their non-use motivations).

Having listed the relevant benefits for the groundwater body and how these would change between the baseline and the change scenario, the final step is to undertake the monetisation of these benefits. For this, it is necessary to:

- decide on the most suitable valuation method for each benefit (Section 3.3);
- calculate or transfer the most suitable estimates of economic value;
- identify the affected population (Section 3.1.3);
- aggregate across each benefit, population and time.

Table 4.1 summarises the steps of benefit assessment for a given groundwater body and the main questions that need to be answered in each step of the assessment. Section 5 adapts this outline for four case studies of groundwater bodies. These case studies look at the total loss of the groundwater body in order to present as general a picture as possible and to get a handle on the magnitude of all the benefits provided by the groundwater bodies. The change scenario of total loss is not realistic, but it is more conducive to the illustration of benefit assessment as well as demonstrating the economic importance of a groundwater body.[11]

[11] Actual or predicted changes in groundwater quality and quantity should ideally be modelled and take localised factors into account, as in the case of the study on the Yazor catchment (JacobsGIBB 2002). In the absence of such modelling, the case studies in this report use the simplest of the possible change scenarios, i.e. that of total loss.

Table 4.1 Benefit assessment outline

Steps	Main questions to be answered/issues to be considered
1. Define the groundwater body	Describe the physical parameters of the groundwater body, e.g. its geographical location, hydrology, geology and hydrogeology.
2. Define the baseline	Go through the benefit categories in Table 3.1 and select the ones that apply to the groundwater body (qualitative and quantitative descriptions). Quantify those that apply in units that will be suitable for further benefit assessment
3. Define the change	Is the change in the quality or the quantity of the water (qualitative and quantitative descriptions)? Is the change an improvement (gaining benefit) or a degradation (loss of benefit or a cost)? What are the implications of change for each of the benefits identified in the baseline? Quantify these changes in units that will be suitable for economic valuation.
4. Value the change in the benefits	What is the most suitable valuation method for each benefit? Refer to the guidance in Table 3.2. Calculate or transfer the most suitable unit estimates of economic value. Who are the affected population (qualitative and quantitative descriptions)? Aggregate across population, benefit types and time.

4.2 Cost–benefit analysis

The intention of cost–benefit analysis (CBA) is to compare the economic efficiency implications of alternative options that may be implemented to address a particular objective. The benefits of a decision are compared to its associated costs within a common analytical framework.

To allow comparison of costs and benefits related to a wide range of impacts primarily measured in different units, a common numeraire of money is employed. Individual costs and benefits need to be estimated and then aggregated across the affected population and time.

CBA enables two questions relevant to decision support to be addressed:

- Is an option is worth undertaking (i.e. do the benefits outweigh costs)?
- Which option among competing alternatives should be undertaken (i.e. which option offers the greatest net benefit)?

CBA can also be used as a tool for negotiation between different stakeholders. Even if incomplete (due to scientific or economic data gaps and uncertainties), CBA allows for a systematic presentation of impact and valuation information.

Typical stages of CBA are presented in Table 4.2. More detailed guidance on UK appraisal of policies and projects via CBA can be found in the Treasury's *Green Book*

(HM Treasury 2003; see Box 4.1). Note that Steps 2, 3 and 6 must also be undertaken for benefit assessment as outlined in Section 4.1.

Table 4.2 Cost–benefit analysis outline

Steps	Main questions to be answered/issues to be considered
1. Define the objective	This relates to the overall aim of the project, programme or policy to be analysed and includes water quality and quantity standards to be met or provision of target levels of benefits.
2. Identify and define the baseline	As for benefit assessment, the baseline scenario refers to the situation that prevails without intervention (not necessarily the same as 'current' conditions). This is not the same as prior to the option. The costs and benefits of different interventions (the 'with' scenario) can then be subtracted from the baseline to ascertain the additional costs and benefits that accrue (over and above) the baseline. For example, water demand in the future may not be the same as water demand today, so a forecast of future demand may be part of the baseline.
3. Identify and define the alternative options	Generally options will have been 'screened' for feasibility so that only the most relevant options are subject to CBA. At this level, other assessments such as engineering feasibility tests, other scientific assessments and even participatory or discursive approaches may provide the screening.
4. Identify the costs and benefits of the decision time frame	The definition of the time horizon is important especially for groundwater where the effects of, say, contamination could take a very long time (longer than the lifetime of infrastructure involved) to occur. If this is the case, this longer time period should also be taken into account.
5. Quantify the costs of each option	Here all costs are relevant including: • real-resource compliance costs; • government regulatory costs; • social welfare losses (e.g. losses that may arise from environmental impacts); • transitional costs (value of resources displaced because of regulation-induced reductions in production); • indirect costs (reductions in productivity, innovation, etc.). The extent to which these aspects of cost are relevant to a given CBA will depend on the specific details of the issue being addressed. Impacts on the environment will usually be identified through assessments such as environmental impact assessment (EIA), health impact assessment (HIA) or life-cycle analysis (LCA). The monetary value of these impacts can be estimated by economic valuation studies and/or benefits transfer approaches. If these impacts are mitigated against, the mitigation costs should appear as part of the financial costs and residual environmental costs (if any) should appear as environmental costs.

Steps	Main questions to be answered/issues to be considered
6. Quantify the benefit of each option	Here all benefits are relevant. These could be market benefits and non-market (environmental and other) benefits. As with costs, assessments such as EIA, HIA, LCA and others are required to establish the link between the different options and their benefits, and to define these benefits.
7. Aggregate and compare costs and benefits over affected population and project lifetime	Aggregating costs and benefits over time requires a process known as discounting (see below). The indicators of cost–benefit comparison are net present value (NPV) and benefit cost ratio (BCR) as defined below.
8. Sensitivity analysis	CBA, like any other decision-making framework, is based on a number of assumptions that define the boundaries of the analysis and also affect the information input to the analysis. Therefore, sensitivity analysis is crucial especially if there is risk and/or uncertainty (scientific or economic) about costs and benefits. Sensitivity analysis in this context involves re-calculating the NPV and BCR indicators for different sets of assumptions.

4.2.1 NPV and BCR

The decision rule of CBA is based on the comparison of net present value (NPV) and benefit cost ratio (BCR). Comparison of the costs and benefits in monetary terms provides an assessment of whether a specific option is worth implementing, i.e. whether the benefits outweigh the costs. In particular, options for which total benefits outweigh total costs are said to have a positive NPV and undertaking these projects would add to overall societal welfare.

When there is a pre-determined budget, BCR is the appropriate indicator. When the objective of the CBA is to identify the welfare (or utility) maximising option, NPV is the appropriate indicator. Where options being considered are alternatives to addressing a particular objective (or addressing different objectives but competing for the same funding), they may be ranked in terms of BCR in order to determine the most preferred project. A BCR >1 implies total benefits exceed cost (i.e. a positive NPV), while a BCR <1 implies that total costs exceed total benefits (i.e. a negative NPV).[12]

4.2.2 Discounting

Perhaps the most controversial aspect of CBA is discounting. Discount rates are often prescribed for public projects and policies, but it is important to understand the different possible rationales.

Discount rates can be chosen to reflect:

- social time preference;
- opportunity cost of capital.

The social time preference argument is based on the assumption that individuals prefer today's gains to gains next year and further into the future. They are impatient and

[12] [0]For long-lived programmes, the impact of the discount rate can be critical. There are examples of programmes that have positive net benefits using one rate, and negative net benefits using another.

have limited life times. Since individuals' preferences are fundamental in economic analysis, this particular time preference of individuals should be taken into account. Similar arguments apply at a social level with the exception that, while individuals have short lives, society must aim to continue indefinitely. This suggests social time preference rates somewhat lower than individual rates.

The opportunity cost of capital argument holds that £1 invested today (instead of spent, say, on the option of concern) would gain a return in a year's time (at its simplest, at the rate of the prevailing interest if invested in a bank account). The discounting process is a mathematical way of showing that:

- gains and losses in future are valued less than gains and losses today;
- the further into the future they occur the less valuable they are in present day terms.

When the entire society is the affected population, it is correct to assume that society's lifetime is longer than an individual's (or that of an individual commercial enterprise) and that the society has many more options to invest its wealth, and hence the opportunity cost of not investing £1 in terms of forgone returns is lower. This again suggests that the social discount rate, even based on the social cost of capital, should be less than the private discount rate.

In the UK, the discount rate that should be applied in public sector appraisals is set by *The Green Book* (HM Treasury 2003). The current advice is to use a hyperbolic discount rate which declines over time as shown in Table 4.3.

Table 4.3 Discount rates (as advised in *The Green Book*)

Rate (%)	Years
3.5	1–30
3.0	31–75
2.5	76–125
2.0	126–200
1.5	201–300
1.0	300+

The discount rate is not related to the certainty or otherwise of the future use of the resource. For example, a groundwater supply which it is known will be reliable 10 years from now is of greater value than one with an uncertain future. However, this uncertainty should be treated through the use of probabilities and/or sensitivity analysis. Use of the discount rate is not related to such differences in value.

Box 4.1: *The Green Book*

Annex 2 of *The Green Book* (HM Treasury 2003) provides guidelines on the valuation of non-market impacts, and in particular on environmental impacts. The following points are made:

- The valuation of non-market impacts should be attempted wherever feasible in policy or project appraisal.
- Revealed or stated preference techniques are acceptable. The technique chosen will depend on individual circumstances and should be judged on a case-by-case basis.
- Readers are advised to refer to *The Green Book* website (http://greenbook.treasury.gov.uk/) for up-to-date information in this constantly evolving field.
- Various specific notes are made on the appraisal of policies related to greenhouse gas emissions, air quality, landscape, water, biodiversity, noise, woodland recreation and amenity, and transport/waste disamenity.
- Deriving economic values for the damage costs of water pollution is problematic because of the difficulty of devising simple dose–response functions, and because it may not be easy to determine the relevant population.
- For these reasons, water valuation studies do not tend do give figures for the marginal benefit of cleaning up a particular pollutant, but rather focus on observable changes in environmental quality.

5 Case studies

5.1 Introduction

The four case studies illustrate how the benefit assessment framework described in Sections 3 and 4 can be applied to the four groundwater bodies profiled in England and Wales. The groundwater bodies covered are:

- Hampshire (Winchester) Chalk;
- Lincolnshire Limestone outcrop close to Lincoln;
- North Kent (Gravesend and Northfleet) Chalk;
- Nottingham Sherwood Sandstone outcrop.

The case studies are for illustration and are intended to show how an assessment of the value of a groundwater body might be structured. At this level, however, there are significant gaps in both the data and in understanding the physical impacts of changes to the groundwater body – particularly on fluvial, estuarine and terrestrial ecosystems. As shown in a case study of the River Yazor catchment near the English–Welsh border (JacobsGIBB 2002), a full-scale application requires hydrological modelling, stakeholder consultation and more detailed economic analysis. Here, case studies are kept at a more strategic and general stage. Note that:

- the estimates should not be used for any purpose other than to illustrate the benefit assessment framework;
- no groundwater body modelling has been undertaken for these case studies as would be expected for a full application of the methodology.

It should also be emphasised that valuing individual groundwater bodies in isolation dramatically underestimates the total value of all UK groundwater bodies. If only one groundwater body is affected by a change in a pressure or in a policy, alternative groundwater bodies in the same or neighbouring catchment could provide some of the same benefits. If all groundwater bodies are lost (since this is the change to be valued if the total value of all groundwater resources is sought), the cost of this loss would be significantly higher. In other words, the total value of all UK groundwater bodies is far greater than the sum of the value of the individual groundwater bodies. Given that economic valuation usually relates to marginal changes (as described in Sections 3.1 and 4.1), such an overall value may be beyond the scope of economic valuation. Such a value can also be argued to be irrelevant for policy appraisal, which is concerned with marginal changes in water quality and quantity.

A note of caution is also required in considering the different time horizons and time units of different benefits. Some benefits are one-off and will happen at a particular point in time. Others are annual and will happen over a certain number of years, while others are annual and continual. Different components of value occurring over different time scales and measured by different units (i.e. £ rather than £ per year) cannot be simply summed, but can be summed only through appropriate discounting.

Further caveats are required in order to interpret the case studies correctly:

- The description of benefits is generalised. In most cases, the change described in the benefits provided by the groundwater body is the change which would occur in the worst case scenario. It cannot be emphasised too strongly that the change in each benefit that would occur in most realistic scenarios would be very much smaller than this. But without more detailed information on physical impacts and trends in pressures on each groundwater body (e.g. through modelling), it is not possible to calculate the benefit loss that tallies with a smaller scale loss in the quality or quantity of water in a given groundwater body. Furthermore, the method used assumes that the marginal loss of benefits does not increase with size of impact, which may not be a realistic assumption. Finally, it would be interesting to explore the different effects on benefit loss caused by different pressures – in particular to underline the different effects changes in water quality versus water quantity have on the benefits provided by a groundwater body. However, attempting this without detailed impact scenarios is not possible.

- Non-use value is an element in only two of the components of value outlined in Section 5.2.3 (i.e. in the value of wetlands and in the value of maintaining flow in rivers). In both cases, direct and indirect use values are also included and estimates of non-use value are conservative. The case studies demonstrate that groundwater bodies are likely to provide substantial economic benefits regardless of non-use value.
- The case studies in Sections 5.3–5.6 should be read in conjunction with the methodology and default assumptions presented in Section 5.2.

5.2 Case study methodology

The case studies follow the steps of benefit assessment discussed in Section 4.1 and summarised in Table 4.1. For the purposes of these case studies, the steps outlined in Table 4.1 are reorganised slightly, but the ground they cover is the same:

1. Describe the groundwater body and the area and population it affects:
   - definition;
   - contribution to surface waters, abstractions and discharges;
   - surface water and coastal ecology;
   - terrestrial ecology;
   - economy and human geography.

   State explicitly the scope of change to be valued.
2. Define the physical change to be valued:
   - baseline assumptions;
   - physical impacts of the change.
3. Relate the physical change to a change in the value of the benefits:
   a. Identify affected benefits;
   b. Assess data requirements;
   c. Estimate benefits for which data requirements are met;
   d. Aggregate over the affected population (and time where relevant and possible) and each benefit type.

These steps are described further below.

The methodology section describes numerous default assumptions. The case studies only note where the assumptions made for specific groundwater bodies differ from, or append to, these default assumptions.

Although the case studies are couched in terms of a loss of groundwater quality or quantity, the methodology is equally applicable to a gain.

5.2.1 Description of the groundwater body

Information on the groundwater bodies is drawn mostly from Environment Agency Catchment Abstraction Management Strategy (CAMS) documents. However, these documents are for a particular catchment, rather than by groundwater body. Therefore, the information they contain does not fully overlap with groundwater bodies. Sometimes two or more CAMS documents are required to cover one groundwater body. Furthermore, there is little accessible information on the exact geographical extent of most of the groundwater bodies.[13] This meant that some intelligent guesswork was required; this may not be entirely accurate but serves the purpose of illustration.

The following components of the groundwater body description are based on the physical characteristics of the groundwater body and the processes by which they provide the benefits listed in Table 3.1:

- **Basic information** – a basic description in terms of physical geography and hydrogeology of the groundwater body.
- **Contribution to surface waters** – identification of which rivers are fed by the groundwater body, and at what point in the catchment. In some cases, the water from the groundwater body will contribute only a negligible amount to a river; in other cases, a substantial amount. For affected rivers, the ideal is to know the base flow index (BFI), which states how much a river is dependent on groundwater. In almost all cases, however, this information is not available. The estuary/ies and wetlands to which the groundwater contributes should also be identified.
- **Abstractions** – the purposes for which abstraction is made and the identification of any major sources of pollution. CAMS documents discuss both groundwater and surface water abstractions, although only abstractions greater than 20 m^3/day require licences and are mentioned. Major surface water abstractions should also be mentioned if a massive reduction in river flows (due to loss of groundwater recharge) would make them no longer viable. Some abstractions return water to the catchment, while others (e.g. irrigation) are highly consumptive and return little. The timing of abstractions may also be important. For example, peak demands for irrigation abstraction usually coincide with periods of low flow.
- **Surface water and coastal ecology** – the identification of any particular issues affecting surface water or coastal ecology, as well as protected areas such as Sites of Special Scientific Interest (SSSIs) and Special Area of Conservation (SACs) that may be dependent on the groundwater resource. Coastal ecology will be relevant if the groundwater body touches the coast, or if water from it substantially affects the functioning of an estuary.
- **Terrestrial ecology** – identification of any terrestrial ecosystems (including protected habitats) which might be groundwater-dependent. This information is harder to find than information on surface water ecology.

[13] This information is currently being collated and should be available soon as part of the process to implement the WFD in the UK.

- **Economy and human geography** – a description of the administrative areas which the groundwater body covers in terms of counties, unitary authorities and local authorities, as well as any major urban settlements in the area. Information should also be obtained on:
  - how the groundwater body affects industry and agriculture in the area;
  - whether there are any commercial fresh water or estuarine fisheries;
  - whether any other commercial activities depend directly on the quantity or quality of the groundwater or surface waters;
  - recreational activities dependent on surface waters affected by the groundwater body of concern.
- **Scope** – an explicit statement of the geographical area and human population assumed to be affected by any changes to the groundwater body.

5.2.2 Description of the physical impacts of quality and quantity change

As explained above, the gaps in detailed understanding of how the different groundwater bodies would be affected by realistic pressure change scenarios over time mean that a detailed description of the physical change to be valued is not presented in any of the case studies. In a more thorough treatment of any one of the groundwater bodies, the following two stages would need to be observed (as also identified in Table 4.1):

- **Baseline.** This is a description of what would be expected to happen if no change in policy affecting any pressures on the groundwater body occurs. The baseline need not be static and might include assumptions:
  - about how climate change might affect the recharge rate of the groundwater body;
  - about planned house building;
  - implications of policies such as the Water Framework Directive.
- **Physical change scenario**. This is a description of likely changes to the pressures affecting the groundwater body, and therefore changes to groundwater body function, resulting from changes in policy. Changes to different pressures and/or benefits may happen over different timescales.

The change in benefits is the difference between these two scenarios. In the case studies, what may happen to each benefit in the worse case scenario of loss of current quantity and/or quality of groundwater in the selected groundwater bodies is outlined.

5.2.3 Economic valuation of physical changes

The estimate of the economic value of a given change in a groundwater body is based on:

- which benefits are affected by the change;
- what data are needed for the estimation;
- what data are available.

These are discussed below.

(i) Identify the benefits that are affected by the change

Table 5.1 notes the assumptions made in this report about the effect of the worst case scenario on each benefit in terms of a change in groundwater quantity and a change in quality. The benefit categories are taken from Table 3.1. The effects are based on assumptions about what would happen in the absence of the groundwater body of concern.

The pollution dilution benefit listed in Table 3.1 is not valued separately as it affects all other benefits through the 'quality change' scenario. The benefit of providing habitats for hypogean species is not included as it is not possible to quantify or monetise.

Table 5.1 Assumptions about the effect of the loss of groundwater body

Benefit	**How affected in worse case scenario**	
	Quantitative loss	**Qualitative loss**
Water Supply		
Public	Public water supply must be drawn from an alternative source. Surface water abstraction may be possible if the groundwater body contributes only a small amount to surface waters in a large catchment (some additional infrastructure required). Otherwise, it is assumed that major water infrastructure and/or demand management investments would need to be made (e.g. reservoirs, desalination plants or transfers from other regions).	Groundwater abstractions desisted (as per quantitative loss). Surface water abstractions could still be permitted, but the cost of treating surface water taken for the public supply increases.
Private	Private abstractors must obtain water from public water supply. Houses may become uninhabitable if they are prohibitively far away from public water supply infrastructure.	
Agriculture	Farmers do not have sufficient economic means to purchase the large quantities of water required for irrigation from elsewhere. Crops that cannot survive without irrigation are unsuccessful (assume all yield lost) unless immediately adjacent to plentiful surface water. Livestock-rearing is unaffected.	Depending on the pollutant, crops (or livestock) may not be affected at all, or irrigation cannot continue and hence the crop is lost.
Industrial	(a) Water-intensive manufacturers (e.g. paper mills) go out of business as sourcing large quantities of water from elsewhere is prohibitively expensive. The exception is power stations, which are treated as national strategic priorities (and provided with additional infrastructure). (b) Smaller industrial water users connect to the mains supply. For simplicity, it is assumed that each industrial abstractor falls into	Many industrial users are not particularly sensitive to water quality changes, although some are (e.g. food industry, brewing). Highly context-dependent but would involve increased treatment cost or cost of alternative water sources.

Benefit	How affected in worse case scenario	
	Quantitative loss	**Qualitative loss**
	either category (a) or (b), although in reality there may be producers who initially suffer lost of output and subsequently go out of business.	
Recharge to surface waters		
Ground water-dependent wet ecosystems	Highly dependent on relative contribution of groundwater body to surface water in the catchment. Declining quantity of groundwater is likely to lead surface water flow (or level) to fall below 'acceptable levels' with associated amenity and ecological impacts, exacerbated by the fact that pollutants are no longer diluted. Any wetland habitats sustained by the water to some extent are damaged or even dry up. Recreational users may seek substitutes (if available).	Ecological and some amenity impacts, depending on the pollutant and the contribution of the groundwater body to surface waters in the catchment. Wetland habitats may be damaged. Recreational users may seek substitutes (if available).
Aquaculture	If the contribution of the groundwater body to surface water is significant, plants/fish either die or are no longer fit for human consumption and aquaculture companies go out of business.	
Regulation of flood flow	Depends on the pressure. If recharge water is prevented from entering the groundwater body, more risk of flooding from 'flashy' rivers.	Not affected.
Sink for atmospheric CO_2	The physical science behind this benefit is not understood well enough to determine the likely effects of changes in water quantity or quality. This benefit is excluded from the analysis in this report.	
Maintaining soil stability	Lowering of the water table could result in the drying out and collapse of peat and clay soils, causing subsidence. Assume that affected houses are subsequently inhabitable.	Not affected.
Sustaining habitats		
Coastal	Risk of saline intrusion into coastal ecosystems and intrusion of brackish water further up estuaries. This may have ecological consequences and change composition of flora and fauna.	Higher levels of pollution in estuarine ecosystems with ecological consequences and loss of sensitive species.
Terrestrial non-aquatic	Deep-rooted plants or habitats dependent on a high water table die.	Depends on pollutant.
Sink/source heat	Loss of option value for heat pumps for new-build houses.	Not affected.

(ii) Assess data requirements for benefit assessment

Table 5.2 shows how the data requirements for each benefit category are assessed for the purposes of the case studies. The relevant approaches to economic valuation are selected in light of the criteria listed in Section 3.3.5 and available data within the scope of effort in the study. This template is used for each type of benefit in each case study to ensure transparency and comparability.

Basic information on the recharge and abstraction rates, areas, etc. of each groundwater body is taken from data provided by the Environment Agency (replicated in Annex 5).

Table 5.2 Data requirements for benefit assessment

Issue	Notes
Value to estimate	Explicit statement of the benefit (economic value) that is estimated. Those aspects of value that cannot realistically be assessed are excluded.
Indicator of value	Valuation method as described in Section 3.3. Given the scope of the case studies, market prices and benefits transfer are used. The selection depends on the assessment about what will happen as outlined in Table 5.1.
Data needs	Data that would **ideally** be available in order to estimate the aspect of value of concern.
Data availability and source	Description of the sources of the data, any data gaps and the assumptions made to fill data gaps. Resolution of geographical or population data, where appropriate.
Time issues	Some valuation evidence will be given on an annual basis; others will be in discounted over a particular timescale. The two must be treated differently during aggregation. For this reason, different components of each benefit category may need to be kept separate.
Standard formula(e)	The formula(e) used to calculate the benefit in monetary terms on the basis of the assumptions and data presented in the previous rows.

Tables 5.3–5.12 show how this template can be applied to individual benefit categories. Aspects of each benefit are labelled (a) or (b), and subsequent assumptions and formulae also use these labels.

