ISSN 1020-1203

FAO
WATER
REPORTS

27

Economic valuation of water resources in agriculture

From the sectoral to a functional perspective of natural resource management

Cover photograph:

Farmer pumping groundwater, Gujarat, India.
Marcus Moench

Copies of FAO publications can be requested from:

SALES AND MARKETING GROUP
Information Division
Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla
00100 Rome, Italy

E-mail: publications-sales@fao.org
Fax: (+39) 06 57053360
Web site: http://www.fao.org

Economic valuation of water resources in agriculture

From the sectoral to a functional perspective of natural resource management

FAO
WATER
REPORTS

27

by

Kerry Turner
Stavros Georgiou
Rebecca Clark
Roy Brouwer
Centre for Social and Economic Research on the Global Environment
Zuckerman Institute for Connective Environmental Research
University of East Anglia, Norwich
United Kingdom of Great Britain and Northern Ireland

and

Jacob Burke
FAO Land and Water Development Division

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2004

ISBN 92-5-105190-9

Contents

List of tables

List of figures

List of boxes

Acronyms

DPSIR	Drivers, pressures, states, impacts and responses
GIS	Geographical information system
GNP	Gross national product
IEA	Integrated environmental assessment
M&I	Municipal and industrial
MOC	Marginal opportunity cost
NOAA	National Oceanic and Atmospheric Administration
NPV	Net present value
TEV	Total economic value

Preface

This publication arose from a perceived gap in the literature on the specific problems of raw water allocation for agriculture as distinct from other users. The concern is that pressures on agriculture to reduce its otherwise ‘successful’ capture of raw water will need transparent methods of negotiation. There is also considerable confusion within the agricultural sector on the basic economics of natural resource allocation and the implications of water valuation and the relationship to water ‘pricing’.

The publication is primarily targeted at agriculture policy makers and managers, prompting them to review the economic basis for agricultural water management and offer an approach to water resource valuation that can be accepted by competing sectors and environmental services.

Many books on the subject of water valuation attempt to cover all aspects of water use. This publication confines itself to a consideration of agricultural use simply because this use will continue to dominate global water withdrawals.

Executive summary

The purpose of this report is to produce a review on water resource valuation issues and techniques specifically for the appraisal and negotiation of raw (as opposed to bulk or retail) water resource allocation for agricultural development projects. The review considers raw water in naturally occurring watercourses, lakes, wetlands, soil and aquifers, taking an ecosystem function perspective at a catchment scale, and takes account of the demands from irrigated and rainfed agriculture. It is hoped that the review will have particular application to developing countries where agreed methods for reconciling competing uses are often absent, but nevertheless takes account of valuation approaches that have been made in post industrial economies.

The competition for raw water is intensifying and agriculture is often cited as the principal 'user' of raw water. The fact that agricultural use involves returns of significant (although often degraded) volumes of water is sometimes ignored. Nevertheless, national agricultural policies in developing countries continue to promote irrigated agriculture to minimize perceived risks in food supply and distribution. In addition, the promotion of agricultural activity is considered strategic in fixing and developing rural economies and in many cases the existing systems of water use rights has reinforced the seniority of agriculture user rights. The agricultural sector therefore needs a transparent system of resource evaluation with which to negotiate and regulate allocation of the resource, both at the national level and at the international level in the case of shared river basins, aquifers and catchments.

This review presents a framework and suite of techniques that can be employed to analyse these issues and make the rationale for agricultural use of water explicit and transparent. It is not a field manual in the sense of a practical 'cook book' but rather an 'advocacy' brief which sets out to bring together economic and ecological evidence and argumentation in support of the need to challenge and change the fundamentals of the prevailing technocentric water resources exploitation worldview. A new and more suitable approach to water resources allocation in the new century is necessary if the world's population is to be adequately fed, without further degradation and destruction of the planet's critical ecosystem services. Water productivity needs to be greatly enhanced and economic cost-benefit analysis and pricing regimes can play a significant role in such a process. These economic measures will not, however, be sufficient on their own and will need to be buttressed by technological innovation and institutional changes to encourage a more equitable distribution of resources and to mitigate potential international conflicts across 'shared' waterbasins.

THE WATER RESOURCES MANAGEMENT PROBLEM

Water resources have been experiencing intense and sustained pressure demand from a range of direct and indirect socio-economic driving forces. Although globally, freshwater is abundant, the problem is that it is not available in the right place and at the right time. Arguably the world has been treating water as an almost free resource, despite the fact that competition for raw water is intensifying. Although globally the absolute physical scarcity of water is at best a long term concern, the current management of water resources has been found wanting, with problems relating to inefficient, inequitable and environmentally damaging.

While agriculture is often cited as the principal 'user' of raw water, domestic, municipal and industrial uses of water are increasing, and there is now more widespread recognition of the important environmental services provided by water resources. As such, the management of water is an economic, social and political issue encompassing all sectors of an economy. The management involves trade-offs between these sectoral users, as well as between additional economic growth and further water resource depletion, degradation and related environmental concerns. In spite of these trade-offs, much socio-economic improvement can be secured without the imposition of excessive costs or loss of environment integrity. Striking a balance between the complementarity and the trade-off that exists between economic growth and water resource degradation and depletion defines the context that economic and environmental policies and investments for water resources.