One of the most common benefit indicators used below is the cost of alternative water supply in the absence of the groundwater body of concern. Given the lack of information on the capital and operational costs on the different water supply options that might be required in each case study (within the scope of this exercise at least), Average Incremental Social Cost (AISC) estimates are used where information on the cost of water supply from alternative sources is required.

AISC is used by water companies to weigh up the benefits and costs of different water supply options as part of the Periodic Review of their business plans. The AISC of a water supply option is the sum of its discounted costs over the sum of its discounted benefits; costs are taken to include environmental and social costs as well as financial costs. Large-scale, but still realistic, water supply measures such as reservoirs, desalination plants and water transfer schemes appear to have an AISC in the range of about £400 to £1,200 per ML. This is comparable to the long run marginal costs of water supply given in ODPM (2005). For more detailed and local case studies, more realistic assumptions can be made.

The AISC is only exactly equivalent to an annual cost figure for supplying a given amount of water if the time horizon and discount rate used to calculate it from the literature are the same as the investment in the alternative supply source in the case study. But since the alternative source in the case study is not known, the AISC is used here as a proxy for typical costs of meeting water supply.

Table 5.3 Private abstraction (*B_1*)

	(a) Initial outlay cost to private abstractors of connecting to the mains supply (b) Ongoing costs to water companies of providing the extra volume of water
Indicator of value	Market price proxy: cost of alternatives
Data needs	(a) No. private abstractors; costs of connection (£) (b) Total private abstraction (ML) (Annex 5); costs which additional demand places on public water supply.
Data availability and source	(a) Environment Agency only holds data on number of abstractors drawing > 20 m^3 per day (m^3/d) (i.e. those requiring abstraction licences), so there are no data on the number of smaller abstractors. A proxy for the number of private abstractors is obtained by dividing total private abstraction by mean domestic use (according to the Environment Agency). The cost of connection estimate used in the case studies is based on Severn Trent (2005). Costs of connection vary depending on the type of surface that requires excavating and the length of pipe required; they appear to be in the range of £540-8,890 for a property less than 100 m away from a mains supply. This is an underestimate for properties further away than this. Estimated mean amount abstracted per private abstractor (= 180 L/d) is taken from Environment Agency (2004). (b) Total private abstraction from Environment Agency datasets. Unit cost of supply as other estimates using AISC.
Time issues	(a) Costs of connection incurred in the first year (b) See discussion of AISC above.
Standard formulae	$B_{1a} = \dfrac{\text{total annual private abstraction (ML)}}{\text{average abstracted per private abstractor}} \times \text{cost of average connection (£)}$ $B_{1b} = \text{total annual private abstraction (ML)} \times \text{AISC (£/ML)}$

Table 5.4 Public abstraction (B_2)

	Costs of building alternative infrastructure for public water supply to replace the lost groundwater resource
Indicator of value	Market price proxy: cost of alternatives
Data needs	Capital and operational costs of various infrastructure options
Data availability and source	Total public abstraction from Environment Agency datasets (Annex 5). Costs estimate using AISC.
Time issues	Same as other estimates using AISC.
Standard formula	$B_2 =$ total annual public abstraction (ML) × AISC (£/ML)

Table 5.5 Agricultural abstraction (B_3)

Value to estimate	Benefits foregone of lost agricultural production
Indicator of value	Market price proxy: production function
Data needs	Type of crops (needing irrigation) grown in the area; typical yields and market price
Data availability and source	Total agricultural abstraction from Environment Agency datasets (Annex 5). Data on crop coverage, yields and prices are available from Defra (e.g. June Agricultural Survey) and the Office for National Statistics (ONS). Crop coverage is available at local authority district (LAD) resolution (too much data are suppressed at ward level).
Time issues	Crop losses are annual. In the long term, alternative uses would be found for the land, although what exactly would happen is highly speculative and uncertain. Therefore, only the initial loss in agricultural crops is estimated.
Standard formula	$B_3 =$ area covered (ha) × mean yield (tonne/ha) × average price (£/tonne) for each crop For total agricultural benefit, sum over all affected crops.

Table 5.6 Industrial abstraction (B_4)

Value to estimate	(a) Benefits foregone of lost industrial production (b) Costs of infrastructure for alternative water supply for smaller producers and power stations For simplicity, it is assumed that each industrial abstractor falls into either category (a) or (b). In reality, there may be producers that initially suffer loss of output and subsequently go out of business.
Indicator of value	Market proxies: (a) Production function (b) Cost of alternatives
Data needs	Total industrial abstraction from Environment Agency datasets (Annex 5). (a) Outputs of affected industries and prices of goods produced (b) Costs that additional demand places on public water supply; proportions of industrial water abstraction by different users
Time issues	(a) Losses are annual. (b) See discussion of AISC above.
Data availability and source	(a) Figures on typical outputs of plants and from trade associations. (b) As other estimates using AISC. The proportion of industrial abstraction that would be connected to the mains supply is not known.
Standard formula(e)	B_{4a} = sum over all affected industries of (no. plants affected × mean plant output × unit price) B_{4b} = total annual industrial abstraction (ML) × proportion of industrial abstraction to be connected × AISC (£/ML) Since the proportion of industrial abstraction to be connected to mains supply (unless large industry is known not to exist in the area) is not known, it is assumed to be between 0.1 and 0.9.

Table 5.7 Groundwater-dependent wet ecosystems (*B_5*)

Value to estimate	(a) Wetland loss (b) Loss of fishing recreation (c) Loss of amenity due to reduction in fluvial water levels This category incorporates non-market values (e.g. amenity) as market values associated with well-functioning wet ecosystems (e.g. aquaculture) are covered in B_6 in Table 5.8. However, recreational benefits are included here for which there may be some element of payment (e.g. angling licences).
Indicator of value	Benefits transfer from studies using stated preference method and travel cost for angling licences
Data needs	Loss of values attributable to change in wetland or river ecosystem. Information on the physical impact of groundwater body loss on these ecosystems – either qualitative or quantitative is needed – which can then be valued using benefits transfer from previous economic valuation studies.
Time issues	Benefit estimates are annual. Losses are permanent, but may accrue over different timescales.
Data availability and source	Such information can be highly specific to individual rivers or wetlands, as well as to the change presented in the studies from the literature. Detailed benefits transfer, considering how similar the two goods are, should ideally be used. Proxies using simple unit figures are used in the case studies as follows: (a) Generic typical figures for the per hectare value of wetland taken from a meta-analysis of wetland valuation studies by Woodward and Wui (2001). The figures for average habitat value and the value of recreational bird-watching are used to form a range for the value of wetland biodiversity and recreational values (£960 and £3,900 per ha respectively);[14] data on area of wetlands from Natural England's *Nature on the Map* website (http://www.natureonthemap.org.uk/). (b) A generic figure (£2.83) for the average consumer surplus per trip of coarse fishing in England and Wales taken from Radford *et al*. (2001). Statistics on number of fishing licences issued from Environment Agency (2004). Population figures from ONS. (c) WTP for avoiding a flow reduction/gaining a flow improvement of 10 per cent obtained from a study of the River Darent by Garrod and Willis (1996) and is taken to be £1.30–3.40 per household per year. Household figures from ONS. Specific BFIs were not available, so a range of possible BFIs of 0.05–0.8 (Atkinson 2004) was used.
Standard formula(e)	B_{5a} = typical wetland value per unit area (£/ha) × area of wetland assumed affected (ha)

[14] These values are not additive because, as explained in Woodward and Wui (2001), they overlap to some extent; bird-watching is dependent on the provision of habitat for birds and prey species.

B_{5b} = average value of fishing trip (£/day) × annual no. licensed fishing days (days)

Proxy for annual no. licensed fishing days (based on numbers of different types of passes issued by Environment Agency) =

no. annual passes) × (average no. fishing trips made by a licence holder[15]) + (8 × no. eight-day passes) + (no. daily passes) × (proportion of population of Environment Agency Region living in affected local authority districts)

B_{5c} = (base flow index/0.1)

× WTP to prevent 10 per cent reduction (£/hh/year)

× no. affected households

Table 5.8 Groundwater-dependent terrestrial and coastal ecosystems (B_6)

Value to estimate	Value of groundwater-dependent ecosystems (e.g. wet woodlands, certain coastal habitats) compared with loss in ecological function. Wetlands and estuarine habitats are already covered under B_5 in Table 5.7.
Indicator of value	Benefits transfer from studies using stated preference method
Data needs	Loss of values attributable to change in habitat from changes to reduced groundwater, groundwater pollution or saline ingress. Information on the physical impact of groundwater body loss on these ecosystems, and on what they would change to, which can then be valued using benefits transfer from previous economic valuation studies.
Time issues	Benefit estimates are annual. Losses are assumed to be permanent, but may accrue over different timescales.
Data availability and source	Wet woodland is a Biodiversity Action Plan (BAP) priority habitat. Natural England's *Nature on the Map* indicates where wet woodland is found, but does not provide figures for area coverage. The Ancient Woodland Inventory[16] has very limited information on wet woodland coverage, and none is applicable to the case study areas. There are no valuation studies examining these habitats specifically. Typical values of woodland habitats could be used as a proxy for wet woodland. Coastal habitat values are omitted from the case studies.
Standard formula	B_6 = value of lost habitat (per ha) × area potentially affected habitat

[15] Unknown, but assumed here to be between 10 and 26.
[16] See http://www.english-nature.org.uk/pubs/gis/tech_aw.htm

Table 5.9 Aquaculture (B_7)

Value to estimate	Benefits foregone of lost aquaculture production
Indicator of value	Market price proxies: production function
Data needs	Yield of fisheries/other aquaculture (e.g. watercress cultivation) and market prices
Time issues	Losses annual and continuous
Data availability and source	There is almost no publicly available information on the typical output of fresh water fish farms in England. Information on watercress yields and cultivation area from the Watercress Alliance and Vitacress (a grower; personal communication). Prices from retailers.
Standard formula	$B_7 =$ average annual production of good (tonnes) × average unit price (£/tonne) for an individual product For total benefit, sum over all relevant products.

Table 5.10 Regulation of flood flow (B_8)

Value to estimate	(a) Investments in extra flood risk management measures to make up for the loss of protection provided by the groundwater body (b) Costs of flooding (if flooding allowed to happen) Either (a) or (b) would happen. If alternative investment keeps the flood risk at the same level as the groundwater body did, then there would not be extra flood cost. If alternative investment does not happen, flood risk may increase. While (a) is probably used more frequently, the correct measure is (b), which is needed to justify whether flood damage is large enough to warrant spending on alternative investments.
Indicator of value	Market proxy: (a) Cost of alternative (b) Mitigation (replacement) costs (covers the tangible costs only; see Table 3.2)
Data needs	Probability of being flooded in one year and changes to this due to loss of groundwater. For (a), alternative investments and their costs and (b) no. of properties likely to be affected and cost of damage.
Time issues	Annual
Data availability and source	Data do not appear to be available on the risk of flooding with and without the flood risk regulation service of the groundwater body. Therefore, neither (a) nor (b) above could be estimated.
Standard formula(e)	$B_{8a} =$ cost of alternative flood risk management investment $B_{8b} =$ change in the probability of flooding × no. properties affected × average cost of damage (£/property)

Table 5.11 Preventing subsidence (*B_9*)

Value to estimate	(a) Investments in soil strengthening to make up for the loss of stability provision by the groundwater body (b) Value of damage to housing from subsidence Either (a) or (b) would happen. If alternative investment maintains soil stability, then there would not be extra damage and cost. If alternative investment does not happen, subsidence and associated costs increase. While (a) is probably used more frequently, the correct measure is (b), which is needed to justify whether the cost of subsidence is large enough to warrant spending on alternative investments.
Indicator of value	Market proxy: (a) Cost of alternative (b) Mitigation (replacement) costs (or total loss of property)
Data needs	Probability of subsidence with and without the presence of the groundwater body (a) alternative investments and their costs and (b) no. properties likely to be affected by subsidence, cost of repairs or value of property
Time issues	Damage is continuous and permanent. Property prices are assumed to be in NPV value terms over a period of infinity.
Data availability and source	The scientific understanding of whether subsidence could be caused by groundwater depletion in this country is very poor. There are no data on the number of properties that might be affected by this. For this reason, this component of value cannot be estimated for the case studies.
Standard formula(e)	$B_{9a} =$ cost of alternative soil maintenance investment $B_{9b} =$ change in the probability of subsidence × no. properties affected × average cost of damage (£/property) or: = no. properties affected x average price per property (£/property)

Table 5.12 Sink/source of heat (*B_{10}*)

Value to estimate	Option value of being able to install ground source heat pumps for new-build houses. Assumed no change in the heating of existing housing.
Indicator of value	Avoided impacts of avoided emissions and energy bills from alternative heat sources net of cost of installing ground heat pumps.
Data needs	Assumed to apply to new housing: likely number of new houses in the groundwater body area; likely proportion of new build to be fitted with heat pumps. Also: (a) Average per household energy and CO_2 savings due to heat pump being installed, price of energy and social cost of carbon (b) Cost of installation of a groundwater heat pump system.[1]
Time issues	(a) Benefits of avoided CO_2 emissions and energy bill savings are annual. (b) Cost of installation is one-off.
Data availability	Estimates on likely new housing in area from the Regional Planning Body; (a) energy savings from heat pumps and the number of new houses with ground source heat pumps from the Ground Source Heat Pump Association;[17] carbon content of fuels [14–33 kg carbon (kgC) per GJ depending on whether gas or electricity] from DETR (1999); average domestic energy use from ONS; social cost of carbon from Clarkson and Deyes (2002); total number of new houses per year from the Department for Communities and Local Government (DCLG). The proportion of new build likely to be fitted with ground source heat pumps is assumed to be in the range 0.05 (the current proportion) to 0.5 (the proportion in 10 years' time if current trends persist, although this is a generous upper limit). (b) Average cost of installation (£6,400–9,600) from the Ground Source Heat Pump Association

[17] See http://www.nef.org.uk/gshp/

Standard formula(e)	B_{11a} =	average proportion household heating energy saved by installing a ground source heat pump × average proportion domestic energy used for heating × average domestic energy use (GJ) × (average. price of energy (£/GJ) + social cost of carbon (£/tonne) × average carbon released by domestic energy (tonne/GJ) × expected proportion of new-build houses to have heat pumps × expected number of new-build houses
	B_{11b} =	net cost of installation (£) × expected proportion of new-build houses to have heat pumps × expected number of new-build houses

Notes: [1] This should be net of the cost of installing an alternative. If electricity is used for central heating, there is no boiler or additional equipment to install, therefore the cost of alternative is zero. If gas central heating is used, there would be a boiler to install, but including this in the calculation would involve making estimates of the proportion of houses that have gas central heating rather than electricity. This was considered an unnecessary level of detail, so the possible costs of installing gas boilers rather than groundwater heat pumps were ignored.

(iii) Estimate the changes in the benefits

Estimates are calculated for each benefit in the case studies using the standard formulae given in the tables above. Because many of the variables used in the calculations have approximate ranges, many components of value have low and high estimates. These are denoted by use of superscripts, i.e. B_i^L = low estimate of benefit *I* and B_i^H = high estimate of benefit *i*.

(iv) Aggregate the changes in benefits across all benefit and time

The different components of value are a mixture of annual continual values and one-off values. Each benefit can be aggregated over time using discounting as follows:

$$B_i = \sum_{t=0}^{t=T-1} \frac{B_{it}}{(1+r)^t}$$

where B_{it} is the benefit occurring at time *t*, *r* is the discount rate, and *T* is the overall number of years to take into account.

For one-off values, B_{it} = 0 for all years except one. For annual continual values, B_{it} is the same for all years.

Total discounted benefit *B* over *N* benefits is therefore:

$$B = \sum_{i=1}^{N} B_i = \sum_{i=1}^{N} \sum_{t=0}^{t=T-1} \frac{B_{it}}{(1+r)^t}$$

Given the assumptions on the timing of when benefits occur, this translates in the case studies to:

$$B = \sum_{j} B_j + \sum_{k} B_k \sum_{t=0}^{T-1} \frac{1}{(1+r)^t}$$

where *j* denotes a one-off benefit assumed to happen in year *t*=0, and *k* denotes a continual annual benefit.

A discount rate of 3.5 per cent is recommended by *The Green Book* (HM Treasury 2003).

If used with a time period of 10 years, the sum of the discount factors on the right of the above expression is 8.61.

5.3 Hampshire Chalk case study

5.3.1 Description of groundwater body area

Basic information

The groundwater body is situated in Hampshire. Figure 5.1 shows a map of the catchment of the Rivers Test and Itchen, both of which are fed by spring water passing through the groundwater body. The surface area of the groundwater body is 498 km^2, but its exact geographical characteristics are not clear from publicly available information.

The area is one of chalk downland. The chalk is a porous, fine-grained limestone which is generally very permeable. Over half of the annual rainfall that falls on it soaks in and is stored. Rain takes several months to filter through the chalk, so periods of heavy winter rainfall emerge as higher stream flows in late spring. The long residence time in the ground leads to high water quality through filtration.

Contribution to surface waters

Chalk streams such as the Test and Itchen provide much of the water used in Hampshire, particularly from their lower reaches. These rivers are almost entirely fed from groundwater. The exact base flow indices of the Test and Itchen are either unknown or not publicly available. However, the groundwater body is very important for the flow levels and ecological functioning of these two rivers.

Abstractions and discharges

The total abstraction from the groundwater body is 315 ML/d. This is 24 per cent of a recharge of 1,364 ML/d. The chalk streams fed by the groundwater body provide much of the water used in Hampshire. Abstraction from the groundwater body itself accounts for a substantial component of public water supply and contributes heavily to agricultural irrigation. Large abstractions from surface waters are also made for fish and watercress farming and gravel washing; most of these particular abstractions are returned to the rivers. Major surface water abstractions for public water supply are made near Southampton, near the Test's tidal limit.

River flow is augmented in places by groundwater to provide dilution of sewage discharges downstream. Industrial abstraction accounts for 5 per cent of total abstraction, agriculture 57 per cent and public water supply 37 per cent.

Figure 5.1 The catchments of the Rivers Test and Itchen

Surface water and coastal ecology

The Rivers Test and Itchen flow into Southampton Water, an arm of the Solent, and are both SSSIs along their entire length. Parts of the tidal Solent are designated as Special Protection Areas (SPAs) or SACs. Eling and Bury Marshes, where the Test meets Southampton Water, is an SSSI.

Terrestrial ecology

Natural England's *Nature on the Map* website indicates that there are wet woodlands in the affected area.

Economy and human geography

The groundwater body is mostly within Hampshire; relevant local authority districts (LADs) are assumed to be Havant, Eastleigh, Fareham, Gosport, Test Valley, Winchester, Portsmouth and Southampton. The area is predominantly rural, though it contains large urban areas such as Winchester, Eastleigh and Southampton (Figure 5.1).

There is little industrial abstraction on the Test, although there is one paper mill. According to the Partnership for Urban Southampton (2004), 80,000 homes are expected to be built in the area over the next 20 years.

Important arable crops in the region are wheat, barley and oilseed rape. There is also extensive livestock-rearing. There are fresh water fish and watercress farms dependent on surface water quantity and quality.

Scope

The geographical scope is the area of groundwater body, as well as the Test, Itchen and Hamble estuaries, and coast of Southampton Water service area. Rivers fed by the groundwater body do not flow out of the area.

The potentially affected population is the population of the affected geographical areas, as well as tourists and recreational visitors to these areas.

5.3.2 Valuation

Estimation of benefits

Table 5.13 lists numerical estimates of the benefits provided by the Hampshire groundwater body that would be lost under a worst case scenario. Lines 2-4 in the table in italics explain the information noted in each line for each benefit.

Table 5.13 Benefits assessment summary for the Hampshire groundwater body

Benefit	Benefit lost under worst case scenario	Result
	How impact and data assumptions vary from the default (Tables 5.3–5.12)	
	Benefit calculation (numbers)	*Result and unit*
	Any additional data sources used.	
B_1: Private	As default	
	$B_{1a}^{L} =$ (total private abstraction/average abstraction) × lower estimate cost of connection	
	$B_{1a}^{L} = \frac{0.69}{1.8 \times 10^{-4}} \times 540 =$	£2.1 million
	$B_{1a}^{H} =$ (total private abstraction/average abstraction) × higher estimate cost of connection	
	$B_{1a}^{H} = \frac{0.69}{1.8 \times 10^{-4}} \times 8,890 =$	£34.1 million
	$B_{1b}^{L} =$ lower estimate AISC × no. days in year × daily total private abstraction	
	$B_{1b}^{L} = 400 \times 365 \times 0.69 =$	£101,000/year
	$B_{1b}^{H} =$ upper estimate AISC × no. days in year × daily total private abstraction	
	$B_{1b}^{H} = 1,200 \times 365 \times 0.69 =$	£302,000/year
	n/a	
B_2: Public	As default. Public water supply would have to be drawn from another region or from desalination plants, requiring major infrastructure – upper estimate more likely.	
	$B_{2}^{L} =$ lower estimate AISC × no. days in year × daily total public abstraction	
	$B_{2}^{L} = 400 \times 365 \times 117 =$	£17.1 million/year
	$B_{2}^{H} =$ upper estimate AISC × no. days in year × daily total public abstraction	
	$B_{2}^{H} = 1,200 \times 365 \times 117 =$	£51.2 million/year
	n/a	
B_3: Agriculture	As default. Crops affected are wheat, barley, potatoes, sugar beet, oilseed rape and small fruit.	

Benefit	Benefit lost under worst case scenario	Result
	B_3 = sum over all crops of (area covered × average yield × average unit price) Wheat: 27,610 × 7.7 × 73 Barley: 16,460 × 5.7 × 70 Potatoes: 230 × 41.8 × 107 Oilseed rape: 11,660 × 3.3 × 156 Small fruit: 90 × 17 × 20,000 Total =	£59.7 million/year
	n/a	
B_4: Industrial	As default. One paper mill goes out of business (although this abstracts from surface water, rivers in this area are particularly reliant on groundwater).	
	B_{4a} = no. paper mills × average turnover of a UK paper mill B_{4a} = 1 × 71,000,000	£71 million/year
	B_{4b}^{L} = lower estimate AISC × no. days in year × daily total industrial abstraction × low estimate proportion of industry connecting to mains B_{4b}^{L} = 400 × 365 × 15.0 × 0.1 =	£219,000/year
	B_{4b}^{H} = upper estimate AISC × no. days in year × daily total industrial abstraction × high estimate proportion of industry connecting to mains B_{4b}^{H} = 1,200 × 365 × 15.0 × 0.9 =	£5.9 million/year
	Data available from the Confederation of Paper Industries on average turnover of UK paper mills.	
B_5: ground water-dependent wet eco-systems	As default. There do not appear to be any significant wetlands in the area that would be affected by changes to groundwater. Base flow indices tend to be higher for chalk rivers, so component B_{5c} likely to be at the higher end of the range.	

Benefit	Benefit lost under worst case scenario	Result
	B^L_{5a} = area of Eling and Bury Marshes × low estimate average annual per ha value of wetland B^L_{5a} = 112 × 960 =	£107,000/year
	B^H_{5a} = area of Eling and Bury Marshes × high estimate average annual per ha value of wetland B^H_{5a} = 112 × 3,900 =	£437,000/year
	B^L_{5b} = average value of fishing trip × lower estimate annual no. licensed fishing days B^L_{5b} = 2.83 × (77,800 × 10 + 4,200 × 8 + 27,700) × 0.24 =	£570,000/year
	B^H_{5b} = average value of fishing trip × higher estimate annual no. licensed fishing days B^H_{5b} = 2.83 × (77,800 × 26 + 4,200 × 8 + 27,700) × 0.24 =	£1.4 million/year
	B^L_{5c} = base flow index/0.1 × lower estimate per household annual value of preventing 10 per cent reduction × no. affected households B^L_{5c} = 0.05/0.1 × 1.30 × 485,000 =	£315,000/year
	B^H_{5c} = base flow index/0.1 × higher estimate per household annual value of preventing 10 per cent reduction × no. affected households B^H_{5c} = 0.8/0.1 × 3.40 × 485,000 =	£13.2 million/year
B_6: ground water dependent terrestrial and coastal eco-systems	There is evidently wet woodland in the affected area, but data are not available on the amount of area covered.	
B_7:Aqua-culture	As default. Fish and watercress farms go out of business. There are several watercress farms and at least three fish farms in Hampshire, including one trout farm.	

Benefit	Benefit lost under worst case scenario	Result
	$B_7 =$ average yield of watercress × area under cultivation × retail price fetched by a unit of output	
	$B_7 =$ 24.4 × 54 × 11,600 =	£15.3 million/year
	Ideally would be able to add fishery components to this.	
	Information on watercress yields and cultivation area from the Watercress Alliance and Vitacress (a grower). Prices from retailers. No information available on output of fisheries.	
B_8: Regulation of flood flow	*Not enough data for assessing the physical impact of the change.*	
B_9: Soil stability	*Not enough data for assessing the physical impact of the change.*	
B_{10}: Sink/ source heat	As default	
	$B_{10a} =$ heating energy saved × proportion of domestic energy used for heating × *(average domestic energy bill + social cost of carbon* × *carbon content of energy)* × proportion of new-build houses to have heat pumps × no. new-build houses	
	$B_{10a}^{L} =$ 0.75 × 0.62 × (250 + 70 × 14) × 0.05 × 80,000 =	£2.3 million/year
	$B_{10a}^{H} =$ 0.75 × 0.62 × (250 + 70 × 33) × 0.5 × 80,000 =	£47.6 million/year
	$B_{10b}^{L} =$ - cost of installation × proportion of new-build houses to have heat pumps × no. new-build houses	
	$B_{10b}^{L} =$ -9,600 × 0.05[1] × 80,000 =	-£38.4 million
	$B_{10b}^{H} =$ -6,400 × 0.5 × 80,000 =	-£256 million
	As default. Housing figures from the Partnership for Urban Southampton.	

Notes: [1]Although using the proportion 0.5 instead of 0.05 here would produce a lower (i.e. more negative) figure for B_{10b}^{L}, the number of houses assumed has to be the same for both B_{10b}^{L} and B_{10a}^{L} in order for the final aggregation below to make sense. A similar argument applies for B_{10b}^{H}. Given a long enough payback period, the benefits of installing a ground source heat pump do outweigh the cost.

Aggregation

The following makes a big simplifying assumption that all benefits/losses happen over the same timescale (i.e. immediately from *t=0* to *t=T*) some time in the future. In reality, it would either take many years for some of the losses detailed above to materialise or they would be in an intermediate state before they reached their 'worse case' state; other losses would happen immediately.

This caveat aside, the aggregation of total benefits *B* over time would be as follows:

$$B_i = \sum_{t=0}^{t=T-1} \frac{B_{it}}{(1+r)^t}$$

$$B = B_{1a} + B_{10b} + [B_{1b} + B_2 + B_3 + B_{4a} + B_{4b} + B_{5a} + B_{5b} + B_{5c} + B_{10a}]\sum_{t=0}^{T-1} \frac{1}{(1+r)^t}$$

Using lower estimates above, with a timescale of 10 years (*T* = 10) and a discount rate of 3.5 per cent (*r* = 0.035) gives (units of *B* and components are £million):

$$B^L = 2.1 - 38.4 + [0.1 + 17.1 + 59.7 + 71.0 + 0.2 + 0.1 + 0.6 + 0.3 + 15.3 + 2.3] \times 8.61$$

$$B^L = -36 + 1{,}436 = 1{,}400$$

$$B^H = 34.1 - 256 + [0.3 + 51.2 + 59.7 + 71 + 5.9 + 0.4 + 1.4 + 13.2 + 15.3 + 47.6] \times 8.61$$

$$B^H = -222 + 2{,}291 = 2{,}069$$

5.4 Lincolnshire Limestone case study

5.4.1 Description of groundwater body area

Basic information

The Lincolnshire limestone groundwater body stretches from just south of Lincoln through the catchments of the Rivers Witham, Welland and Nene, all of which eventually flow into the Wash (Figures 5.2 and 5.3). Much of the area is below sea level, with the result that water does not naturally discharge to the sea by gravity.

The groundwater body is the most substantial in the Lincolnshire area, with a surface area of 58 km^2 and an average recharge rate of 160 ML/d. There are smaller groundwater bodies to the north-east of Lincoln, in the form of the Chalk and Spilsby Sandstone groundwater body and Bain Gravels.

This case study incorporates information from the Witham and Nene CAMS documents only, as the Welland CAMS document has not yet been published.

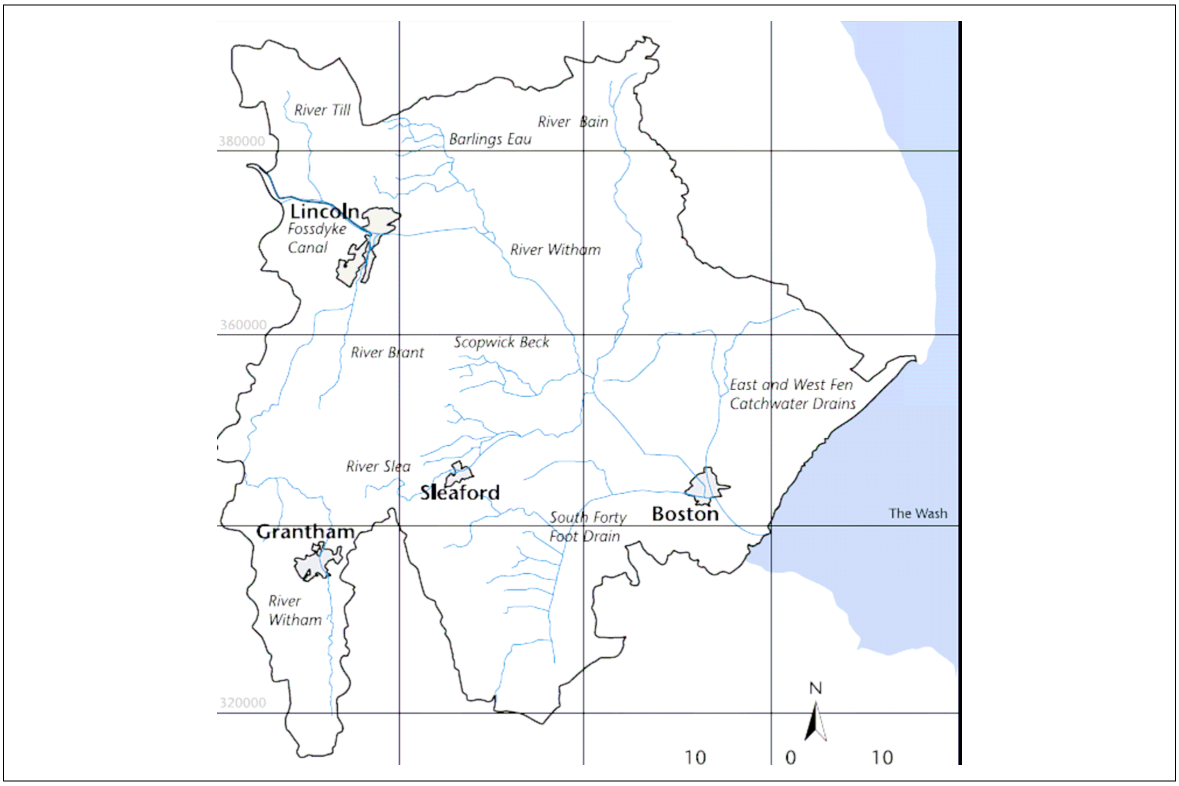

Figure 5.2 Witham catchment

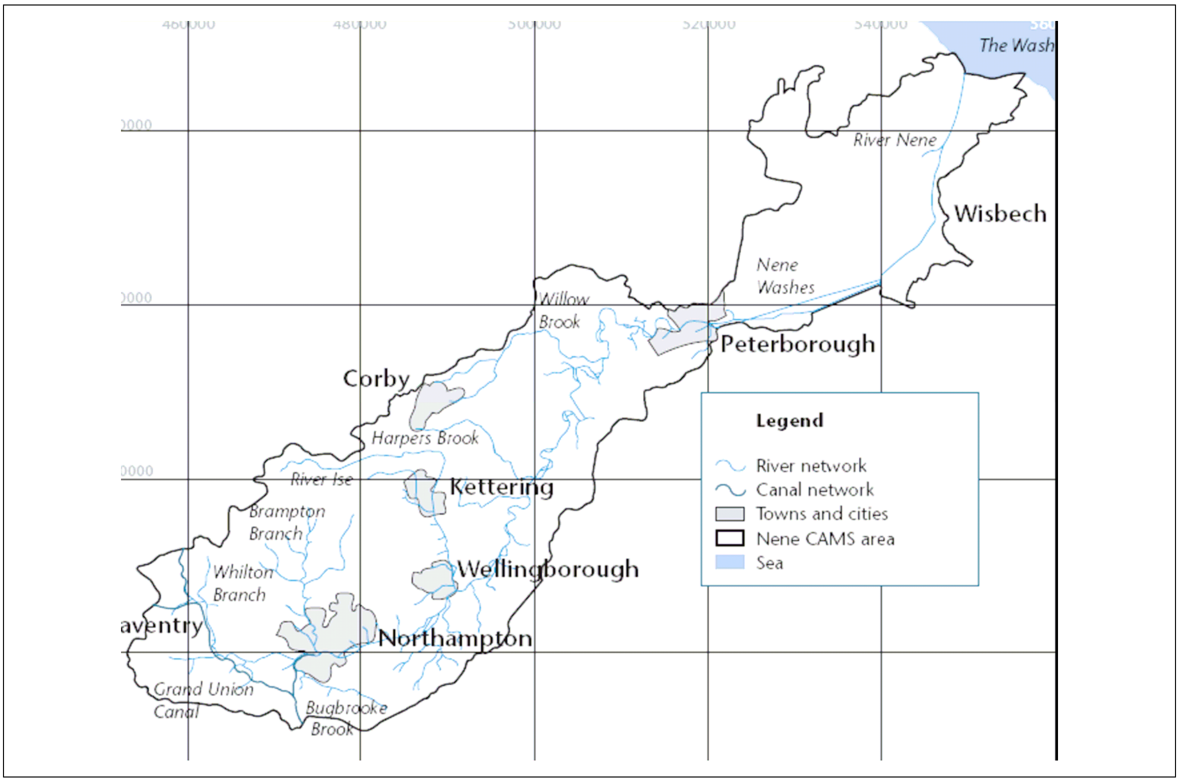

Figure 5.3 Nene catchment

Contribution to surface waters

The groundwater body is important for maintaining flows in the Witham; substantial base flows for many of its tributaries are derived from the groundwater body. The base flow indices of the Witham and Nene are either unknown or not publicly available.

Abstractions and discharges

Abstraction is mainly for the purposes of public water supply, but the groundwater is also important for agricultural and industrial supply. There is considerable public water supply abstraction in the Witham and Welland catchments, but little in the Nene catchment. Water is also abstracted out of the Witham to the neighbouring Ancholme catchment when indigenous resources cannot meet demand. A large amount of water is abstracted from the Nene to fill Rutland Water Reservoir in the adjacent Welland catchment. Three other smaller reservoirs in the Nene catchment are filled from the river. There are various transfers from the Nene to a smaller river (Thorney) and an important bird-watching SAC (Nene Washes). Industrial abstraction accounts for 5 per cent of total abstraction, agriculture 4 per cent and public water supply 91 per cent.

The majority of agricultural abstraction licences are for spray irrigation. During periods of low flow, these abstractions can have a significant impact on other abstraction needs. The small amount of industrial abstraction in the Witham catchment is mostly around Lincoln; it is mainly used for vegetable washing, food processing, cooling and process water. Industrial abstractions are more significant in the Nene catchment and include a surface water abstraction for mineral washing (although this water is largely recycled and returned) and a groundwater abstraction for brewing in Northampton.

The majority of discharges in the Nene are from sewage treatment works. During periods of low flow as much as 70 per cent of the Nene's flow near Northampton is made up of effluent returns. The Witham has two major sewage works at Lincoln and Marston, as well as major trade discharges from quarries, landfills and a factory.

Surface water-dependent and coastal ecology

The Rivers Witham and Nene and their tributaries suffer from seasonal low flow stress during which point source discharges cause localised water quality problems and poor dilution of effluent. In particularly dry years, upper reaches can dry out completely. Local flora and fauna are sensitive to low flow; important species include the white clawed crayfish, otter, water vole, marsh harrier and Witham orb mussel.

Nutrient enrichment of surface waters by fertiliser and sewage treatment works is a significant ecological issue in both catchments, leading to problems of weed overgrowth and is particularly problematic at times of low flow. The lower Witham experiences saline ingress, particularly in drought years.

Both catchments contain several water-related SSSIs and Sites of Nature Conservation Importance in the form of rivers, reservoirs, flood meadows, gravel pits and wetlands. Some of these are managed by the RSPB. The Wash is a National Nature Reserve (NNR) and supports the largest numbers of migrating waterfowl of any site in the UK, as well as being home to the largest colony of common seals in England.

Terrestrial ecology

There does not appear to be any wet woodland in the affected area. No further information on groundwater-dependent terrestrial ecosystems was found.

Economy and human geography

The groundwater body is apparently mainly in Lincolnshire (North Kesteven and South Kesteven LADs), but touches on Northamptonshire (Corby, Kettering, Wellingborough, Northampton and East Northamptonshire LADs) and the Peterborough and Rutland Unitary Authorities (UAs). However, its exact geographical coverage is unclear and this scope is to some extent approximate.

The area is predominantly rural, with a few urban settlements such as Lincoln, Peterborough and Northampton. Significant housing development is planned in Corby, Kettering and Wellingborough.

Important arable crops in the region are wheat, barley, sugar beet and oilseed rape; arable is more important than livestock-rearing. There do not appear to be any commercial fisheries in the Witham or Nene.

Pleasure boating is the main recreational activity on the Nene; the Witham catchment also contains navigable waterways. Walking and cycling on the 'Nene Way', which extends along the whole length of the Lower River Nene, are also popular.

Scope

The potentially affected geographical area is assumed to be:

- the area of the groundwater body itself;
- the lengths of the Witham, Slea, Welland and Nene and their tributaries;
- the Wash.

The potentially affected population is the population of the affected geographical areas, as well as tourists and recreational visitors to these areas.

5.4.2 Valuation

Estimation of benefits

Table 5.14 lists numerical estimates of the benefits provided by the Lincolnshire groundwater body that would be lost under a worst case scenario. Lines 2–4 in the table in italics explain the information noted in each line for each benefit.

Table 5.14 Benefits assessment summary for the Lincolnshire groundwater body

Benefit	Benefit lost under worst case scenario	Result
	How impact and data assumptions vary from the default (Tables 5.3–5.12)	
	Benefit calculation (numbers)	*Result and unit*
	Any additional data sources used.	
B_1: Private	As default	
	$B_{1a}^{L} =$ (total private abstraction/average abstraction) × lower estimate cost of connection	
	$B_{1a}^{L} = \frac{0.01}{1.8 \times 10^{-4}} \times 540 =$	£30,000
	$B_{1a}^{H} =$ (total private abstraction/average abstraction) × higher estimate cost of connection	
	$B_{1a}^{H} = \frac{0.01}{1.8 \times 10^{-4}} \times 8{,}890 =$	£490,000
	$B_{1b}^{L} =$ lower estimate AISC × no. days in year × daily total private abstraction	
	$B_{1b}^{L} = 400 \times 365 \times 0.01 =$	£1,500/year
	$B_{1b}^{H} =$ upper estimate AISC × no. days in year × daily total private abstraction	
	$B_{1b}^{H} = 1{,}200 \times 365 \times 0.01 =$	£4,400/year
	n/a	
B_2: Public	As default	
	$B_{2}^{L} =$ lower estimate AISC × no. days in year × daily total public abstraction	
	$B_{2}^{L} = 400 \times 365 \times 34 =$	£5.0 million/year
	$B_{2}^{H} =$ upper estimate AISC × no. days in year × daily total public abstraction	
	$B_{2}^{H} = 1{,}200 \times 365 \times 34 =$	£14.9 million/year
	n/a	
B_3: Agriculture	As default. Crops affected are wheat, barley, potatoes, sugar beet, oilseed rape and small fruit.	

Benefit	Benefit lost under worst case scenario	Result
	B_3 = sum over all crops of (area covered × average yield × average unit price)	
	Wheat: 148,330 × 7.7 × 73	
	Barley: 25,140 × 5.7 × 70	
	Potatoes: 2,960 × 41.8 × 107	
	Sugar beet: 11,180 × 54.4 × 32	
	Oilseed rape: 44,670 × 3.3 × 156	
	Small fruit: 70 × 17 × 20,000	
	Total =	£172.9 million/year
B_4: Industrial	n/a	
	As default. There are no industrial abstractions significant enough to cause business closures; all industrial abstraction connects to the mains.	
	$B_{4a} = 0$	£0/year
	B_{4b}^{L} = lower estimate AISC × no. days in year × daily total industrial abstraction	
	B_{4b}^{L} = 400 × 365 × 2.0 =	£29,000/year
	B_{4b}^{H} = upper estimate AISC × no. days in year × daily total industrial abstraction	
	B_{4b}^{H} = 1,200 × 365 × 2.0 =	£876,000/year
B_5: Ground water dependent wet eco-systems	n/a	
	Rivers and streams lose base flow. Wetlands dependent on groundwater suffer effects of drying out. Large proportion of protected areas affected.	

Benefit	Benefit lost under worst case scenario	Result
	Areas of effected wetlands:	
	The Wash: 62,000 ha	
	Nene Washes: 1,510 ha	
	Orton Pit: 146 ha	
	Various other wetlands of comparatively negligible size (8–55 ha).	
	Not all of the Wash would be affected, as the Ouse also drains into it. The low and high estimates below assume either that none of it or all of it respectively is affected.	
	$B_{5a}^{L} =$ low estimate average annual per ha value of wetland × wetland area	
	$B_{5a}^{L} =$ 960 × 1,700 =	£1.6 million/year
	$B_{5a}^{H} =$ low estimate average annual per ha value of wetland × wetland area	
	$B_{5a}^{H} =$ 3,900 × 63,000 =	£245.7 million/year
	$B_{5b}^{L} =$ average value of fishing trip × lower estimate annual no. licensed fishing days	
	$B_{5b}^{L} =$ 2.83 × (145,700 × 10 + 6,200 × 8 + 36,100) × 0.20 =	£0.9 million/year
	$B_{5b}^{H} =$ average value of fishing trip × higher estimate annual no. licensed fishing days	
	$B_{5b}^{H} =$ 2.83 × (145,700 × 26 + 6,200 × 8 + 36,100) × 0.20 =	£2.2 million/year
	$B_{5b}^{L} =$ base flow index/0.1 × lower estimate per household annual value of preventing 10 per cent reduction × no. affected households	
	$B_{5b}^{L} =$ 0.05/0.1 × 1.30 × 420,000 =	£273,000/year
	$B_{5b}^{H} =$ base flow index/0.1 × higher estimate per household annual value of preventing 10 per cent reduction × no. affected households	
	$B_{5b}^{H} =$ 0.8/0.1 × 3.40 × 420,000 =	£11.4 million/year

Benefit	Benefit lost under worst case scenario	Result
B_6: ground water dependent. terrestrial and coastal eco-systems	*Does not appear to be relevant for this groundwater body.*	
B_7: Aquaculture	*Does not appear to be relevant for this groundwater body.*	
B_8: Regulation of flood flow	*Does not appear to be relevant for this groundwater body.*	
B_9: Soil stability	*Not enough data for assessing the physical impact of the change.*	
B_{10}: Sink/ source heat	As default	
	B_{10a} = heating energy saved × proportion of domestic energy used for heating × (average domestic energy bill + social cost of carbon × carbon content of energy) × proportion of new-build houses to have heat pumps × no. new-build houses	
	B_{10a}^{L} = 0.75 × 0.62 × (250 + 70 × 14) × 0.05 × 99,500 =	£2.8 million/year
	B_{10a}^{H} = 0.75 × 0.62 × (250 + 70 × 33) × 0.5 × 99,500 =	£59.2 million/year
	B_{10b}^{L} = - cost of installation × proportion of new-build houses to have heat pumps × no. new-build houses	
	B_{10b}^{L} = -9,600 × 0.05 × 99,500 =	-£47.8 million
	B_{10b}^{H} = -6,400 × 0.5 × 99,500 =	-£318 million
	As default. Housing figures from the East Midlands Regional Economic Strategy.	

Notes: [1]Although using the proportion 0.5 instead of 0.05 here would produce a lower figure for B_{10b}^{L}, the number of houses assumed has to be the same for both B_{10b}^{L} and B_{10a}^{L} in order for the final aggregation below to make sense. A similar argument applies for B_{10b}^{H}. Given a long enough payback period, the benefits of installing a ground source heat pump do outweigh the cost.

Aggregation

The following makes a big simplifying assumption that all benefits/losses happen over the same timescale (i.e. immediately from *t=0* to *t=T*) some time in the future. In reality, it would either take many years for some of the losses detailed above to materialise or they would be in an intermediate state before they reached their 'worse case' state; other losses would happen immediately.

This caveat aside, the aggregation of total benefits *B* over time would be as follows:

$$B_i = \sum_{t=0}^{t=T-1} \frac{B_{it}}{(1+r)^t}$$

$$B = B_{1a} + B_{10b} + [B_{1b} + B_2 + B_3 + B_{4a} + B_{4b} + B_{5a} + B_{5b} + B_{5c} + B_{10a}] \sum_{t=0}^{T-1} \frac{1}{(1+r)^t}$$

Using lower estimates above, with a timescale of 10 years ($T = 10$) and a discount rate of 3.5 per cent (r = 0.035) gives (units of *B* and components are £million):

$$B^L = 0.03 - 47.8 + [1.5 \times 10^{-3} + 5.0 + 173 + 0 + 0.03 + 1.6 + 0.9 + 0.3 + 2.8] \times 8.61$$

$$B^L = -48 + 1{,}581 = 1{,}533$$

$$B^H = 0.49 - 318 + [4.4 \times 10^{-3} + 14.9 + 173 + 0 + 0.88 + 246 + 2.2 + 11.4 + 59.2] \times 8.61$$

$$B^H = -318 + 4{,}370 = 4{,}052$$

5.5 North Kent case Study

5.5.1 Description of groundwater body area

Basic information

The exact geographical coverage of the North Kent chalk groundwater body is not clear from publicly available information. However, it covers at least the section of the Medway catchment which is north of Maidstone, including the Hoo Peninsula, as well as most of the North Kent and Swale CAMS area, extending under the Isle of Sheppey (Figures 5.4 and 5.5). Spring flows from the groundwater body enter both the Thames and Medway estuaries. The groundwater body has a surface area of 36 km^2 and is recharged at an average rate of 97 ML/d.

The groundwater body is the most important of a group in the area. To the south there is a lower greensand aquifer, with the superficially larger but less important 'Hastings Beds' to the south of that.

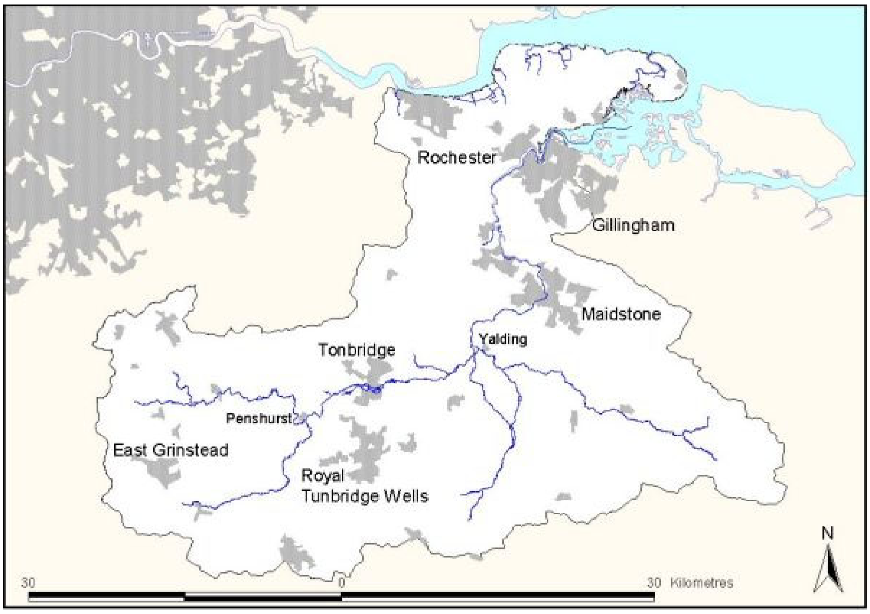

Figure 5.4 Medway catchment area

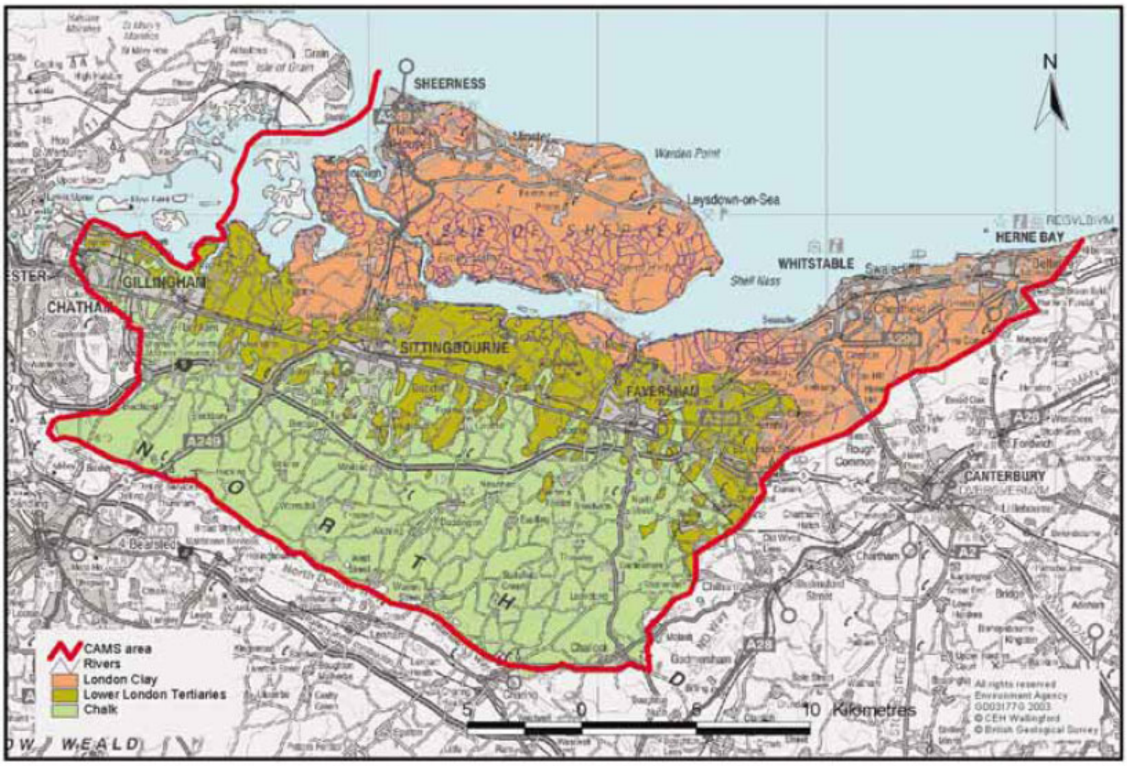

Figure 5.5 North Kent/Swale CAMS.
The Lower London Tertiaries (deposits of sand, silts and clays) and the London Clay layers shown in the diagram overlie, rather than replace, the chalk groundwater body.

Contribution to surface waters

The base flow indices of the Medway and other rivers/streams in the area are either unknown or not publicly available. Many of the streams flowing through the Swale and Medway marshes depend on groundwater levels. The Medway already suffers from drought stress. The Medway and Swale Estuaries are both part of the wider Thames Estuary.

Abstractions and discharges

There are some large industrial abstracters of groundwater in the area, primarily paper, chemicals and cement manufacturers. Industrial abstraction accounts for 16 per cent of total abstraction, agriculture 1.5 per cent, energy 5 per cent and public water supply 76 per cent.

The most important public water abstraction in the Medway catchment, the Medway Scheme, transfers water to Bewl Reservoir. However, this abstraction occurs near Yalding to the south of the groundwater body and is therefore unaffected by changes to it.

Surface water and coastal ecology

There is a fair amount of intensive agriculture in the area, and pesticides and herbicides have affected water quality. Parts of land overlying the groundwater body are Nitrate Vulnerable Zones.

The Thames and Medway Estuaries and Marshes are designated as SSSI, SPA and Ramsar sites, and are thought to be vulnerable to groundwater abstraction levels. Biodiversity Action Plan (BAP) priority habitats in the area include grazing marsh, reedbed and saline lagoons, all of which are sensitive to reductions in river flows. Protected species in the area include otter, water vole, white-clawed crayfish and depressed river mussel.

Terrestrial ecology

BAP priority habitats in the area include wet woodland and lowland heath, both of which are sensitive to changes in groundwater levels.

Economy and human geography

The groundwater body is shared between the county of Kent (apparently Swale, Gravesham and Dartford LADs) and the Medway Unitary Authority. The area contains major urban settlements such as Gravesend, Gillingham and Rochester. Significant house building is planned for the area, as it includes part of the Thames Gateway. Water supply is already a political issue in the area, with frequent hosepipe bans.

Important arable crops in the region are wheat, oilseed rape and top fruit (apples and pears); the area is well-known for its orchards. There is also extensive livestock-rearing. The area contains a fair amount of heavy industry, most of it in either the Medway Estuary just to the north of Maidstone, or around Gravesend. There is a power station (Kingsnorth) on the Isle of Grain.

There are important commercial fisheries (bass, sole, shellfish, etc.) in the Medway and Swale Estuaries, but very little in the way of fresh water fisheries.

Scope

The potentially affected geographical area is assumed to be:

- the area of the groundwater body itself;
- the length of the Medway north of Maidstone;
- the whole of the North Kent/Swale catchment;
- the Medway and Swale Estuaries.

The potentially affected population is the population of the affected geographical areas, as well as tourists and recreational visitors to these areas.

5.5.2 Valuation

Estimation of benefits

Table 5.15 lists numerical estimates of the benefits provided by the North Kent groundwater body which would be lost under a worst case scenario. Lines 2–4 in the table in italics explain the information noted in each line for each benefit.

Table 5.15 Benefits assessment summary for the North Kent groundwater body

Benefit	Benefit lost under worst case scenario	Result
	How impact and data assumptions vary from the default (Tables 5.3–5.12)	
	Benefit calculation (numbers)	*Result and unit*
	Any additional data sources used.	
B_1: Private	As default	
	$B_{1a}^{L} =$ (total private abstraction/average abstraction) × lower estimate cost of connection	
	$B_{1a}^{L} = \frac{0.44}{1.8 \times 10^{-4}} \times 40 =$	£1.3mn
	$B_{1a}^{H} =$ (total private abstraction/average abstraction) × higher estimate cost of connection	
	$B_{1a}^{H} = \frac{0.44}{1.8 \times 10^{-4}} \times 8{,}890 =$	£21.7mn
	$B_{1b}^{L} =$ lower estimate AISC × no. days in year × daily total private abstraction	
	$B_{1b}^{L} = 400 \times 365 \times 0.44 =$	£64,000/year
	$B_{1b}^{H} =$ upper estimate AISC × no. days in year × daily total private abstraction	
	$B_{1b}^{H} = 1{,}200 \times 365 \times 0.44 =$	£193,000/year
	n/a	
B_2: Public	As default. Public water supply would be drawn from other groundwater bodies in the area or from the Medway; lower end estimates likely.	
	$B_{2}^{L} =$ lower estimate AISC × no. days in year × daily total public abstraction	
	$B_{2}^{L} = 400 \times 365 \times 42 =$	£6.1 million/year
	$B_{2}^{H} =$ upper estimate AISC × no. days in year × daily total public abstraction	
	$B_{2}^{H} = 1{,}200 \times 365 \times 42 =$	£18.4 million/year
	n/a	
B_3: Agriculture	As default. Crops affected are wheat, oilseed rape, top fruit and small fruit.	

Benefit	Benefit lost under worst case scenario		Result
	B_3 = sum over all crops of (area covered × average yield × price)		
	Wheat:	10,950 × 7.7 × 73	
	Potatoes:	150 × 41.8 × 107	
	Oilseed rape:	4,960 × 3.3 × 156	
	Top fruit:	2,630 × 17.8 × 550	
	Small fruit:	450 × 17 × 20,000	
	Total =		£188 million/year
	n/a		
	As default. Nine paper mills in Dartford, Gravesham and Medway go out of business.		
	B_{4a} = 9 × 71,000,000 =		£639 million/year
	B_{4b}^{L} = lower estimate AISC × no. days in year × daily total industrial abstraction × low proportion of industry connecting to mains		
B_4: Industrial	B_{4b}^{L} = 400 × 365 × 8.7 × 0.1 =		£127,000/year
	B_{4b}^{H} = upper estimate AISC × no. days in year × daily total industrial abstraction × high proportion of industry connecting to mains		
	B_{4b}^{H} = 1,200 × 365 × 8.7 × 0.9 =		£3.4 million/year
	Data available from the Confederation of Paper Industries on average turnover of UK paper mills.		
B_5: Ground water dependent wet eco-systems	As default		

Benefit	Benefit lost under worst case scenario	Result
	Areas of affected wetlands: South Thames Estuary and Marshes: 5,290 ha Medway Estuary and Marshes: 4,750 ha Sub-total: 10,040 ha The Swale: 6,510 ha Total: 16,550 ha The Swale SSSI is partly mudflat and grazing marsh, partly open water (i.e. not all of it is wetland). Therefore the sub-total without the Swale and the total including it are used as the upper and lower estimates of wetland area in the calculation below.	
	B_{5a}^{L} = low estimate average annual per ha value of wetland × low estimate wetland area	
	B_{5a}^{L} = 960 × 10,040 =	£9.6 million/year
	B_{5a}^{H} = high estimate average annual per ha value of wetland × high estimate wetland area	
	B_{5a}^{H} = 3,900 × 16,550 =	£64.5 million/year
	B_{5b}^{L} = average value of fishing trip × lower estimate annual no. licensed fishing days	
	B_{5b}^{L} = 2.83 × (77,800 × 10 + 4,200 × 8 + 27,700) × 0.11 =	£260,000/year
	B_{5b}^{H} = average value of fishing trip × higher estimate annual no. licensed fishing days	
	B_{5b}^{H} = 2.83 × (77,800 × 26 + 4,200 × 8 + 27,700) × 0.11 =	£649,000/year
	B_{5c}^{L} = base flow index/0.1 × lower estimate per household annual value of preventing 10 per cent reduction × no. affected households	
	B_{5c}^{L} = 0.05/0.1 × 1.30 × 154,000 =	£100,000/year
	B_{5c}^{H} = base flow index/0.1 × higher estimate per household annual value of preventing 10 per cent reduction × no. affected households	
	B_{5c}^{H} = 0.8/0.1 × 3.40 × 154,000 =	£4.2 million/year

Benefit	Benefit lost under worst case scenario	Result
B_6: Ground water dependent terrestrial and coastal eco-systems	*Does not appear to be relevant for this groundwater body.*	
B_7: Aquaculture	*Does not appear to be relevant for this groundwater body.*	
B_8: Regulation of flood flow	*Does not appear to be relevant for this groundwater body.*	
B_9: Soil stability	*Not enough data for assessing the physical impact of the change.*	
B_{10}: Sink/ source heat	As default	
	B_{10a} = heating energy saved × proportion of domestic energy used for heating × (average domestic energy bill + social cost of carbon × carbon content of energy) × proportion of new-build houses to have heat pumps × no. new-build houses	
	B_{10a}^{L} = 0.75 × 0.62 × (250 + 70 × 14) × 0.05 × 45,000 =	£1.3 million/year
	B_{10a}^{H} = 0.75 × 0.62 × (250 + 70 × 33) × 0.5 × 45,000 =	£26.8 million/year
	B_{10b}^{L} = - cost of installation × proportion of new-build houses to have heat pumps × no. new-build houses	
	B_{10b}^{L} = -9,600 × 0.05 × 45,000 =	-£21.6 million
	B_{10b}^{H} = -6,400 × 0.5 × 45,000 =	-£144 million
	As default. Housing figures from the Thames Gateway Kent Partnership website.	

Notes: [1]Although using the proportion 0.5 instead of 0.05 here would produce a lower figure for B_{10b}^{L}, the number of houses assumed has to be the same for both B_{10b}^{L} and B_{10a}^{L} in order for the final aggregation below to make sense. A similar argument applies for B_{10b}^{H}. Given a long enough payback period, the benefits of installing a ground source heat pump do outweigh the cost.

Aggregation

The following makes a big simplifying assumption that all benefits/losses happen over the same timescale (i.e. immediately from *t=0* to *t=T*) some time in the future. In reality, it would either take many years for some of the losses detailed above to materialise or they would be in an intermediate state before they reached their 'worse case' state; other losses would happen immediately.

This caveat aside, the aggregation of total benefits *B* over time would be as follows:

$$B_i = \sum_{t=0}^{t=T-1} \frac{B_{it}}{(1+r)^t}$$

$$B = B_{1a} + B_{10b} + \left[B_{1b} + B_2 + B_3 + B_{4a} + B_{4b} + B_{5a} + B_{5b} + B_{5c} + B_{10a}\right]\sum_{t=0}^{T-1} \frac{1}{(1+r)^t}$$

Using lower estimates above, with a timescale of 10 years (*T* = *10*) and a discount rate of 3.5 per cent (*r* = 0.035) gives (units of *B* and components are £million):

$$B^L = 1.3 - 21.6 \; + \left[6.4 \times 10^{-2} + 6.1 + 188 + 639 + 0.1 + 9.6 + 0.3 + 0.1 + 1.3\right] \times 8.61$$

$$B^L = -20 + 7{,}272 = 7{,}252$$

$$B^H = 21.7 - 144 \; + \left[0.2 + 18.4 + 188 + 639 + 3.4 + 64.5 + 0.6 + 4.2 + 26.8\right] \times 8.61$$

$$B^H = -122 + 8{,}137 = 8{,}015$$

5.6 Nottingham Sherwood case study

5.6.1 Description of groundwater body area

Basic information

This sandstone groundwater body is situated mostly in Nottinghamshire, stretching beneath the conurbation of Nottingham. It has a surface area of 41 km^2 (Figure 5.6). The groundwater body is unconfined and receives little protection under the city, leaving it susceptible to contamination. To the south and east, it is overlain and thus confined by Triassic Mudstones. Groundwater flows (through gravity and abstraction) from the north-east to the south-west. The daily recharge rate is 112 ML/d.

Serious pressures on the groundwater body include:

- point pollution sources;
- urban pollution sources;
- nutrient and pesticide pressures from agriculture.

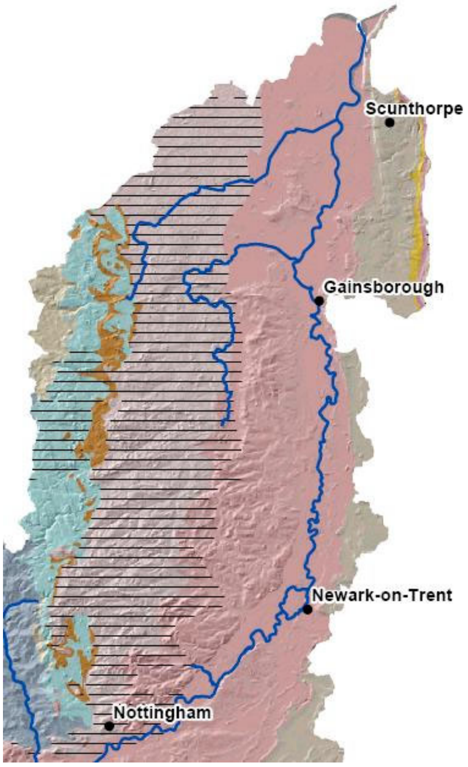

Figure 5.6 The Nottingham Sherwood groundwater body

Horizontal lines indicate Nitrate Vulnerable Zones. The long pale area overlaid with horizontal lines is the groundwater body.

Contribution to surface waters

The groundwater body feeds the Rivers Torne and Idle, both tributaries of the Trent, which is the major river in the area. Waters from the Trent enter the North Sea via the Humber Estuary. The Torne and Idle both join the Trent fairly near the end of its course. The groundwater body is only one source of water in the Trent catchment, and it is assumed that the Torne and Idle do not contribute much to its overall flow.

To explain, the mean flow of the Trent at its tidal limit near Newark-on-Trent is 7,653 ML/d (Environment Agency 2004). This point is some way upstream of the points at which the Torne and Idle meet the Trent. The groundwater body's release to surface waters is small by comparison,[18] making its contribution to the total amount of water in the Trent negligible. It is therefore assumed that effects on the Trent and Humber Estuary of changes to the groundwater body are negligible.

Because the Torne and Idle CAMS document is at a very early stage of preparation, much less information is available on these two rivers than those in the other case studies. Base flow indices are either unknown or not publicly available.

[18]This assertion is based on the fact that the groundwater body's recharge rate is 112 ML/d and the assumption that the natural release rate cannot be much higher than this for the groundwater body to have built up over time.

Abstractions and discharges

The sandstone groundwater body has been extensively developed for public and industrial water supply; the water is thought to be of generally good quality. Industrial abstraction accounts for 14 per cent of total abstraction, agriculture 9 per cent and public water supply 77 per cent.

The total abstraction from the groundwater body is 148 ML/d. This is more than the daily recharge of 112 ML/d. The groundwater body is the only one of the four examined which is actually being depleted.

The [0]total amount abstracted from the groundwater body is 148 ML/d. This is about 2 per cent of the amount of water in the Trent near Newark. Therefore, it is possible that the Trent could act as an alternative source of water in the event of the aquifer facing serious issues concerning the quality or quantity of water supply.

Surface water and coastal ecology

There is currently little information on ecological considerations for the Torne and Idle. There do not appear to be any wetlands dependent on them.

Terrestrial ecology

Natural England's *Nature on the Map* website indicates that there are wet woodlands in the affected area, but less than in the other case study areas.

Economy and human geography

The groundwater body is shared between the counties of Nottingham (apparently Newark and Sherwood, Mansfield, Gedling, Nottingham, Ashfield and Bassetlaw LADs) and South Yorkshire (Rotherham and Doncaster LADs). The area contains major urban settlements, such as Nottingham and its satellite settlements, although it is mostly rural. Information on planned house building in the area is not included in the East Midlands Regional Economic Strategy.

Important arable crops in the region are wheat, barley, potatoes, sugar beet and oilseed rape. There is also extensive livestock-rearing. There are no commercial fisheries in the Torne, Idle or Trent, although there is exploitation of salmon in the Humber Estuary. Salmon spawning grounds are present in tributaries of the Trent (e.g. Derwent) upstream of the groundwater body.

Scope

The potentially affected geographical area is assumed to be:

- the area of the groundwater body itself;
- the lengths of the Torne and Idle.

The potentially affected population is the population of the affected geographical areas, as well as tourists and recreational visitors to these areas.

This is the only case study area where affected rivers flow out of the assumed actual groundwater body area. The populations of the Local Authority District of West Lindsey and the Unitary Authority of North Lincolnshire must also be considered when examining benefits related to river ecosystems.

5.6.2 Valuation

Estimation of benefits

Table 5.16 lists numerical estimates of the benefits provided by the Nottingham groundwater body that would be lost under a worst case scenario. Lines 2–4 in the table in italics explain the information which is noted in each line for each benefit.

Table 5.16 Benefits assessment summary for the Nottingham Sherwood groundwater body

Benefit	Benefit lost under worst case scenario	Result
	How impact and data assumptions vary from the default (Tables 5.3–5.12)	
	Benefit calculation (numbers)	*Result and unit*
	Any additional data sources used.	
B_1: Private	As default	
	$B_{1a}^{L} =$ (total private abstraction/average abstraction) × lower estimate cost of connection	
	$B_{1a}^{L} = \frac{0.03}{1.8 \times 10^{-4}} \times 540 =$	£90,000
	$B_{1a}^{H} =$ (total private abstraction/average abstraction) × higher estimate cost of connection	
	$B_{1a}^{H} = \frac{0.03}{1.8 \times 10^{-4}} \times 8{,}890 =$	£1.5 million
	$B_{1b}^{L} =$ lower estimate AISC × no. days in year × daily total private abstraction	
	$B_{1b}^{L} = 400 \times 365 \times 0.03 =$	£4,400/year
	$B_{1b}^{L} =$ upper estimate AISC × no. days in year × daily total private abstraction	
	$B_{1b}^{L} = 1{,}200 \times 365 \times 0.03 =$	£13,000/year
	n/a	
B_2: Public	As default. Lower end estimates are probably more likely, as the Trent could act as an alternative source of water.	

Benefit	Benefit lost under worst case scenario	Result
	$B_2^L =$ lower estimate AISC × no. days in year × daily total public abstraction	
	$B_2^L = 400 \times 365 \times 115 =$	£16.8 million/year
	$B_2^H =$ upper estimate AISC × no. days in year × daily total public abstraction	
	$B_2^H = 1{,}200 \times 365 \times 115 =$	£50.4 million/year
B$_3$: Agriculture	n/a As default. Crops affected are wheat, barley, potatoes, sugar beet, oilseed rape and small fruit. $B_3 =$ sum over all crops of (area covered × average yield × price) Wheat: 52,020 × 7.7 × 73 Barley: 16,260 × 5.7 × 70 Potatoes: 3,700 × 41.8 × 107 Sugar beet: 6,500 × 54.4 × 32 Oilseed rape: 16,610 × 3.3 × 156 Small fruit: 130 × 17 × 20,000 Total =	£116.3 million/year
B$_4$: Industrial	n/a As default $B_{4a} = 0$	£0/year
	$B_{4b}^L =$ lower estimate AISC × no. days in year × daily total industrial abstraction	
	$B_{4b}^L = 400 \times 365 \times 20.1 \times 0.1 =$	£0.3 million/year
	$B_{4b}^H =$ upper estimate AISC × no. days in year × daily total industrial abstraction	
	$B_{4b}^H = 1{,}200 \times 365 \times 20.1 \times 0.9 =$	£7.9 million/year
	Unable to find specific information on whether any industries in the groundwater body area would be assumed to go out of business.	
B$_5$: Ground water dependent wet eco-systems	As default. (a) Coastal habitats not affected as the groundwater body does not touch the coast and the groundwater body is only one source of waters which eventually reach the Humber Estuary. No wetlands are affected by the groundwater body. (b) and (c) Unlike other case studies, only the populations of those LADs/UAs through which the Torne and Idle flow are relevant to the calculation of these benefits, rather than of all those which overlie the groundwater body.	

Benefit	Benefit lost under worst case scenario	Result
	$B^L_{5a} = B^H_{5a} =$	£0/year
	$B^L_{5b} =$ average value of fishing trip × lower estimate annual no. licensed fishing days	
	$B^L_{5b} =$ 2.83 × (445,200 × 10 + 16,800 × 8 + 126,600) × 0.03 =	£410,000/year
	$B^H_{5b} =$ average value of fishing trip × higher estimate annual no. licensed fishing days	
	$B^H_{5b} =$ 2.83 × (445,200 × 26 + 16,800 × 8 + 126,600) × 0.03 =	£1.0 million/year
	$B^L_{5c} =$ base flow index/0.1 × lower estimate per household annual value of preventing 10 per cent reduction × no. affected households	
	$B^L_{5c} =$ 0.05/0.1 × 1.30 × 377,000 =	£245,000/year
	$B^H_{5c} =$ base flow index/0.1 × higher estimate per household annual value of preventing 10 per cent reduction × no. affected households	
	$B^H_{5c} =$ 0.8/0.1 × 3.40 × 377,000 =	£10.3 million/year
	The LADs/UAs are Bassetlaw, Doncaster, Rotherham, West Lindsey and North Lincolnshire. These span the Environment Agency's North East, Anglian and Midlands Regions; hence the numbers in the bracket used to calculate B_{5b} are larger than in the other case studies.	
B_6: Ground water dependent terrestrial and coastal eco-systems	*Does not appear to be relevant for this groundwater body.*	
B_7: Aquaculture	*Does not appear to be relevant for this groundwater body.*	
B_8: Regulation of flood flow	*Does not appear to be relevant for this groundwater body.*	
B_9: Soil stability	*Not enough data for assessing the physical impact of the change.*	
B_{10}: Sink/ source heat	As default. Approximate projected new housing figures for the area did not seem to be available. A range is used of 10,000 (zero would almost certainly be inaccurate) to 100,000 (the largest number found for any of the other case studies).	

Benefit	Benefit lost under worst case scenario	Result
	B_{10a} = heating energy saved	
	× proportion of domestic energy used for heating	
	× (average domestic energy bill + social cost of carbon	
	× carbon content of energy)	
	× proportion of new-build houses to have heat pumps	
	× no. new-build houses	
	B_{10a}^{L} = 0.75 × 0.62 × (250 + 70 × 14) × 0.05 × 10,000 =	£59,000/year
	B_{10a}^{H} = 0.75 × 0.62 × (250 + 70 × 33) × 0.5 × 100,000 =	£59.5 million/year
	B_{10b}^{L} = - cost of installation	
	× proportion of new-build houses to have heat pumps	
	× no. new-build houses	- £3.2 million
	B_{10b}^{L} = -6,400 × 0.05 × 10,000 =	
	B_{10b}^{H} = -9,600 × 0.5 × 100,000 =	- £480 million
	As default. Information on expected number of new houses in the area does not appear to be available.	

Notes: [1]Although using the proportion 0.5 instead of 0.05 here would produce a lower figure for B_{10b}^{L}, the number of houses assumed has to be the same for both B_{10b}^{L} and B_{10a}^{L} in order for the final aggregation below to make sense. A similar argument applies for B_{10b}^{H}. Given a long enough payback period, the benefits of installing a ground source heat pump do outweigh the cost.

Aggregation

The following makes a big simplifying assumption that all benefits/losses happen over the same timescale (i.e. immediately from *t=0* to *t=T*) some time in the future. In reality, it would either take many years for some of the losses detailed above to materialise or they would be in an intermediate state before they reached their 'worst case' state; other losses would happen immediately.

This caveat aside, the aggregation of total benefits *B* over time would be as follows:

$$B_i = \sum_{t=0}^{t=T-1} \frac{B_{it}}{(1+r)^t}$$

$$B = B_{1a} + B_{10b} + \left[B_{1b} + B_2 + B_3 + B_{4a} + B_{4b} + B_{5a} + B_{5b} + B_{5c} + B_{10a}\right]\sum_{t=0}^{T-1} \frac{1}{(1+r)^t}$$

Using lower estimates above, with a timescale of 10 years (*T* = *10*) and a discount rate of 3.5 per cent (*r* = 0.035) gives (units of *B* and components are £million):

$$B^L = 0.1 - 3.2 + \left[4.4 \times 10^{-3} + 16.8 + 116.3 + 0 + 0.3 + 0 + 0.4 + 0.2 + 0.06\right] \times 8.61$$

$$B^L = -3 + 1{,}154 = 1{,}151$$

$$B^H = 1.5 - 480 + \left[1.3 \times 10^{-2} + 50.4 + 116.3 + 0 + 7.9 + 0 + 1.0 + 10.3 + 59.5\right] \times 8.61$$

$$B^H = -479 + 2{,}113 = 1{,}635$$

5.7 Summary of case studies

5.7.1 Comparison of case studies

Table 5.17 compares the relative size of the different components of value of the case study groundwater bodies expressed in proportion to the corresponding component of value provided by the Hampshire groundwater body. For example, the value of agricultural abstraction has been calculated as 3.2 times greater for the North Kent groundwater body than for the Hampshire groundwater body. The table also provides an explanation of these differences.

Table 5.17 Summary of size of benefit components expressed in proportion to the Hampshire groundwater body

Benefit/ component	Component symbol	Size of benefit[1]			Explanation
		Lincs	North Kent	Sher-wood	
Private abstraction – all	B^L_{1a}, B^H_{1a}, B^L_{1b}, B^H_{1b}	0.01	0.6	0.04	There is little private abstraction from the Lincolnshire and Sherwood GWBs.
Public abstraction – both	B^L_2, B^H_2	0.3	0.4	1.0	The Hampshire and Sherwood GWBs are the most important for public water supply among those studied.
Agricultural abstraction	B_3	2.9	3.2	1.9	The Lincolnshire and Sherwood areas have a greater proportion of arable farmland, while North Kent grows more higher market value small and top fruit.
Industrial abstraction					
Maintaining high-water use businesses	B_{4a}	0	9.0	0	North Kent has a higher number of high water-use businesses; none identified in Lincolnshire and Sherwood.[2]
Avoiding cost of connection to public water supply	B^L_{4b}, B^H_{4b}	0.2	0.6	1.3	Nottingham has the highest total amount of industrial abstraction.
Groundwater-dependent wet ecosystems					
Maintaining wetlands – low	B^L_{5a}	15	90	0	The Hampshire GWB supports very little wetland. Without including the Wash in the calculation for the Lincolnshire GWB, Kent supports the most.

Benefit/ component	Component symbol	Size of benefit[1]			Explanation
		Lincs	North Kent	Sher-wood	
Maintaining wetlands – high	B^H_{5a}	569	148	0	Including the whole Wash in the calculation for the Lincolnshire GWB massively increases this component.
Maintaining angling opportunities	B^L_{5b} , B^H_{5b}	1.5	0.5	0.7	The proxy for the annual number of fishing trips shows this to be highest for the Lincolnshire GWB.
River amenity through maintaining flow levels	B^L_{5c} , B^H_{5c}	0.9	0.3	0.7	As actual BFI data were not available, these differences relate solely to the estimated affected population.
Aquaculture	B_7	0	0	0	Existence of aquaculture in the other case studies was not established.
Sink/source of heat – all	B^L_{10a} , B^H_{10a} , B^L_{10b} , B^H_{10b}	1.2	0.6	n/a[3]	The greatest amount of new housing is predicted in the Lincolnshire GWB area (particularly near Corby and Northampton).
Total					
Low	B^L	1.1	5.2	0.8	The North Kent figures are high mainly because of the loss of the paper mills and significant wetlands. Wetlands are also important in making the Lincolnshire figures a little higher and the Sherwood figures a little lower. The Lincolnshire case study also contains significant house building.
High	B^H	2.0	3.9	0.8	

Notes: [1]In proportion to the Hampshire groundwater body.
[2]This does not mean that such businesses do not exist; just that they were not identified during the time allotted for the case studies.
[3]Housing forecast figure was not available.
GWB = groundwater body

As Table 5.17 shows, some of the differences in the components of value can be attributed to very real differences in the groundwater bodies or their surrounding areas. Other differences are artefacts of the way in which surrogate data were used in some elements of the calculations due to a lack of real data.

Of particular note is the fact that the Hampshire case study has the lowest value for agricultural abstraction despite abstracting the largest actual amount of water for agricultural purposes. This could be for a genuine reason – that Hampshire has a lot more livestock-rearing and less arable farming than the other regions – or it could be because it was not possible to obtain gain real information on actual agricultural abstractors, thus making it necessary to introduce simplifying assumptions about how farming would be affected in the area instead.

5.7.2 Lessons learnt and recommendations

A number of lessons were learnt from these case studies, which may need further reflection before any original benefit assessment exercises are commissioned. While the case studies may seem detailed, the estimation of many benefits is simplified and only very rough estimates of the order of benefits could be produced given the time and information available. Even with this simplified approach, however, the indication is that benefits are significant (and certainly not zero), with little use of non-use values.

Understanding of physical impacts

An extensive application of the case study methodology to a real groundwater body would need a much fuller understanding of the physical causal mechanisms at work. In particular:

- Not all the benefits of a groundwater body may be affected by a given pressure on water quality or quantity exacerbated or reduced by a particular policy. The alternative state to the groundwater body existing in its current or projected state is not for a void to appear in its place, but for it to exist in a degraded or improved form. For example, even a groundwater body that was totally polluted and which was so over-abstracted that the ground on top of it had subsided might still provide some benefit in soaking up rainwater which may otherwise cause a river to flood. If it is not possible to simultaneously turn all the benefits 'on' or 'off', there can be no 'total value' figure that applies to all circumstances. A change in value always relates to a particular change in pressures. But for the purposes of demonstrating the benefits, it was necessary to make such a simplifying assumption in the case studies.
- For this reason, identification of the hypothetical change of interest would be essential before carrying out a valuation. A good understanding of the physical and ecological consequences of a change in a particular pressure greatly increases the accuracy of any subsequent economic valuation.
- When considering the impacts of a change to the quantity or quality of groundwater on either surface water-dependent or groundwater-dependent ecosystems if that ecosystem is to be irrecoverably altered, a greater understanding of what may replace it would produce more accurate estimates of the 'net' loss of benefits. This point relates to the two points above.
- Calculation of a baseline requires an understanding of trends in pressures such as abstraction, urbanisation, climate change and intensiveness of farm inputs which it was not possible to obtain for these simplified case studies. In reality, the baseline is unlikely to be static. The case studies effectively assume that the pressures on the groundwater body remain identical over the course of the period under consideration.
- A lack of both full information on the physical causation of how benefits would be affected and a realistic change scenario meant that assumptions on the timing of benefit impacts were greatly simplified. This method – assuming that benefits are either one-off or continual and constant, and in either case starting in the first year – is unrealistic and not recommended in the event of a full study.

- The case studies had to exclude some of the benefits of groundwater due to a lack of scientific understanding of the processes that lead to these benefits. See Section 6.2 for further details.
- Much of the above – to a greater or lesser extent – show the dependence of economic valuation in general on a solid understanding of the physical changes in the quality and quantity of the environmental resource of concern, and are not specific to the case of groundwater.

Information management

Benefits assessment is complex due to the different spatial and temporal scales on which many of the benefits operate. This can result in considerable information being required for a full assessment of benefits. A single valuation study is likely to have the scope to collect more precise information, while a benefits transfer exercise is more likely to focus on a single benefit type. In the case studies above, however, there are different populations for different benefits owing to the fact that the benefits of groundwater can stretch far away from the body itself via rivers which have benefits of their own.

Furthermore, information on populations is not always immediately available at the right spatial scale or resolution. For example, it may be useful to have Census data available by catchment area as well as by LAD. Information such as the amounts abstracted by different industries could be obtained from Environment Agency staff in charge of abstraction licences.

The case study exercise has shown the importance of good information management in any future similar valuation exercise. The use of spreadsheets is recommended to:

- collate and manipulate the information according to the formulae used;
- perform sensitivity analyses.

In some cases, the case study was not able to take into account the existence of substitutes for groundwater-dependent ecosystems. The amenity, recreation and biodiversity benefits of a river or wetland are less if there is a substitute for it nearby. It may be possible to assess the details of how people's behaviour might change if the river or wetland was degraded. However, this was not possible at this level of analysis.

A perhaps more important recommendation is to prioritise the effort to acquire information according to the likely magnitude of benefits. If it is known that a benefit is small relative to other benefits, there is little merit in spending time trying to fine tune any initially crude economic value estimate. Groundwater-dependent wetlands, heavy industry and agriculture are likely to contribute significant components of value; private abstraction and (surprisingly) angling less significant – though very important to the individuals concerned.

The extrapolations of marginal values used here for the totality of the benefit affected results in potentially large underestimates of the value of each groundwater body. The important lesson to take from these case studies is not the valuation figures themselves, but that the value of each groundwater body is substantially more than zero.

6 Gaps and recommendations

6.1 Overview

The purpose of the study was to develop a framework for the valuation of groundwater, not to calculate 'off-the-shelf' values which could be used to demonstrate that value for different groundwater bodies. Any valuation figures that have been generated for the case studies are by necessity incomplete, subject to a variety of simplifying assumptions, and physically unrealistic. However, they have been useful in:

- demonstrating the technique;
- illustrating the order of magnitude of value that might be expected from a more rigorous study;
- flagging up some of the data and conceptual issues in advance of any real benefits assessment exercise.

It is likely that the economic value of groundwater is significant without much inclusion of non-use values, which only appear in the case studies in the wetland and river amenity components. Groundwater bodies that provide a substantial contribution to surface water ecosystems, dependent heavy industry and agriculture are likely to be more valuable than those which do not.

6.2 Gaps

The case studies highlighted the following potential data gaps in any future benefits assessment:

- **Carbon sequestration.** This was left out of the case study benefits assessment altogether because no scientific studies were found on how much carbon groundwater bodies actually sequester.
- **Regulation of flood flow.** This study was not able to relate changes to a groundwater body to changes in how it might provide this function. Any future assessment that included this benefit would also need information on the baseline flood risk in the area.
- **Prevention of subsidence.** No scientific studies relating subsidence to groundwater in the UK have been carried out. Therefore there appears to be a lack of understanding in how much would have to be abstracted from a given UK groundwater body for this to be a risk worth considering in a benefits assessment.
- **Wet woodlands.** There are no specific valuation studies of wet woodlands, although benefits transfer could be used from studies on other types of woodland. More importantly, there was no information available on the areas of wet woodland in each case study area.
- **Coastal habitats.** There are valuation studies for coastal habitats and market proxies can be found for alternative investments for erosion control. However, it is not clear from this study how easily they could be transferred to the types of changes to these habitats brought about by changes in groundwater. The scientific understanding of this (if clear to specialists) would need to be made clearer to the economist.

- **Affected population.** This is often difficult to estimate as population data are not readily available in the same geographical units as benefits, i.e. they are on a local authority district/unitary authority basis rather than a 'river length' basis. Such data could be reconfigured by the researcher, but the process would be time-consuming.

This list shows that there are gaps in:

- scientific understanding;
- terms of data being in an easy-to-use format;
- terms of economic value estimates.

Not all of these gaps would be 'significant' because the benefit types likely to make a significant change to the benefit assessment of CBA should be given priority. 'Significant' here would apply to cases where, say, the recommendation of a CBA would change (e.g. NPV from negative to positive or vice versa) if a benefit category was added.

Even when significant gaps in information are identified, it does not necessarily follow that the gap should be filled by research commissioned by the Environment Agency. The discussions contained in this report and the experience of the case studies could be used to influence the research agendas of related policy areas – especially the Collaborative Research Programme for the Water Framework Directive.

6.3 Recommendations

The benefits transfer used in the case studies in estimating the components of value attributable to groundwater-dependent ecosystems was the simplest kind described in Section 3.3.4, i.e. transferring figures unadjusted for any characteristics of the local population for whom they apply. It is recommended that the more sophisticated techniques described in that section are used in future applications of the methodology.

In any benefits assessment aggregation, some benefit estimates may be missing. However, they may not be relevant – either because they are likely not to be 'material' or because the decision-making context or the quality/quantity change itself does not affect a particular benefit type.

For cases of remediation of contamination, any consideration of the benefits of remediation versus the cost of contamination should include the costs and benefits to other parties – possibly well beyond the immediate geographical location of the contamination – as well as the benefits to the site holder.

For more strategic needs for benefit assessment (e.g. the Water Framework Directive), the analysis should not only include the benefits of improving the quality of groundwater but also incorporate the interactions between surface and groundwater bodies.

A more strategic analysis of the costs and benefits of a project or policy affecting groundwater should not be limited to the effects of the decision in hand. It should also consider:

- interactions of the groundwater with surface waters;
- cumulative effects of all related policies and projects;
- changes over time and over geographical area.

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List of abbreviations

AISC	Average Incremental Social Cost
BAG	benefits assessment guidance
BAP	Biodiversity Action Plan
BCR	benefit cost ratio
BFI	base flow index
CAMS	Catchment Abstraction Management Strategy
CBA	cost–benefit analysis
CE	choice experiment
CS	consumer surplus
CV	contingent valuation
DC	dichotomous choice
Defra	Department for Environment, Food and Rural Affairs
DWU	drinking water utility
E(*CS*)	expected consumer surplus
EIA	environmental impact assessment
EU	expected utility
ha	hectare
hh	household
HIA	health impact assessment
LAD	Local Authority District
LB	lower bound
LCA	life-cycle analysis
ML(/d)	megalitres (per day)
NPV	net present value
OE	open-ended
ONS	Office for National Statistics
OP	option price
OV	option value
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SD	standard deviation
SPA	Special Protection Area

SSSI	Site of Special Scientific Interest
TEV	total economic value
TWTP	total willingness to pay
UA	Unitary Authority
WFD	Water Framework Directive
WTP	Willingness to accept [compensation for]
WTP	Willingness to pay

Glossary

Altruistic value	Willingness to pay of person A for the continued enjoyment of person B's use of environmental resources.
Avertive expenditures (or avoidance cost)	Expenditures undertaken to avoid or mitigate the impacts of pollution.
Consumer surplus	The difference between the amount paid for a good or service (price), and the maximum amount that an individual would be willing to pay.
Contingent valuation	A survey technique used to derive values for environmental change by estimating individuals' willingness to pay (or to accept compensation) for a specified change in the quality of quantity of a resource.
Cost–benefit analysis	A form of economic analysis in which costs and benefits over time expressed in monetary units are compared.
Discounting	Converts costs and benefits occurring at different points in future into comparable units of today (present value).
Existence values	Values that result from an individual's desire to ensure that an environmental asset is preserved for its own sake (a type of non-use value).
Externalities	Changes that are not reflected in actual market prices; uncompensated impacts that affect third parties. Goods that remain unpriced and thus are external to the market (i.e. free goods such as those relating to the environment, with an example being pollution).
Financial analysis	Aimed at determining the cash flow implications of a policy or a project to the commissioning organisation.
Hedonic pricing method	An implicit price for an environmental attribute is estimated from consideration of the actual markets influenced by the quality and quantity of the environmental resource of concern (e.g. water quality improvements and property values).
Marginal	A small change in a quantity in relation to another quantity, frequently defined by the first derivative. For example, the 'marginal cost of production' is the cost of producing an additional unit of output.
Market price approach	In a perfectly competitive market, the market price of a 'good' provides an appropriate estimate of its economic value. In markets that are not perfectly competitive, economic value is calculated by removal of subsidies or other price distortions.
Net present value	The present value (i.e. in year 0) of the difference between the discounted stream of benefits and the discounted stream of costs.
Non-use value	Values that are not related to direct or indirect use of the

	environment (existence, altruistic and bequest values).
Opportunity cost	The value of a resource in its next best alternative use.
Option value	Value to a consumer of retaining the option to consume a 'good'.
Replacement costs	Impacts on environmental assets are measured in terms of the cost of replacing or recreating the asset.
Total economic value	The sum of use values (direct use, indirect use and option) plus non-use values (altruistic, bequest and existence).
Transfer payment	A payment for which no 'good' or service is obtained in return, e.g. a tax or subsidy.
Travel cost method	The benefits arising from the recreational use of a site are estimated in terms of the costs incurred in travel to the site.
Uncertainty	Stems from a lack of information, scientific knowledge or ignorance and is characteristic of all predictive assessment.
Use value	A value related to the actual direct or indirect use of the environment (e.g. recreational values).
Willingness to accept (WTA) compensation	The amount of money an individual would be willing to accept as compensation for forgoing a benefit or tolerating a cost.
Willingness to pay (WTP)	The amount of money an individual would be willing to pay to secure a benefit or avoid a cost.

Annex 1: Value, cost and price

Three terms — value, cost and price — are often used interchangeably. However, these terms have distinct meanings in economics, which in turn have important implications for how available 'valuation' data can and should be interpreted. These terms arise in the context of their roles in the 'market'. This Annex provides an analysis on the differences between value, cost and price.

Value

Value is a fundamental concept in the field of economics and, while related, is distinct from the concept of price. In economic parlance, the worth, or value, of a commodity is defined in terms of the quantity of other commodities, or money, one is willing to give up to acquire the good of interest. In modern economies, money is typically the unit of exchange. Value depends on the desirability and need of the good, while price also depends on its relative scarcity.

The concept of value can be expressed by two common terms of welfare economics:

- willingness to pay (WTP)
- willingness to accept (WTA).

WTP is defined as the amount of money, or other goods, an individual would be willing to pay to acquire the good (in this case, a specific quantity and quality of water). WTA is the quantity of money, or goods, that an individual would be willing to accept to give up the good.

WTP and WTA can be driven by any number of characteristics of the good, such as quality, timing and location. These attributes are all important factors in the value of water. For example, all other things being equal, one would likely be willing to pay more for high-quality potable water than for the same quantity of lower quality water.

Whether WTP or WTA is the correct measure of value depends on the issue of property rights. If one currently holds rights to the good, such as water rights, then the amount that one is willing to accept to give up those rights is the correct measure of value. Whereas when one is trying to acquire the rights, WTP is considered the correct measure of value. Therefore, while value may be driven by the quantity and quality of a good, it is also related to the rights of the individual seeking to either acquire or relinquish the good.

To more fully understand the concept of value and its relationship to price, it is necessary to appreciate the idea of 'consumers' and 'producers', or suppliers, of water. From the consumer's perspective, the 'demand' for water is simply a tracing of an individual's willingness to pay for (i.e. preference for or value placed on) different quantities of water, holding all else equal. People place the highest value on the first unit of a good they seek to consume. For water, the highest value is presumably assigned by consumers to the quantity required to meet their family's drinking and related needs for basic survival.

Typically, the next marginal unit of water provides less value to individuals than the previous unit. For each customer, the value of each next unit of water tends to decrease as more water is consumed because, after the highest value applications are satisfied (e.g. for basic needs such as human consumption and bathing), subsequent quantities of water go to less valued applications (e.g. lawn irrigation). Hence, the 'demand curve' for water — as for most goods and services — slopes downward in a typical ‘quantity versus value’ diagram (where value or price is on the vertical axis and quantity is on the horizontal axis).

Demand curves can be for an individual, a group of people, or society. A demand curve for an individual shows what he or she is willing to pay for various quantities. An aggregate demand curve represents what a group is willing to pay for various quantities; it is the summation of individual demand across the group. Thus, the area-wide residential demand curve for water faced by a given water company is an aggregate demand; it can be represented by the horizontal summation of individual household water demand curves whose slope and position vary, in part, due to differences in household characteristics.

In turn, individual household water demand equals the horizontal summation of household components of demand. It is categorised here as basic necessity indoor demands, indoor discretionary demands, and outdoor discretionary demands (hereafter, landscape irrigation demands). Figure A1.1 shows the components of household water demand and how they combine to portray a household’s overall or aggregate demand curve for water.

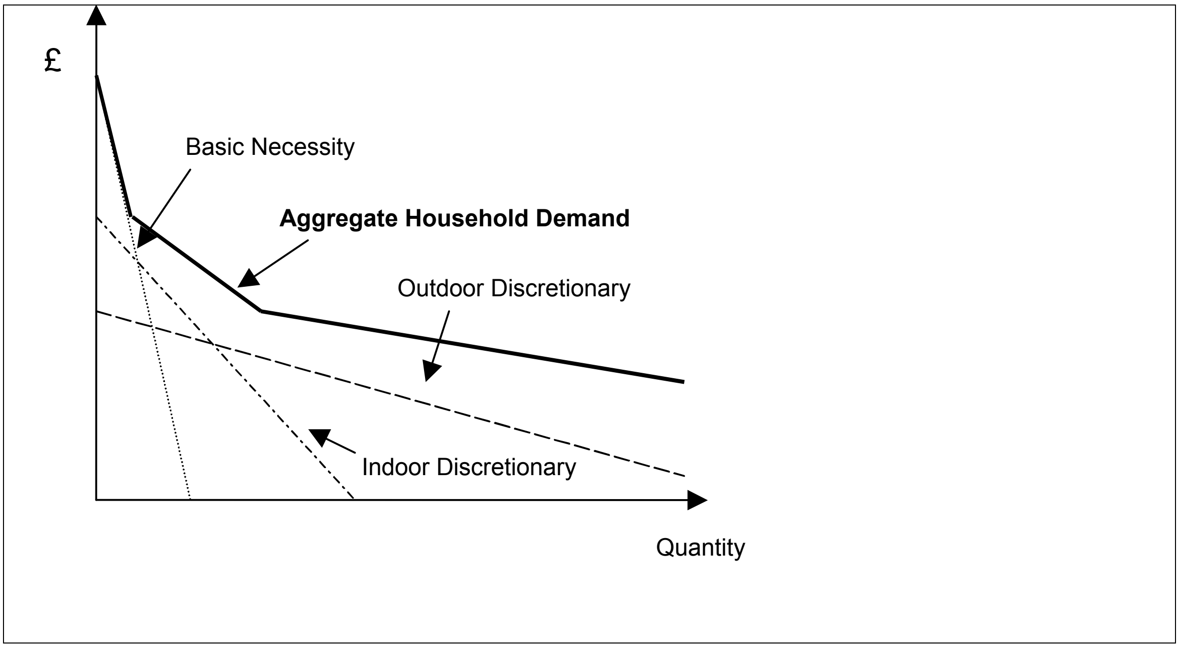

Figure A1.1 Components of household water demand

Cost

A number of factors contribute to the cost of providing water to customers. This cost often becomes the basis for the price of the water charged to customers. The total cost of water supply or clean-up can be divided into two main factors:

- internal (or market) costs;
- external costs, which could be both market and non-market (outside the actual markets).

Internal costs include:

- variable costs associated with the expense of operation and maintenance of supply and clean-up facilities;

- fixed costs for capital outlays in infrastructure (e.g. pipes, treatment plants and land) and water rights or abstraction licenses (where applicable).

Fixed costs do not vary with the quantity of water provided. Variable costs (e.g. chemical, labour or pumping cost) do vary with the quantity of the water provided.

These internal costs often do not reflect the full cost to society of water supply, because the full social costs need to reflect the opportunity costs, i.e. the returns or value that would otherwise be obtained from allocating water to its best alternative uses (e.g. cropland irrigation). These opportunity costs increase as more water is diverted from other uses (as water is diverted from uses that have increasing values of their own such as from low value crops to higher valued returns on irrigation). In summary, demand is a driver of cost. If there is a drought or an unanticipated increase in population, the quantity demanded of water will increase, as will its price.

In addition to opportunity costs for the resource itself, full social costs of water supply should include any 'externalities'. Externalities are third party impacts not compensated by the market such as environmental damage that may occur because of excessive reductions in quantity or quality of surface or groundwater as well as non-water environmental impacts of supply and clean-up (e.g. energy use and related emissions to air, visual impact and transport, etc.). External costs can be:

- 'market' costs, e.g. reduction in the yield of a crop (financial revenue from that crop) or extra spending on water treatment due to quality degradation;
- 'non-market' costs, e.g. the effect of changes in the water quality and flow on informal recreation opportunities.

Water companies and regulators typically seek to minimise the full social costs to their customers, and so provide water in a manner that takes advantage of their least cost supply options. In England and Wales, this is assessed by calculating the Average Incremental Social Cost (AISC) through the Periodic Review process.

A company will therefore first tap and deliver sources that require relatively little pumping or treatment. If demand grows to exceed the lowest cost supply option, then the company will add its next lowest cost option to meet the next increment of demand. This results in a de facto water supply curve that might resemble an upward sloping curve. The sequencing of the supply options depends on the cost of providing that block of supply. As increasing quantities are needed to meet the demands of a growing community, companies often find that they face increasing costs to supply each new increment of demand. This is illustrated in Figure A1.2.

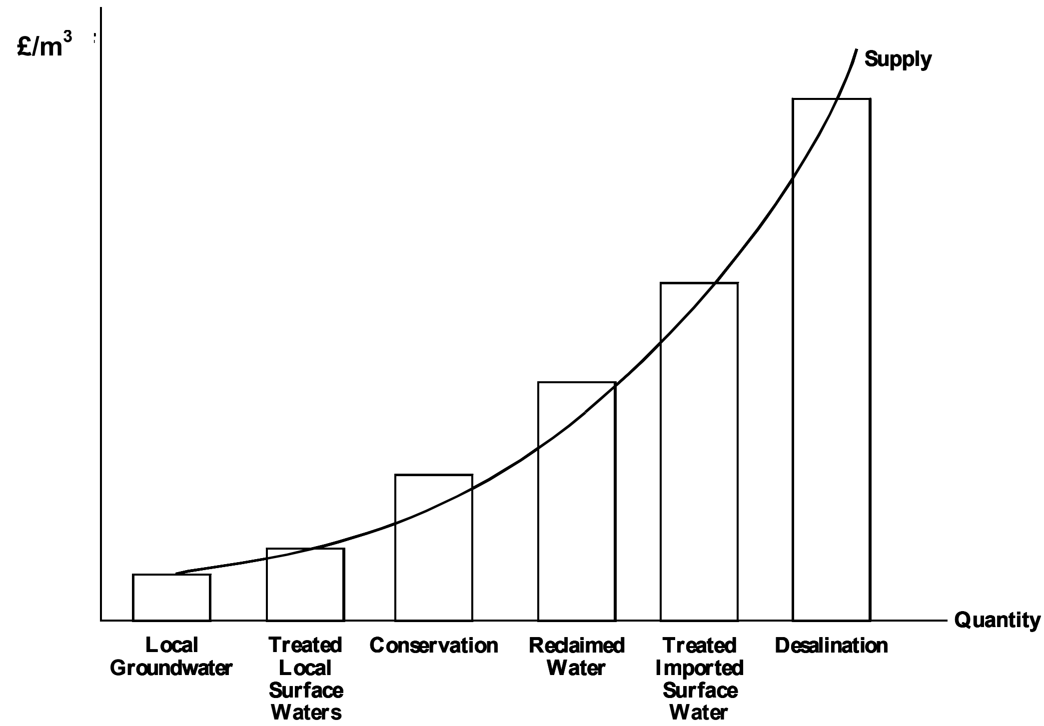

Figure A1.2 **Cost of options for delivering potable water shapes a water company's supply curve**

Price

In a market, a price is determined by where the supply and demand curves intersect. At this unique market-clearing point, price, cost and value are all equal (when quantity is Q* in Figure A1.3). However, the terms still represent different concepts and, at all other quantities of water supplied, the cost and value (WTP) have different monetary values.

In markets where there are many suppliers and consumers, price is often considered to be a good estimate of the marginal value of the good to both consumers and producers. It is thus considered economically efficient to allow the market process (i.e. prices determined in competitive market) to dictate the allocation of resources. However, even in these markets, there will be quantities of water for which an individual would be willing to pay more for than the market price, or in the aggregate there will be consumers who would be willing to pay more than the market price. Getting water at a price lower than one's WTP is known as consumer surplus, denoting the benefit gained through the difference between the market price and WTP.[19]

[19] There is also an equivalent concept for suppliers, i.e. producer surplus, which is the difference between the market price and suppliers' WTA for a given quantity of water when price exceeds what suppliers are willing to sell at. Consumer surplus is more relevant to the discussion here.

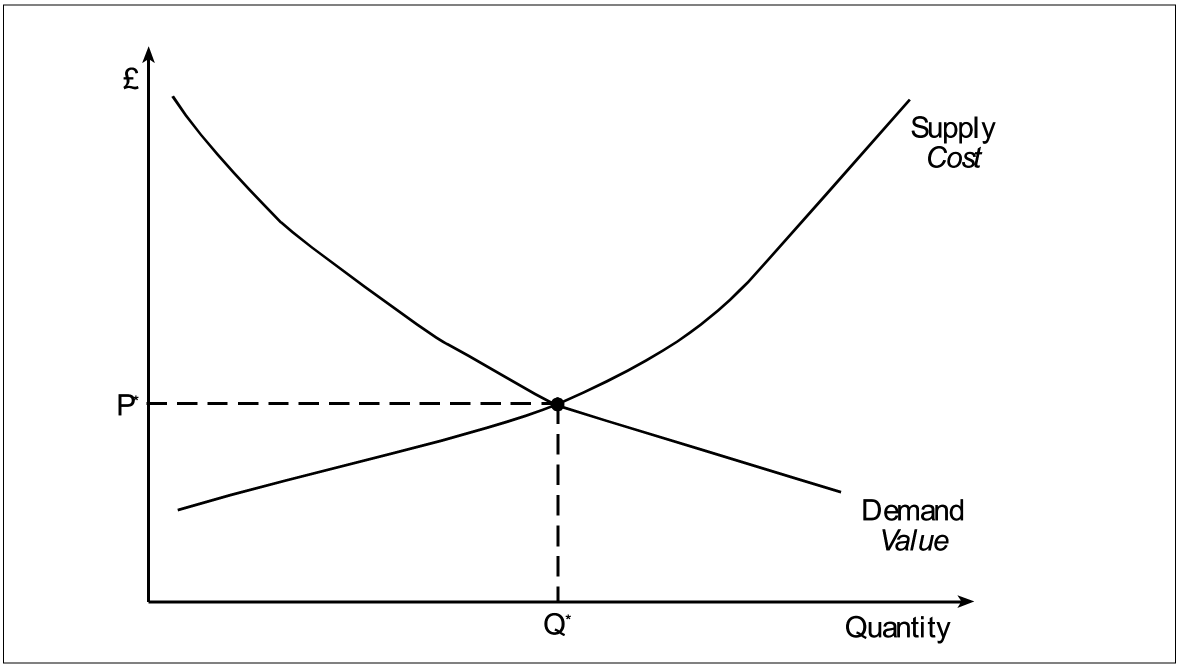

Figure A1.3 **Supply and demand: price relative to value and cost**

Annex 2: Option value

A2.1 Valuation concepts

This study is interested in determining total economic value of an environmental change in an uncertain world. In such a world, there is risk or a positive probability of a less desirable outcome. The increased risk of groundwater contamination is a relevant example:

$$TEV = \mathrm{E}(CS) + OV$$

where:

E(*CS*) is the expected consumer surplus (CS) from current and anticipated future active use (which may include bequest values), where the future states of nature may be unknown;

OV is option value – a value measure discussed in this Annex.

Consumer surplus is the amount of money someone is willing to pay over and above what they have to pay for a good or service, and is the relevant measure of net benefits on a per person basis.

In the presence of risk, an individual maximises 'expected' utility (EU). Assuming the axioms of EU as satisfied, one can maximise EU subject to the usual budget constraint. In other words, consumers voluntarily make decisions, subject to their incomes, that make them the most well off. In this framework, one of the often-discussed welfare measures is E(*CS*), which is simply the probability-weighted *ex post* consumers' surpluses summed together over the risky states of nature (e.g. whether a groundwater source is available in an uncontaminated state or not). The problem is that *ex post* surplus calculations imply resolution of the uncertainty and, thus, the measure is of limited use in practice. In other words, it is the *ex ante* values that are relevant to valuing policies that address future risks. Consumer's surplus estimates should reflect both the risk and the *ex ante* fact that the outcomes are unknown at the time of valuation. (This paragraph is adapted from Jakus *et al*. 2003).

Weisbrod (1964) was the first to argue that, when uncertainty is present, a person's maximum willingness to pay to ensure access to an environmental resource may exceed E(*CS*). These values reflect a risk premium households are willing to pay for the availability of water if there is an emergency need to use the water such as an extended drought or dramatic increase in demand. *OV* reflects a value other than expected future use values. Even if water is not used at all in any given period, water users may have OVs for its availability. Option value is thus the amount (above any use value) that an individual would be willing to pay to ensure that the water resource could be used in the future – regardless of whether a current user – because of uncertainty regarding future income or tastes (i.e. demand uncertainty) or future availability of suitable water quality at the site (i.e. supply uncertainty).

Buffer value

The term buffer value, for example, has been used to describe the gains realised by the use of groundwater to 'mitigate undesired fluctuations in the supply of surface water' (Tsur and Graham-Tomasi 1991).
This is the same concept as OV (e.g. Weisbrod 1964, Fisher and Raucher 1984). In the context of conjunctive use, groundwater resources often provide

a back-up source of water (e.g. for irrigation) in years when surface supplies cannot meet demands (e.g. in drought years when surface supplies are below normal, or in years when demands may be above average, or both). In effect, this type of buffer benefit is also reflective of storage value because the groundwater stock reflects past surface water (including rainfall) that is held in reserve until years in which the water demands exceed surface supplies. Therefore, analysts should again be aware that often the same element of economic value may have different labels. The key for practitioners is to make sure that all the legitimate and important benefits are identified and included where feasible, so that there is neither a double counting of benefits nor the omission of potentially important benefits.

Option price

The option price (OP) has been found to be the most desirable welfare measure of uncertainty because it incorporates the idea that an *ex ante* payment could be made prior to the resolution of uncertainty. Graham (1981) was one of the first to define OP in the context of collective risk and provision of a public 'good' such as clean water source.

OP can be defined as the maximum amount that the consumer would be willing to pay now for an option to use the services of a public good at some designated future date. It is the sum of the expected value of consumer surplus, E(*CS*), from using the resource **plus** OV that accounts for uncertainty in demand or in supply. Thus, in this model (where TWTP is total willingness to pay):

$$OP = TWTP = \mathrm{E}(CS) + OV$$

Put simply, if preferences are stable over time and there are no income effects (i.e. there is no demand uncertainty), then OV will be positive and TWTP > E(*CS*) (Bishop 1982). That is, when the source of uncertainty is on the supply side of the ledger OV > 0. For the source of demand uncertainty that seems most relevant for water-quality-related analyses, OP will exceed E(*CS*) (Freeman 1983).

Zeckhauser (1970), Cicchetti and Freeman (1971), Krutilla and Fisher (1975) and Fisher (1981) examined the effects of uncertainty about the future demand for the services of a resource, with some mention of the effects of supply uncertainty. They found that risk-averse individuals (those who value a fair bet less than the weighted value of the outcomes) will be willing to pay a premium above their expected consumer surplus to ensure their to a particular public good. Thus, risk-averse behaviour also implies a positive OV, which is an intuitive outcome.

A2.2 Groundwater valuation studies

For non-user benefits such as option value, there may be no techniques for inferring public 'good' demands and benefits from market data. In these cases, it is necessary to rely on alternatives such as stated preference surveys (Freeman 1979).

Numerous contingent valuation studies of groundwater have been conducted where survey respondents are essentially asked to make hypothetical choices. The valuation scenarios in these studies have typically elicited TWTP responses for reducing the probability that groundwater resources would be contaminated or for remediating contaminated groundwater resources. Therefore, most of the values from these studies are OPs for future use. It is generally difficult, if not impossible, to disentangle E(*CS*) from OV because the likelihood of active use under different states of nature is unknown.

Results of these studies show that groundwater values vary quite significantly by location and survey sample. The studies show that option prices held at the household level for clean groundwater resources can range from tens to hundreds of dollars per year. However, the factors that determine the suitability of valuation estimates for benefits transfer applications caution against directly incorporating these results to estimate potential values. For example:

> 'Groundwater values obtained from both indirect and direct methods are dependent on the specific groundwater management context. Attempts to generalise or transfer values from one context to another should be pursued with caution' (National Research Council 1997, p. 95).

A2.3 Inability to separate expected willingness to pay from option value

As discussed, option value is an important component of total value and is the value to have the resource available for use in the future, regardless of whether it is currently being used. Essentially, option value is how much someone is willing to pay to eliminate the risk of loss of the resource. Expected WTP, E(*WTP*), is the weighted mean value for current use when it is not known if the resource would in fact be used during the current period. When OV is added to E(*WTP*), it equals option price (OP).

The total value of groundwater is often estimated using a stated preference method (e.g. contingent valuation or choice experiments) whereby respondents state their TWTP for improved groundwater conditions. Typically, hypothetical scenarios are presented where respondents are asked to provide either a value for avoiding some specified level of risk to groundwater or a value for a contaminated groundwater body that might otherwise have been available for current or future use.

In both cases, surveys are used to elicit option price.

While conceptually and theoretically option price is the sum of the two components, in practice it is not possible to query respondents in such a way to make it possible to disentangle the two sources of benefits. Or at a minimum, it simply has not been attempted. To obtain reliable estimates of each component, much more about risk profiles and expected use would need to be known than is usually the case. Ultimately, however, this may not matter because option price is the theoretically correct estimate of total economic value.

Annex 3: Literature list

This Annex lists the results of a literature search undertaken for this study. Conceptual studies as well as economic valuation and appraisal examples from the UK, USA, Europe, Australia and the rest of the world are included. A sub-selection of these studies is summarised in Annex 4 to illustrate different approaches to various quality and quantity changes influencing groundwater.

By relevance

General

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UK

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UK: related studies

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North America

North America: groundwater studies

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Australia

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Rest of world

Rest of world: groundwater studies

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Annex 4: Review of selected studies

This section contains summaries of a selection of economic valuation studies (Table A4.1) to illustrate how the methods have been used to address issues influencing the quality and abundance of groundwater.

Table A4.1 Selected economic valuation studies

Reference	Scope
Rinaudo *et al.* (2005)	Testing the likely impacts of Water Framework Directive
Garrod *et al.* (2000)	Implementing stated preference method for a real and recent decision making context for the UK water sector.
Hasler *et al.* (2005)	Using both contingent valuation and choice modelling.
Stevens and Krug (1995)	Testing a groundwater policy option.
Randall *et al.* (2001)	Estimating the ecosystem-related benefits of groundwater with implications for the assessment of Water Framework Directive.
Lichtenberg and Zimmerman (1999)	Assessing farmers' willingness to pay for a policy similar to possible national measures for Water Framework Directive.
Epp and Delavan (2001)	Introducing the element of risk of failure to the value estimation for groundwater protection policies.
Brox *et al.* (2003)	Estimates the value trade off between urban development and its effects on groundwater quality.
Bergstrom *et al.*(2004)	Tests the effect of different payment methods on willingness to pay to reduce nutrient pollution in an area heavily dependent on groundwater.
Travis and Nijkamp (2004)	Presents contaminated land and groundwater simultaneously.

Rinaudo *et al.* (2005)

Study reference

Rinaudo J D, Arnal C, Blanchin R, Elsass P, Meilhac A and Loubier S, 2005 Assessing the cost of groundwater pollution: the case of diffuse agricultural pollution in the Upper Rhine valley aquifer. *Water Science and Technology*, 52 (9), 153-162.

Abstract

This paper presents an assessment of the costs of diffuse groundwater pollution by nitrates and pesticides for the industrial and the drinking water sectors in the Upper

Rhine valley, France. Pollution costs that occurred between 1988 and 2002 are described and assessed using the avoidance cost method. Geo-statistical methods (kriging) are used to construct three scenarios of nitrate concentration evolution. The economic consequences of each scenario are then assessed. The estimates obtained are compared with the results of a contingent valuation study carried out in the same study area 10 years earlier

Groundwater asset

The study focused on the Upper Rhine valley aquifer, which covers over 4,200 km^2 between Germany and France. It has a reserve of approximately 45 billion m^3 of water and is one of the largest fresh water reserves in Europe. Around 3 million inhabitants of the Alsace and Baden region are directly dependent on this resource for their water supply.

Since the 1970s, the aquifer has become increasingly affected by diffuse nitrate and pesticide pollution, mainly due to agricultural intensification. Analysis of recent agricultural trends suggests that the area under intensive crops will continue to rise and experts expect diffuse pollution will continue increasing. The French authorities are increasingly concerned by the consequences on the local economy of further groundwater degradation.

Economic valuation methodology

The authors developed an innovative approach for constructing a baseline scenario as required by the Water Framework Directive.

The study combines the use of geo-statistical mapping and the avoidance cost method to assess the economic implications for anticipated water quality in 2015. The methodology involved two main steps:

- assessing the past damage costs of pollution;
- estimating future evolution of groundwater quality.

The first step involved assessing the damage costs of diffuse pollution for mains water uses for the period 1988–2002[20] based on:

- **Damage costs of past pollution for the drinking water sector.** These were estimated for each of the 28 drinking water utilities (DWUs) identified as being affected by nitrate/pesticide pollution in the area (collectively supplying water to 432,000 inhabitants). Estimates of the financial costs of pollution between 1988 and 2002 were compiled from the reported market costs of the response strategies of each DWU, which included:
  - desertion or reduced exploitation of polluted boreholes without replacement;
  - replacement of polluted boreholes;
  - dilution of water extracted from polluted water borehole;
  - construction of a treatment plant;
  - co-operative agreements between farmers and DWU;
  - purchase of the borehole catchment area.

[20] Data prior to 1988 were not considered to be fully reliable.

- **Household avertive expenditure.** This was calculated on the basis of findings of earlier national public opinion poll surveys of household water use. The following important assumptions were made:
  - Seventy per cent of inhabitants receiving tap water pumped in the aquifer consume bottled water (925,000 inhabitants.
  - The fear of presence of nitrates and pesticides in tap water explains only 12 per cent of the consumption of bottled water.
  - The 'average' bottled water drinker purchases 1.5 litres per day at a cost of €0.5.

  It was also assumed that the consumption of bottled water had linearly increased from 10 per cent in 1970 to 70 per cent in 2002.
- **Cost of pollution for industry.** These were assessed for three broad categories of industry:
- those not sensitive to nitrates and pesticides;
- those that are very sensitive;
- the food and beverage industry, where water is used as a basic ingredient, and which needs to comply with drinking water standards.

  The food and beverage industry was subjected to more rigorous assessment with 32 semi-structured interviews undertaken to assess costs of past pollution, perceptions of current water quality and possible evolution.

The second step anticipated future evolution of groundwater quality in 2015[21] using the results from five surveys of groundwater quality undertaken in 1973, 1983, 1991, 1997 and 2003. Future damage costs were assessed using a spatial representation of the expected future nitrate concentration using the Kriging estimates method. Three different scenarios were constructed using the maps as a basis for extrapolation:

- scenario 1 assumed average yearly concentration will remain equal to value observed between 1997 and 2003;
- scenario 2 takes into account the error of the Kriging estimation process;
- scenario 3 is similar to scenario 2 but assumes the concentration evolution rate is equal to the value observed between 1997 and 2003.

A geo-referenced database was developed to estimate the anticipated socio-economic impact using all the economic entities located in the area where nitrate concentration was expected to exceed 40 mg/l in 2015. Assuming degradation as described in scenario 3, 37 DWUs were identified as being likely to be affected by nitrate and/or pesticide pollution.

Valuation context

This study serves to assess past costs of pollution damage incurred through diffuse groundwater pollution in the Upper Rhine valley aquifer between 1988 and 2002, and to forecast the possible future damage costs that could be avoided.

[21] Data constraints meant that only nitrate problem considered.

Valuation results

Based on the avertive expenditure method, the study calculates a lower bound estimate of costs incurred through diffuse groundwater pollution during 1988–2002:

- Costs borne by DWUs and passed onto customers through price increases are estimated to be €1.8 million per year (constant 2001 Euros) or a total of €26.4 million of expenditures for DWUs between 1988 and 2002.
- Households' averting behaviour costs (mainly bottled water purchase) are estimated to be €20 million per year.
- The study comments that there is likely to be a significant cost to industry but does not provide an exact estimate.

These estimates should be considered to be lower bound estimates since they do not take into account the loss of non-use values.

Comments

From a valuation perspective, the study does not include a detailed breakdown of the financial costs incurred by the 28 identified DWUs. It also does not provide an estimate of the costs to other industry. Due to uncertainties attached to the estimation of future water quality maps, the authors' state that the approach adopted does not pretend to forecast a realistic 2015 scenario. Furthermore the study should be regarded only as a lower bound estimate since it fails to take into account non-use values.

Despite these caveats, the estimates produced are consistent with the results of a contingent valuation study carried out in the same area by Stenger and Willinger (1993), who estimated the total benefit of preventing groundwater pollution at €61 million per year, split into €24.5 million of use benefits and €36.5 million of non-use benefits.

Suitability for value transfer

This is one of a relatively small number of recent studies to assess groundwater values in Europe. But uncertainties mean that the approach adopted does not present a realistic forecast of 2015 scenario, stating that it aims only to produce contrasting pictures of different plausible futures and is not to be used as a decision support tool. Furthermore, some fairly large assumptions are made to produce estimates of the costs of households' averting behaviour costs. However it is useful for at least reflecting the impacts of implementing the Water Framework Directive.

Garrod *et al.* (2000)

Study reference

Garrod G, Powe N and Willis K, 2000 *Hardham Artificial Recharge Economic Valuation* Report prepared by University of Newcastle for Southern Water.

Abstract

The purpose of the study was to explore people's preferences and estimate values for impacts to wetlands and rivers caused by increased groundwater abstraction. The study conducted a choice experiment survey of 412 randomly selected households in Sussex in February 2000, which asked respondents to rank and choose their preferred option from scenarios that varied across a number of attributes. The attributes valued were:

- changes in the numbers of birds and plant species;

- changes in the flow levels of local rivers;
- two improvements in the reliability of water supply.

The study found that respondents were willing to pay approximately £1.50 to avoid a 1 per cent decrease in the wetland attributes and £4.20 to avoid a small decrease in river flows (sterling 2000). The study found that the supply attributes did not influence choice of scenario and so implicit WTP amounts could not be estimated. It was considered likely that this was due to the choice experiment format, which allowed people's strong preferences for no reduction in environmental quality to dominate their choices. The authors concluded that the study showed clearly that people are not willing to accept improved water supply at the cost of environmental degradation.

Groundwater asset

The study focused on valuing environmental impacts caused by:

- increased groundwater abstraction from Hardham aquifer in the summer;
- recharge of the aquifer from water abstracted from the River Rother in winter.

The Hardham Artificial Recharge Scheme (HARS) is designed to increase water abstraction from the underlying aquifer during summer months from the current abstraction rate of 75 ML/d. Two schemes are possible:

- increasing the potential abstraction volume by up to 100 ML/d between June and October;
- increasing this by 25 ML/d.

Abstraction in any single year would be limited to 1,875 ML. The impact of this scheme may affect a number of nationally and internationally important wetlands in the area.

Economic valuation methodology

Choice experiment was the method used to investigate preferences for five attributes (two environmental, two relating to water supply and associated cost) defined at three levels. The attributes were:

- frequency of hosepipe bans;
- risk of water supply interruptions lasting longer than 1–3 days;
- changes in bird numbers and plant diversity at two important wetlands;
- changes in river flows;
- changes in annual household water rates.

The levels of the cost attribute were £5, £10, £15 or £20.

Respondents were asked to both rank the alternative choice sets and to choose their most preferred alternative.

Face-to-face interviews were carried with 412 randomly selected households (in 2000), in areas of the Southern Water catchment that could be supplied by the Hardham Water Supply Works.

Valuation context

The main focus of the study was to investigate public preferences for the main impacts of the HARS identified as:

- changes in the numbers of birds and diversity of plants at two internationally important wetlands;
- changes in the levels of local rivers and ponds;
- improvements in the reliability of water supplies that could be measured by reduction in the frequency of hosepipe bans and in the risk of significant outage to consumers (e.g. between 1 and 3 days).

Valuation results

The modal respondents in the study population were:

- aged 36–45;
- modal income £10,000–9,999 (this included the national average of £19,999);
- over half the respondents had not progressed beyond secondary education (although 18.7 per cent had degrees);
- 14–16 per cent claimed they regularly used rivers.

Variables found to be influential in explaining utility levels included the education level and area where the respondent lived. The latter was thought to be a proxy for social class or distance from affected rivers and wetlands. Respondents at more urban sites had a lower utility for choice attributes, while residents in Petersfield had higher utility levels. In addition, respondents who engaged in bird-watching at wetland sites were found to experience higher loss of utility from reduction in wetland biodiversity.

The choice data was modelled using the Most Preferred Alternative Models incorporating a number of variables for attributes, socio-economic characteristics of the residents and experience of the affected river and wetland. Table A4.2 shows the marginal prices obtained by the study for the different changes.

Table A4.2 Marginal prices

Attribute and marginal change	WTP per household per year (2001)
WTP to avoid (achieve) a 1 per cent decrease (increase) in no. of birds	£1.52
WTP to avoid (achieve) a small decrease (increase) in river flows	£4.25
WTP to avoid a decrease of up to 10 per cent in no. of birds and diversity of plant species found	£21.24
WTP for an increase of up to 5 per cent in no. of birds and diversity of plants found	£5.06

Comments

Respondents would not accept increases in supply reliability at the expense of decreases in wetland biodiversity or river levels. Respondents had higher preferences for maintaining levels of biodiversity and river flow compared with enhancing these environmental quality indicators.

The models do not reliably predict WTP for improvements in supply reliability.

Suitability for value transfer

This was a UK-based study, so suitable for transfer in terms of the geographical coverage criterion. However, transferability for supply reliability issues is limited since the model does not predict reliably WTP for improvements in supply reliability.

Hasler *et al.* (2005)

Study reference

Hasler B, Lundhede T, Martinsen L, Neye S and Schou J S, 2005*Valuation of groundwater protection versus water treatment in Denmark by choice experiments and contingent valuation.* NERI Technical Report No. 543. Roskilde, Denmark: National Environmental Research Institute. Available from: http://www2.dmu.dk/1_viden/2_publikationer/3_fagrapporter/rapporter/FR543.pdf [Accessed 13 December 2006].

Abstract

The benefits of groundwater protection are estimated to assess the non-marketed benefits associated with increased protection of the groundwater resource compared with purification of groundwater for drinking water purposes. The study consists of valuation of the effects on drinking water quality and the quality of surface water recipients, expressed by the quality of the living conditions for wild animals, fish and plants in lakes and waterways. The methods discrete choice experiments and contingent valuation are used for the valuation. The results indicate that there is a significant positive willingness to pay for groundwater protection, where the willingness to pay for drinking water quality exceeds that for surface water quality. The value of groundwater protection exceeds that from purification. This result supports the current Danish groundwater policy and the aim of the Water Framework Directive that aims at a holistic management government of the aquatic environment.

Groundwater asset

The study assesses Danish consumers' WTP for groundwater protection and purification of drinking water. Groundwater refers to the general groundwater resources of Denmark and local groundwater pollution problems are not considered. In Denmark, 99 per cent of the drinking water supply comes from groundwater. Danish Environmental Protection Agency (EPA) policy aims to use clean groundwater subject only to simply processing (oxygenation); further treatment is not desirable with regard to existing and future water targets. Good quality drinking water is considered to be that below limit levels for nitrate and pesticides set at 50 mg/l and 0.1 g/l respectively. Surface water quality indicators are based on qualitative indicators, since there are no currently agreed quantitative indicators.

Economic valuation methodology

The study uses both contingent valuation (CV) and choice experiment (CE) in a split sample design to explore consumer WTP to protect ground water quality. The impacts of different water management proposals were presented in terms of two indicators:

- drinking water quality;
- condition of plant and animal life in surface waters (watercourses and lakes).

In the CV survey, respondents were presented with two sequenced valuation questions to assess WTP to move from the status quo to:

- increased groundwater protection;
- water purification.

WTP was elicited using a payment card. Respondents were required to tick the maximum amount they would be willing to pay per year to move from the current situation to each of the two alternatives. The payment vehicle was an additional payment to household water bill.

In the choice experiments, respondents were asked to choose between three policy options – the status quo option and two alternatives. The options were defined in terms of three attributes:

- drinking water quality;
- surface water quality;
- price.

Drinking water quality was set at three levels:

- naturally clean,
- uncertain (current situation);
- treated.

Conditions for plant and animal life in watercourses were also set at three levels:

- very good,
- less good (current situation);
- poor.

The price attribute was annual increase in water bill per household set at six levels.

The survey was delivered in a mail format to 1,800 households across Denmark (900 for CV and 900 for CE).

Valuation context

The purpose of the study was to value the benefits experienced by Danish consumers from increased groundwater protection and with purification of drinking water. The valuation scenario thus consisted of moving from the status quo with uncertain groundwater quality to either increased groundwater protection or water purification. An overview of the scenarios is provided below:

- **Status quo**. Current protection levels of groundwater mean consumers are provided with clean drinking water from new boreholes, but water quality will be uncertain in future and there is risk of pollution of surface waters with impacts on plant and animal life.
- **Increased protection scenario**. Groundwater protected against further pollution, now and in future, meaning consumers are provided with clean drinking water from untreated groundwater now, and in the future, and improved conditions for watercourses.
- **Purification (treatment to clean) scenario**. Polluted groundwater is cleaned using purification procedures meaning consumers are provided with clean drinking water from treated water or bottles, and a risk of pollution of watercourses with negative impacts on plant and animal life.

Valuation results

The combined sample (CV and CE) had a higher proportion of male, older, and richer respondents than the target population and thus cannot be considered representative.

The CE questionnaire received a response rate of 65 per cent (*n*=584). The analysis (using a conditional logit model) indicates that all attributes were statistically significant at 1 per cent level. Thus respondents hold strong preferences for naturally clean water, followed by very good condition for plant and animal life, and subsequently for purified water.

WTP was significantly higher for females, urban residents (as opposed to rural) and respondents who believe the authorities should use additional resources to protect the aquatic environment (for both attributes). On the contrary, respondents who consider that the problems of pollution of the aquatic environment are exaggerated exhibit a lower WTP for very good conditions for plant and animal life. Not surprisingly, respondents who regard purified water as just as good as non-purified groundwater have a lower WTP for naturally clean (non-purified) groundwater compared with the average respondent. Respondents who disagree with drinking water in Denmark as being clean have a lower WTP for purified water compared to the sample, as do respondents who have knowledge of their household's annual water consumption. In addition, respondents were found to hold disutility with status quo as expressed by a negative WTP for average system cost (ASC). ***[JAH: is this what ASC stands for?]*** Table A4.3 shows the implicit marginal prices found by the CE methodology.

Table A4.3 Implicit marginal prices for CE main effects model (DKr 2004)

Attribute: change from (status quo to alternative)	Implicit price (DKr)
Uncertain drinking water quality to naturally clean groundwater	1,899
Uncertain drinking water quality to purified groundwater	912
Less good conditions for animal and plant life to very good conditions	1,204
Less good conditions of animal and plant life to bad conditions	-1,759

The CV survey received a response rate of 73.4 per cent (*n*=663). The analysis investigated WTP for two different scenarios:

- naturally clean water;
- purified clean water.

The analysis of responses to the first scenario using three different models (ordinary least squares, Tobit and multinomial interval regression) suggests WTP for naturally clean water significantly increases with:

- income;
- education;
- medium annual water consumption[22] (75–130 m^3 per year);
- belief that authorities should use more resources to protect the aquatic environment.

[22] Note: only 60 per cent of respondents had knowledge of their annual consumption.

The findings were consistent across the different estimation models. In addition, WTP was found to increase if WTP was motivated by concern for plant and animal life or for future generations. On average, respondents were WTP 711 DKr per household per year for naturally clean groundwater.

The analysis of the second scenario (using the same three models) found WTP for purified water increases significantly with:

- income;
- education;
- respondent that trust the use of purified water as a substitute for naturally clean water;
- respondents that are motivated to pay due to altruism (i.e. good causes).

On average, respondents were WTP 529 DKr per household per year for purified water.

Comparing welfare estimates derived from the CV and CE,[23] the results indicate that WTP from CE survey is approximately 2–4 times higher than WTP from the CV survey. This is consistent with findings elsewhere in the stated preference literature. The authors recommend using the CE results but with CV as a lower bound.

Overall the results seem to confirm the hypothesis that naturally clean water management is preferred to water that has been polluted and then treated for purification. The results also support the hypothesis that WTP for clean drinking water is greater than WTP for good quality surface waters. The authors hypothesise that this is because clean drinking water influences human health more directly than clean surface waters.

Comments

The sample is not representative of Danish population and it is thus not possible to aggregate results.

The authors note that the CV results may suffer from ordering effects as the valuation scenario consisted of two sequenced valuation questions, which were not tested in the opposing order.

The CE tested the a priori hypothesis that respondents who had previously experienced problems with quality of drinking water would have different WTP for purified or naturally clean water. However, this hypothesis was rejected because none of the interactions was statistically significant.

Focus group results found that respondents related more confidently to qualitative rather than quantitative indicators of groundwater quality. The reasons for this included distrust of limit levels because, it was considered, they could be set politically, and because quantitative indicators of pollution effects and flora and fauna levels were considered more cognitively demanding.

Suitability for value transfer

Not ideal for transfer as the sample is Danish.

[23] To do this, the marginal WTP for the two CE attributes was added to reflect the aggregate scenario valued in the CV question. Thus the mean WTP for naturally clean groundwater and very good plant life conditions in the CE is 3,104 DKr versus 711 DKr in the CV. For the purified water, the mean WTP in the CE is 912 DKr versus 529 DKr in the CV.

Stevens and Krug (1995)

Study reference

Stevens T H and Krug D C, (1995) *Public attitudes and economic values for groundwater protection in western Massachusetts*. *Resources and Environment: Management Choices*. Amherst, MA: Department of Resource Economics, University of Massachusetts.

Abstract

Groundwater is the sole source of water supply for more than half of all Massachusetts communities. According to a legislative commission on water supply, 15 per cent of Massachusetts municipalities have experienced at least one public water supply contamination episode and over 50 per cent have reported private well contamination incidents. A number of communities have established groundwater protection districts in the vicinity of the wellheads, some have regulated land uses over aquifer recharge areas, and new septic tank regulations were recently enacted at the state level. However, many aquifers remain vulnerable. Communities continue to struggle with this problem, but not much is known about public attitudes or economic values associated with groundwater quality. This study reports on a survey of 1,000 randomly selected western Massachusetts residents about their attitudes, knowledge, beliefs and economic values for groundwater protection.

Groundwater asset

Groundwater is the sole source of water supply for more than a half of all Massachusetts communities. Approximately 15 per cent of Massachusetts municipalities have experienced at least one public water supply contamination episode and over 50 per cent have reported private well contamination incidents. In response, a number of communities have established groundwater protection districts in the vicinity of the wellheads, some have regulated land uses over aquifer recharge areas and new septic tank regulations have been enacted at the state level. Despite this many aquifers remain vulnerable. The focus of the valuation was to estimate how much households would be WTP to insure the quality of their groundwater did not get any worse.

Economic valuation methodology

A contingent valuation study was undertaken to estimate economic values for groundwater protection among residents of Massachusetts.

The CV question asked respondents to express their WTP per year for a town-wide special aquifer protection district. The payment vehicles differed depending on the household water supply. For households on public water supplies, the payment vehicle was an increase in water utility bills and, for households served by private wells, an increase in property taxes.

A payment card approach was adopted which presented respondents with a choice of the following amounts: $0; $1–10; $11–20; $21–30; $31–40; $41–50; $51–75; $76–100; $101–125; and $125–150. The survey was delivered to a total of 1,000 residents, 397 usable responses were returned, giving a response rate of 40 per cent.

Valuation context

Respondents were asked to express their WTP to establish a town-wide aquifer protection district which would prevent groundwater pollution. Respondents were advised that:

- the pollution prevention programme would be specifically designed to meet the needs of the town;
- households on public water systems as well as those with private wells would benefit.

Examples of possible actions included:

- drilling new wells is an area where the water in uncontaminated;
- development restrictions on land near well fields and in aquifer recharge areas.

The valuation question specifically asked respondents to state how much they would be willing to pay per year for groundwater pollution prevention programmes which would ensure that the quality of their groundwater did not get any worse.

Valuation results

Approximately 50 per cent of the residents had private wells, the remainder being connected to a public water utility which used groundwater for all or most of its supply. Responses to attitudinal questions suggest that protection of groundwater was an important concern for residents and over 45 per cent expected groundwater contamination to be more of a problem within five years.

The paper does not report on the details of the CV analysis, providing only basic observations on WTP estimates as follows:

- Average WTP for the aquifer protection programme was $63 per year.
- Respondents' breakdowns of WTP suggest non-use accounted for 71 per cent of total value of aquifer protection.
- Average WTP declined with the perceived groundwater safety level, ranging from US$48.62 per household per year where the safety level was perceived to be 'absolutely secure' to US$129.67 where respondents considered safety levels to be presently contaminated.

Comments

No information provided on details of the CV analysis, the WTP bid function or on any internal tests of validity. Estimate of average WTP appears to be consistent with similar studies.

Suitability for value transfer

The study is not suitable for transfer as there is no information regarding WTP function, or internal validity testing. It is also a US-based study.

Randall *et al.* (2001)

Study reference

Randall A, DeZoysa D and Yu S, 2001 Ground water, surface water and wetlands valuation in Ohio. In *The Economic Value of Water Quality* (ed. J C Bergstrom, K J Boyle and G Poe), pp. 83-89. Cheltenham: Edward Elgar Publishing.

Abstract

The overall objective of the research was to perform a comprehensive split-sample contingent valuation study that would estimate benefits of three environmental services

– enhancements to groundwater, surface water and wetland habitat. While groundwater was a primary focus, this effort continues a long-standing research programme addressing the relationships among components of complex policy. The analysis and discussion builds upon the general water quality valuation model by testing empirical hypotheses using multivariate analysis of the relationship between vote responses to an offered protection programme and a set of explanatory variables, and testing hypotheses concerning the value relationships among components of multipart policies. In addition, continuous WTP responses were examined to address the effect of referendum offer price, functional form and the relative magnitudes of mean and median WTP from referendum versus continuous WTP response data. ***[JAH: citations deleted because have come over from original paper and details not given in this report, to which they are of only limited interest]***

Groundwater asset

The focus of the study was the evaluation of three different environmental services provided by the Maumee River basin in north-west Ohio, USA. Specifically it estimated WTP for moving from actual baseline conditions to situation under three different protection programmes:

- reduction and stabilisation of nitrate levels in groundwater in the Maumee river basin to between 0.5 and 1 mg/l (groundwater programme);
- reduction of volume of sediment entering the Maumee River by 15 per cent, enhancing recreation in and around river and improving quality of household water (surface water programme);
- protection and improvement of existing wetlands, restoration of 3,000 additional acres of wetlands and provision of 20 per cent more wildlife habitat for migrating wildlife (wetland programme).

Economic valuation methodology

A contingent valuation study employed a split sample design with each respondent receiving a single proposal which consisted of one, two or all three of the proposed protection programmes and a single tax-price.

Respondents were asked a single-bounded referendum question at a randomly assigned tax price and then asked to state their maximum WTP in an open-ended question. Prices used were $0.25, $10, $30, $54, $80, $120 and $200. The payment vehicle was a one-time tax, with the proceeds dedicated to the programme.

A total of 1,050 residents were surveyed using a mail format from three populations:

- Maumee drainage rural residents;
- Maumee drainage urban residents;
- residents out of the region.

The survey received an overall response rate of 51 per cent with 427 useable returns.

Valuation context

Three protection programmes were presented:

- stabilisation and reduction of nitrate levels in groundwater in the Maumee River basin in north-west Ohio;
- reduction of sediments due to soil erosion in streams and lakes in the Maumee River basin;

- protection and enhancement of wetlands along the shore of the western basin of Lake Erie.

For the groundwater and surface water proposals, the funds raised would be used to provide incentives for farmers to adapt to environmentally benign crop-growing practices and, for the wetlands programme, the purchase of wetland easements.

Valuation results

Results obtained were consistent with a priori expectations:

- price variable was a highly significant predictor of voting behaviour;
- income was positive and significant.

The following attitudinal variables were all positive and statistically significant:

- high priority for water quality and wetland protection;
- desire to increase public spending on education, health and vocational programmes;
- expectation of future visits to the region,.

All programme dummy variables had the expected sign compared with the omitted programme, suggesting more public goods are preferred to fewer.

WTP estimates were reported from result of single-bounded referendum (using lognormal probit model) and the open-ended continuous data (using a Tobit model with gamma distribution). The single-bounded WTP estimates (median and lower-bound mean) were reported for each of the seven programmes pooled across the three samples and for each of the samples pooled across the programmes (Table A4.4).

Table A4.4 WTP estimates for referendum data (original year of data not specified)

Programme	Sample	WTP $/household/one-off	
		Median	LB mean
Groundwater	Pooled	20.80	52.78
Surface water	Pooled	50.27	78.38
Wetlands	Pooled	29.56	62.57
Groundwater and wetlands	Pooled	41.83	72.65
Groundwater and surface water	Pooled	66.32	87.98
Surface water and wetlands	Pooled	34.08	66.63
All three programmes	Pooled	75.70	91.41
All three programmes (pooled)	Maumee rural	35.27	74.56
All three programmes (pooled)	Maumee urban	32.96	72.96
All three programmes (pooled)	Out of region	52.45	68.37
Groundwater	Pooled	20.80	52.78
Surface water	Pooled	50.27	78.38

Analysis of the open-ended WTP answers using a Tobit model with gamma distribution provided best fit of continuous WTP data but may underestimate mean WTP; the results suggested that the true median and mean WTP lies between the two models (Table A4.5).

Table A4.5 Mean and median WTP ($/household) all programmes pooled

Analysis method	Median WTP	Mean WTP
Referendum (YNP data) log-normal	$52	$68
Continuous gamma (zeros assumed real)	$24	$32
Continuous (raw data)	$25	$47

Based on lower bound estimates of WTP, aggregation across the in-region population suggested the benefits of the groundwater programme amount to $4.04 per acre of cropland; including the out-of-region population sample increases this to $17.55 per acre and, for all households in the non-Maumee basin, to a total of $71.02 per acre.

The benefits of surface water programme per acre of cropland were:

- $6.05 for the in-region population;
- $26.06 for all three sample populations;
- $101.30 when aggregated for population of Ohio.

The benefits of wetland programme amounted to:

- $1,077 per acre for in-region population;
- $21,566 per acre for all three populations;
- $85,215 per acre for population of Ohio.

Comments

The high number of 'protest no's' were not expected. Possible explanations included:

- respondents felt uncomfortable with subsidising farmers;
- multi-county programme region was not consistent with the ordinary taxing jurisdictions;
- protest follow-up questions may have influenced voting behaviour.

Analysis of the referendum responses using lognormal probit model provided good estimates of median WTP but generated implausibly high estimates of mean WTP, such that a lower bound estimate calculated from log-normal probit was preferred. Results of a Kruskal–Wallis non-parametric test suggested that median reported WTP is an unbiased estimator of median WTP.

Comparisons of welfare estimates across the programmes indicate that the more comprehensive goods are valued higher than the lesser goods, i.e. median WTP for three programmes valued as a whole higher than median WTP for any of the individual programmes or pairs of programmes. The value of the multi-component programme is less than the sum of its components when evaluated separately with one exception, which maybe explained by a small sub-sample size. A Wald test was used to reject the null hypothesis of no difference between the programmes; signs were correct although the differences were not significant.

Higher WTP estimates for the out-of-region sample may have been motivated by passive use to a greater degree than the other samples.

The validity of the results is somewhat comprised by the small dataset given the large number of split samples. However, multivariate analysis demonstrated construct validity and theoretical expectations regarding the sign of WTP across single and multi-component programmes were met (although significant in only one case).

Suitability for value transfer

Internal validity and reliability were good, but the study has limited transferability as it is US-based.

Lichtenberg and Zimmerman (1999)

Study reference

Lichtenberg E and Zimmerman R, 1999 Farmers' willingness to pay for groundwater protection. *Water Resources Research*, 35 (3), 833-841.

Abstract

The effectiveness of current groundwater protection policies depends largely on farmers' voluntary compliance with leaching reduction measures, an important component of which is their willingness to adopt costlier production practices in order to prevent leaching of chemicals. Data from an original survey of 1,611 corn and soybean growers in the mid-Atlantic region were used to estimate farmers' willingness to pay to prevent leaching of pesticides into groundwater. The results indicate that farmers are willing to pay more for leaching prevention than non-farm groundwater consumers, both absolutely and relative to total income. The primary motivation appears to be concern for overall environmental quality rather than protection of drinking water or the health and safety of themselves and their families. Hobby farmers are willing to pay more than farmers with commercial activity. Certified pesticide applicators are willing to pay less than farmers without certification.

Groundwater asset

The study examined WTP to prevent leaching of pesticides into groundwater by farmers in Maryland, New York, Pennsylvania.

Economic valuation methodology

A contingent valuation survey was undertaken to estimate willingness to pay by farmers to prevent leaching of pesticides into groundwater. A simple dichotomous choice question format was employed. A total of 2,700 farmers were surveyed using a mail format. The total sample size was 1,611 giving a very high response rate of 60 per cent.

Valuation context

The context was farmers' willingness to pay to prevent pesticide leaching in groundwater in Maryland, New York, Pennsylvania.

Valuation results

On average, farmers in the sample obtained 36 per cent of their income from farming, suggesting average total incomes in the order of $48,000 to $65,000. Average age was 50.5 years, 44 per cent of households had children and 91 per cent of respondents lived on the farm. The average Likert rank of attitudes towards seriousness of water pollution from pesticide runoff/leaching was 3.54 (scale 1 – not at all serious to 5 – very serious).

The authors estimated mean WTP for prevention of pesticide leaching as a function of:

- responses to the contingent valuation question;
- socio-economic characteristics of the respondent;
- statistical model used to estimate the confidence interval).

Response to the dichotomous choice (DC) question were used to estimate a demand curve for the prevention of pesticide leaching and to calculate the 95 per cent confidence intervals for the willingness to pay to prevent pesticide leaching on a per acre, corn acreage and total acreage basis. Welfare estimates were derived using Turnbull estimator and the random utility probit model, reported in US$1995 (Table A4.6).

The willingness to pay to prevent leaching on the total acreage was estimated at $3,475 using the Turnbull model and $7,050 using the probit model.

Table A4.6 Study findings

Good	WTP (US$1995)[1]	
	Turnbull estimator	Random utility probit model
WTP to prevent pesticide leaching (per acre)	35.35 (29.50–46.63)	17.37 (16.75–18.00)
WTP to prevent pesticide leaching (corn acreage)	1,112 (1,072–1,152)	2,256 (1,888–2,984)
WTP to prevent pesticide leaching (total acreage)	3,475 (3,349–3,601)	7,050 (5,900–9,326)

Notes: [1]95 per cent confidence intervals in brackets

Comments

Farmers were willing to pay more for leaching prevention than non-farm groundwater users – both absolutely and relative to total income. The primary motivation appears to be concern for overall environmental quality rather than protection of drinking water or the health and safety of themselves and their families. Hobby farmers are willing to pay more than farmers with commercial activity. Certified pesticide applicators are willing to pay less than farmers without certification.

The study did not include a ‘not sure’ option, which is generally recommended as a method for reducing yea-saying in the use of dichotomous choice formats.

There is no evidence of qualitative research in the preparation of the questionnaire. No explanation is given for the selection of the bid vector, which under the random utility model, does not include the mean value within its range.

The probit model had acceptable explanatory power (ρ^2 = 0.15), and several attitudinal and socio-demographic coefficients were significant. Confidence intervals were calculated using Fieller’s theorem.

Suitability for value transfer

The validity of the estimates is queried in view of the inappropriate selection of bid vector and limited information in the paper regarding tests for biases. The study population is from the USA.

Epp and Delavan (2001)

Study reference

Epp D and Delavan W, 2001 Measuring the value of protecting ground water quality from nitrate contamination in south-eastern Pennsylvania. In *The Economic Value of Water Quality* (ed. J C Bergstrom, K J Boyle and G Poe), pp. 66–82. Cheltenham: Edward Elgar Publishing.

Abstract

The study addressed the economic consequences of nitrate pollution by reporting the results of a case study in Pennsylvania which examined WTP to protect groundwater quality and factors affecting WTP. Estimated WTP was a measure of the benefits of a specific protection programme. The paper adds to existing empirical work on water quality valuation by estimating WTP and its covariates for a hypothetical groundwater management programme intended to protect the residents in the study area from nitrate contamination, and comparing different ways of eliciting WTP to test for anchoring (the tendency of respondents unfamiliar with a good to focus on some cue or clue in the questionnaire.

Groundwater asset

The study evaluates the economic consequences of nitrate pollution in south-eastern Pennsylvania. This area contains some of the richest non-irrigated farmlands in the world, though intensive manure and chemical fertiliser applications have resulted in some of the highest groundwater nitrate levels recorded in the north-east USA. In the past five years, over 50 per cent of private wells and nearly a quarter of all public water supplies in the study area have exceeded the US federal nitrate standard of no more than 10 mg NO_3-N per litre.

Economic valuation methodology

Contingent valuation was used to estimate household WTP for a plan to protect groundwater quality. Two different CV question formats were employed in a split sample design:

- a referendum dichotomous choice question followed by an open-ended question (as per Randall *et al.* 2001);
- an alternative valuation question that presented additional information about the average cost per household of local government expenditures for safety related activities (e.g. fire protection, police services, and the construction and maintenance of street and highways) followed by an open-ended question.

The payment vehicle was an additional annual tax collected from each household for 10 years.

The survey was conducted using a mail format delivered to 1,000 randomly chosen households in two rural counties in Pennsylvania. A total of 617 usable questionnaires were returned, giving an overall response rate of 67 per cent.

Valuation context

The study estimated WTP for reduced nitrate contamination from different sources in two counties in south-eastern Pennsylvania. The specific details of the proposed change were not reported. A distinctive feature of the valuation scenario was that it did not present the success of the proposed measures as guaranteed; instead it included respondents' expectations about the effectiveness of the programme as a variable in the survey. This was introduced as an independent variable based on the difference between respondents' ratings of the likelihood that water in the study area would remain safe to drink over the next 10 years if the programme was approved and if it was not approved.

Valuation results

The sample population was predominantly male (70 per cent) with a mean respondent age of 52 years. Over half of the respondents had a high school education or less; the majority of households (68 per cent) had incomes <$30,000 per year although a significant portion (26 per cent) were in the $40,000–50,000 range. Approximately two-fifths of the respondents used private wells for their main source of drinking water. The two sub-samples were not found not to be statistically different for any of the relevant variables, except for WTP.

WTP was significantly and positively influenced by:

- household income;
- perceived effectiveness of the programme;
- previous action to protect household water supply (e.g. households that had previously used bottled water or filters were more likely to make a higher bid – this variable was regarded as a proxy for concern about clean groundwater).

The presence of children in the household did not have a significant effect on WTP; neither did gender or age of household head. Surprisingly, private well ownership had a significant negative impact on WTP, meaning that WTP of households with their own drinking water well was lower than that of households with municipal water supply, despite both being served by the same aquifer. It was speculated that owners of private wells might hold the erroneous assumption that groundwater protection would fall into their own responsibility. Alternatively it could be due to the influence of those that had had well tests that were negative for nitrates.

Based on the responses to the open-ended questions, mean WTP was estimated for each of the valuation formats using a Tobit regression (Table A4.7); a conservative approach was adopted with protest bids and missing values being removed. (When protest bids were not eliminated, mean WTP decreased considerably such that is was not possible to assert mean WTP was significantly different from zero).

Table A4.7 Estimates of WTP from open-ended responses

Question format	Mean WTP	Standard deviation (SD)
Dichotomous choice (open-ended)	$74	$125
Informed open-ended	$51	$92

Estimates of mean and median WTP for the study region ranged between $0 and $67 depending on the valuation question and the removal of protests. The aggregated results range from zero to US$5.1 million annually or US$51 million for the ten-year contribution period.

Comments

The response rate for the informed open-ended format was statistically, significantly higher than for the dichotomous choice format.

Mean WTP was significantly different between the two valuation formats; the open-ended DC question exhibited significantly higher WTP bids than the informed open-ended format. This was largely explained by the effect of starting point bias in the DC open-ended format. A likelihood ratio test rejected the null hypothesis that the two elicitation formats measure the same preferences; the elicitation format was thus found to significantly affect responses. The study concluded that providing an open-ended question as the second part of a double-bounded DC bid elicitation format does not avoid anchoring biases associated with the DC format.

A significant finding of the study was the importance of subjective perceptions of the effectiveness of the programme. The more effective the programme is perceived to be, the more people are willing to pay for it.

Suitability for value transfer

This US study has limited transferability.

Brox et al. (2003)

Study reference

Brox J A, Kumar R C and Stollery K R, 2003 Estimating willingness to pay for improved water quality in the presence of item non-response bias. *American Journal of Agricultural Economics*, 85 (2), 414-428.

Abstract

This article deals with the problem of item non-response in contingent valuation surveys, using a payment card method, by applying a grouped-data sample-selection estimation technique that is capable of inserting the missing values conditional upon a respondent's decision to answer a willingness-to-pay question. The advantage of the technique lies in its ability to utilise all of the information in the sample, permitting a more efficient estimation in the presence of item non-response bias. The major determinants of willingness to pay appear to be household income, number of children, education, perception of existing water quality, and identification with environmental issues.

Groundwater asset

The Grand River watershed in south-western Ontario near Toronto is a Canadian heritage river. It has the largest urbanised watershed in southern Ontario, emptying into the eastern end of Lake Erie and draining an area of approx. 6,800 km^2 with a population of approximately 663,700 people. The ecology of the river system is threatened by rapid urban development. One of the main issues of public concern is the safeguarding of residential water resources including underground aquifers as well as surface water.

Economic valuation methodology

A contingent valuation study to measure WTP/WTA for residential water quality improvements within the Grand River watershed was performed.

Three different questions were used to elicit the value placed on improved water quality. The first two asked respondents to express their WTP for enhanced water quality at two different levels of scope; the third elicited willingness to accept compensation for a decline in water quality.

In each case, WTP (or WTA) was elicited as an increase (or reduction) in the respondent's monthly water bill using a payment card format and presenting a choice of the following amounts: $1; $2.50; $5.00; $10.00; $15.00; $20.00; and > $20.00.

Responses were analysed using a simultaneous equation model capable of deriving the missing values conditional upon a respondent's decision to answer a WTP question, thereby utilising the information contained in the entire sample rather than only those who responded to the WTP question.

The overall sample consisted of 3,070 households. Out of a total of 2,182 responses, the usable sample for the CV questions varied between 899 and 1,003.

Valuation context

Respondents were asked to express their WTP/WTA for a change in the quality of their household drinking water under three different scenarios:

- WTP for a water treatment project to bring water quality back to within required standards following a [major] pollution incident;
- WTP for a water treatment project to bring water quality back to within required standards following a (minor) pollution incident that would affect taste and odour of water supplies;
- WTA compensation if the quality of drinking water supplies were to deteriorate without becoming a health hazard.

Under the WTA scenario, respondents were asked to imagine a situation where no new projects would be undertaken to protect or improve the current quality of the region's water supply, which in time would result in the deterioration of water quality (due to population and industrial growth).

Valuation results

The analysis (using maximum likelihood estimation) reported both on the determinants of an individual's decision to respond to the WTP/WTA question and on the determinants of WTP/WTA amount.

For the WTP questions, an increase in either income or home ownership and a sense of attachment with the Grand River increased the likelihood of response, while an increase in the age of the respondent reduced it. Prioritisation of the economic growth of the region also reduced the rate of response for the major pollution scenario, but was not significant for the minor pollution question. Under the WTA question, the significant determinants for response were age, home ownership and a sense of attachment to the Grand River. The most notable difference between the explanatory determinants for participation under the WTP and the WTA questions is that household income is not an important determinant for the WTA.

The WTP function suggests that, for both minor and major pollution scenarios, higher income, better educated and environmentally conscious residents, who view current water quality as being high, possess a greater WTP to rectify water contamination problems. The results of the WTA analysis suggest that relatively younger residents, living upstream, and who do not feel as closely attached to the watershed tend to demand larger compensation.

For comparison purposes welfare estimates were derived for the simultaneous-equation model and the single-equation estimates (Table A4.8).

Table A4.8 Welfare estimates in Canadian dollars (1994 prices)

	WTP/WTA (monthly water bill/per household)	
	Simultaneous equation	**Single equation**
Major water problem WTP	$8.29	$9.21
Minor water problem WTP	$4.56	$5.98
WTA water problem	$9.42	$8.08

Aggregating the $8.29 estimate for the 259,164 households in the Grand River watershed yields a total WTP for new water quality improvements projects of $21.5 million per year. Using a 5 per cent discount rate and assuming a 25-year lifetime for capital projects to increase water quality, this corresponds to a capital value of $1,400 per household. This means watershed residents are implicitly willing to fund a one-time investment of $363.6 million in capital projects for water quality enhancement.

Comments

The main focus of the study was to report on the application of a grouped-data sample-selection estimation technique capable of determining the missing values conditional upon a respondent's decision to answer a WTP question. The main advantage of the technique lies in its ability to utilise all the information in the sample, permitting a more efficient estimation in the presence of item non-response bias. The results suggested that not adjusting for item non-response bias would have led to overestimation of the two WTP amounts and underestimation of the WTA amount.

The single-equation estimates are comparable with those derived from earlier, similar studies by Gramlich (1977), Greenly *et al.* (1982), Schultz and Lindsay (1990) and Jordan and Elnagheeb (1993). Comparing the estimate derived from these earlier studies (when corrected for inflation and exchange rate differences) with those of the current simultaneous equation model suggests that these estimate are likely to be larger than the estimate produce by the current study of $8.29. The authors cite this as further possible evidence that ignoring missing observations is likely to have caused an upward bias in the estimates of these earlier studies.

Estimates were in accord with a priori expectations under the simultaneous equation model:

- mean WTP for the major pollution scenario was significantly greater than for the minor pollution scenario at the 1 per cent level;
- estimated WTA amount was closer to the estimated WTP for the major pollution scenario despite the usual divergence between WTP and WTA amounts.

The insignificance of household income in the decision to respond to WTA question was suggested to be due to multi-collinearity between income and the other socio-economic variables.

The significance of the home ownership variable in the decision to answer the WTP/WTA question is a noteworthy finding since it has rarely been included in earlier studies.

The study did not report any test for ordering effects across the three valuation questions.

Suitability for value transfer

This is difficult to assess since the study does not include summary statistics of the socio-demographics nor does it report on the representativeness of the survey sample. It is a Canadian study so has limited transferability to the UK.

Berstrom *et al.* (2004)

Study reference

Berstrom J C, Boyle K J and Yabe M, 2004 Trading taxes vs. paying taxes to value and finance public environmental goods. *Environmental and Resource Economics*, 28 (4), 533-549.

Abstract

The potential sensitivity of environmental resource valuation to payment vehicles is of interest to researchers and decision-makers involved in estimating and applying these numbers. A conceptual model is developed which provides insight into how the different payment vehicles of a special tax and a tax reallocation affects the willingness to pay (WTP) for environmental goods. Hypothesis testing using contingent valuation data suggests WTP with a tax reallocation is higher than WTP with a special tax for groundwater quality protection in Georgia and Maine, USA. Technical measurement and welfare analysis implications, and limitations of valuing and financing public environmental goods using tax reallocations, are discussed.

Groundwater asset

This study focuses on household values to protect ground water quality from potential nitrate contamination in Dougherty County, Georgia, and Aroostook County, Maine, USA. Approximately 100 per cent residents in Dougherty County and 83 per cent in Aroostook County obtain their water supply from groundwater supplies. At the time of the study, about 98 per cent of public and private ground water supplies in Dougherty County and around 87 per cent in Aroostook had nitrate levels meeting federal safety standards.

Economic valuation methodology

A CV study was carried out to collect data on preferences and values for groundwater protection in Georgia and Maine.

The survey used a split sample design to elicit bids using different payment vehicles – a special tax and a tax reallocation, in both cases payable every year for 10 years.

A dichotomous choice (DC) question asked whether respondents would vote to support the groundwater quality protection programme given a specified cost in terms of a special tax or tax reallocation. Offer amounts were $25, $50, $75, $100, $150, $200, $350 and $500.

To gain additional information, respondents were also asked to state their maximum WTP for the programme using an open-ended (OE) question.

A mail survey was conducted from September 1996 to March 1997. A total of 1,050 households in Maine and 1,049 in Georgia were randomly selected. The survey received an overall response rate of 53 per cent.

Valuation context

The survey elicited household WTP to protect groundwater quality from potential nitrate contamination using different payment vehicles. The special tax needed to fund the programme would reduce the amount of money a household currently has to spend on all other foods and services. The tax reallocation payment vehicle represented a general bundle of 'all other public goods'. To help respondents to think about trade-offs between groundwater quality and all other public goods, prior to the valuation question they were asked to evaluate the priority government agencies should place on spending limited budgets on typical social and community problems and issues.

Valuation results

The CV responses were analysed using Tobit and probit models for the OE bids and an empirical logit model for the DC acceptance rate.

For the special tax, WTP was found to be statistically significantly influenced by:

- offer price in the DC question;
- income (positive);
- subjective probabilities for groundwater safety with and without the programme – the more or less people expected groundwater to be safe with the programme the more or less they are WTP;
- the priority placed on public agenda for protecting groundwater quality – the more the person has a priority for the higher the WTP.

State and gender were not statistically significant. Additional explanatory factors that were not significant but had the correct sign were the priority placed on air quality and presence of a water filter.

For the tax reallocation, WTP was statistically significantly influenced by:

- size of offer bid was (positive or negative according to the model);
- subjective probabilities for groundwater safety with and without the programme;
- priorities for water quality, air quality and presence of filter.

Income was not found to be statistically significant influence on WTP under the tax reallocation. The study findings are summarised in Table A4.9.

Table A4.9 Comparison of mean open-ended bid between special tax and tax reallocation for WTP for groundwater protection

Location	Special tax (US$/household)		Tax reallocation (US$/household)	
	Mean (SD)	***n***	**Mean (SD)**	***n***
Maine	$40.27 (79.73)	208	$109.1 (244.5)	154
Georgia	$64.85 (124.8)	166	$113.7 (167.8)	133
Overall	$69.04		$130.40	

Using the pooled samples, mean WTP under the OE data for groundwater quality protection was found to be $69.04 for the special tax and $130.40 for the tax reallocation.

Comments

A key feature of the survey was to examine how different payment vehicles of a tax and tax reallocation affect WTP for groundwater quality programme. The use of a tax reallocation adds a novel contribution to the existing literature.

Hypothesis testing using a contingent valuation method suggests WTP with a tax reallocation is significantly higher than WTP with a special tax for groundwater quality protection in Maine and Georgia, USA.

The case study did not meet the necessary conditions under which tax reallocation welfare measures can be regarded as equivalent to welfare measure using traditional public good financial mechanism and payment vehicles such as a special tax.

Suitability for value transfer

The welfare results from the tax reallocation cannot be easily generalised to other populations because the relative marginal values of disposable income and all other public goods are conditional upon the existing bundles of private and public goods and the specific public good included in the tax reallocation payment mechanisms. The population is US and thus not suitable for transfer.

Travis and Nijkamp (2004)

Study reference

Travisi C M and Nijkamp P, 2004 *Willingness to pay for agricultural environmental safety: evidence from a survey of Milan, Italy*. Milan: Department of Management Economics and Industrial Engineering, Polytechnic of Milan.

Abstract

The widespread use of pesticides in agriculture provides a particularly complex pattern of multidimensional negative side-effects, ranging from food safety related effects to the deterioration of farmland ecosystems. The assessment of the economic implications of such negative processes is fraught with many uncertainties. This paper presents results of an empirical study recently conducted in the north of Italy aimed at estimating the value of reducing the multiple impacts of pesticide use. A statistical technique known as conjoint choice experiment is used here in combination with contingent valuation techniques. The experimental design of choice modelling provides a natural tool to attach a monetary value to negative environmental effects associated with agrochemical use. In particular, the paper addresses the reduction of farmland biodiversity, groundwater contamination and human intoxication. The resulting estimates show that, on average, respondents are prone to accept substantial WTP premium for agricultural goods (in particular foodstuffs) produced in environmental benign ways.

Groundwater asset

The study explores public values in Milan for reducing harmful effects of pesticide use on environmental goods, including contamination of soil and groundwater in agricultural land. The impact of pesticides on soil and groundwater is measured in terms of the percentage of farmland areas contaminated by pesticides. The baseline scenario is 65 per cent of farmland areas contaminated.

Economic valuation methodology

The study uses two stated preference approaches to estimate the value of reducing the multiple impacts of pesticide use.

- **Conjoint choice experiments**. Respondents were asked to choose their preferred 'green' food expense payment package defined by four attributes:
  - reduction in farmlands biodiversity specified as number of endangered farmland bird species (15, 9, 6, 3);
  - reduced contamination of soil and groundwater in agricultural land specified as the percentage of contaminated agricultural land (65 per cent, 45 per cent, 25 per cent, 15 per cent);
  - reduced health effects of pesticide use on the general public, specified as number of cases of intoxication/year (250, 150, 100, 50);
  - a monetary attribute specified as an increase in monthly household food expenditure – respondents were required to specify their current monthly expenditure on foodstuffs earlier in the survey instrument (current, +€50, +€100, +€200).

  In each choice set, respondents were required to make a choice between the status quo scenarios (represented by the conventional scenario of agricultural practices) and two alternatives (obtained with more environmentally benign practices); respondents were presented with four or five choice sets in total. Choice sets were developed using a cyclic experimental design technique.

- **Contingent valuation**. Following the choice experiments, respondents were presented with a double-bounded dichotomous choice CV question and asked to report maximum WTP for eliminating all risks, both to human health and the environment, associated with pesticide application in agriculture.

  The survey was self-administered by respondents intercepted at three shopping malls in Milan; overall, 484 questionnaires were distributed. The survey received a response rate of 62 per cent, with a total of 302 completed surveys returned.

Valuation context

The study assesses people's preferences for alternative scenarios of agricultural production based on lower pesticide inputs. Specifically it focuses on the value of reducing the multiple impacts of pesticide use, reporting on consumers WTP to eliminate negative effects on:

- reduction in farmland biodiversity;
- contamination of soil and groundwater in agricultural land;
- health effects of pesticides on the public.

Valuation results

The sample was not fully representation of the target population; respondents were on average younger (average age 34 years compared with 44 years) and richer (respondent household income was 25 per cent higher than Milan average).

The analysis (using a conditional logit model) found that all attributes had the expected a priori sign and were highly statistically significant with the exception of biodiversity. The coefficient for groundwater was negative and statistically significant; this implied that, all things being equal, reducing groundwater contamination by 50 per cent raises the probability of selecting the agricultural scenario by 2 per cent.

A priori expectations on the effect of differences in respondent's socio-economic profile on attribute coefficient were confirmed.

The choice experiment was conducted under three scenarios. Scenario A depicts the relationship between WTP and respondent socio-economic variable and agricultural attributes. Scenarios B and C depict adjustment intercepts that are weighted with population weights to balance the sample age distribution according to the distribute age of Milan. Implicit prices are reported in Table A4.10.

Table A4.10 Implicit marginal prices (€/hh/month (2003 €)

Attribute and marginal change	Implicit price		
	Scenario A	Scenario B	Scenario C
Avoid loss of one farmland bird species	23.01	24.36	24.57
Avoid contamination of 1 per cent of farmland and soil aquifer	12.28	16.21	16.21
Avoid one case per year of human ill-health	2.5	3.07	3.14

CV analysis estimates of 'overall' WTP for reducing all pesticide negative side-effects (uses a Weibull distribution but limited information on WTP functions) are given in Table A4.11.

Table A4.11 CV estimates: mean and median WTP (€/hh/month)

Good	Mean WTP	Median WTP	Lower bound
WTP to reduce 'all' pesticide negative side-effects	19.78	15.01	14.54

Comments

The conjoint analysis confirmed that the choice between agricultural scenarios does depend in predictable ways on the attributes.

Respondents were found to consider food shopping less attractive if the groundwater pollution generated from the production process is increased.

WTP was substantially larger for environmental attributes than for health, although not directly comparable due to different measurement units.

Trade-offs between attributes suggest that, on average, respondents are willing to tolerate five cases of human intoxication to reduce soil and groundwater contamination by 1 per cent.

Suitability for value transfer

This European study gives an indication of the size of consumer's preferences for protecting groundwater from negative effects of pesticide use.

Annex 5: Benefit assessment matrix for case studies

See separate Microsoft® Excel file.

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