The key issues can be summarized as comprising the following (Turner and Dubourg, 1993):

- Water is generally non-substitutable (although at the limit there is an almost infinite supply of seawater, which can be converted into freshwater at a cost of energy and some pollution);
- Water faces rising overall demand and use intensification;
- Water has limits to use. There are physical limits, for example, the rate of recharge of groundwater. However at the aggregate level the notion of an absolute physical limit is less valid since adjustment mechanisms (recycling, etc.) mean that water (for the foreseeable future) will be available at affordable prices. There are relative cost limits, in the sense that as usage of existing supplies intensifies and new supplies are sought, the cost of extraction and usage will escalate. Finally there are social limits set by the social acceptability of the effects of certain uses, for example, water quality and flow conditions for recreational activities.

An international consensus in policy regarding water management has emerged, based on growing concerns about efficiency in the use of government and donor resources, disappointing outcomes from past efforts, and greater awareness of environmental issues. This consensus adopts an integrated approach to water resources and multi-sectoral view of water use an at least a catchment scale. Water management is considered in relation to key issues of economic efficiency, environmental protection, sustainability, and the needs of marginalized and poor people. Despite the consensus on water policy there is considerable debate over the practical implementation of any reforms. Efficiency is a necessary but not sufficient condition for sustainability, but just how constraining sustainability standards ought to be remains an open scientific and policy question. The methods and techniques reviewed in this report can provide a decision support toolbox to assist in the answering of these composite 'sustainability' questions and challenges.

AN INTEGRATED FRAMEWORK TO WATER RESOURCE VALUATION, APPRAISAL AND MANAGEMENT

Given the generic goal of sustainable water resource management, the approach taken is based on an interdisciplinary, analytical framework in which water is viewed as an integral component of a catchment-wide ecosystem, a natural resource, and a social and economic good, whose value is based on the linkage between water resource structures and processes and the goods and services that they provide at the respective temporal and spatial scale.

The evaluation framework and decision support system proposed in this document is in line with the sustainable water resource management approach advocated by the World Bank (World Bank, 1993). This has as its core the adoption of a comprehensive policy framework and the treatment of water as an economic good, combined with decentralized management and delivery structures, greater reliance on pricing, environmental protection and fuller participation by stakeholders. The adoption of this framework facilitates the consideration of relationships between the ecosystem and socio-economic activities on an extended geographical scale. It takes into consideration social, environmental, and economic objectives and the views of all stakeholders. Water management at this scale needs to be underpinned by coupled hydrological economic models and information (Rosegrant *et al.,* 2000). This form of analysis is still in a fairly rudimentary stage but is evolving quickly.

At the heart of this approach are a number of generic **principles** that together form a powerful and comprehensive case for the wider adoption of a decision support system based around economic analysis, and which provides a thorough and powerful analysis of key issues related to agricultural use of water:

The principle of economic efficiency and cost-benefit analysis. In an environment of increasing water scarcity, the allocation of water should be at least informed, if not guided (for political reasons), by the full economic value of water in its various uses. When determining the efficiency of water use, as many costs (e.g. destruction of wetlands through over-extraction of water) and benefits (e.g. purification of water through groundwater recharge by using household waste water for irrigation) of water use as is feasible need to be considered. The value of water to a user is the cost of obtaining the water plus the opportunity cost. The latter is given by the willingness to pay for the water in the next best alternative use (in terms of social welfare). For goods and services that are marketed, economic value can be determined using market prices. Methods are available that provide proxy estimates of value for goods and services that are not marketed, though application of many of these is sometimes problematic in the context of developing countries. Water pricing remains a complex process with its own ‘political economy’ arising from the set of legal, institutional and cultural constraints that condition water resource allocation and management in all countries. Economic efficiency as an objective will often have to be traded off against other decision criteria, but will gain in significance as the full social costs of water service provision escalate.

The principle of integrated analysis. The allocation of water has social, cultural, political, as well as economic impacts on society. For it to be sufficient, assessment of water allocation options is therefore required to assess these multiple impacts and interactions between them. This entails a shift away from a more simplistic and narrow sectoral view to a wider perspective that encompasses relevant economic, social, cultural, and political processes. Such an approach is provided by the proposed framework for integrated assessment.

The principle of an extended spatial and temporal perspective. The volume and quality of water supplies and the functions that they provide are determined by the abstraction of water, recharge of water resources and processes of the hydrological system. The thorough assessment of options for water allocation entails consideration of these processes and therefore requires the adoption of an extended geographical perspective. Such a perspective incorporates surface water processes at the catchment scale, ground water processes at the aquifer scale, interactions between surface and ground water, and socio-economic drivers in the wider environment that impact on water resources. Sustainability of water resources also requires a longer i.e. intergenerational, time scale for planning and management, with due regard for precautionary motivations.

The principle of functional diversity maintenance. Water resources provide many environmental goods and services that are of economic benefit to society (e.g. the amenity and recreational value of wetland sites, maintenance of biodiversity in surface water systems, purification of water through aquifer recharge). Diversity in the environmental functions that are provided by water resources contributes to the stability of the associated ecosystems and to the capacity of the ecosystems to recover from stresses and shocks. Of more importance to human development, the maintenance of this diversity also allows the continued provision of goods and services. Maintenance of functional diversity is, therefore, a key component of sustainable water resource management. This is fostered through the adoption of a functional perspective in integrated assessment, which indicates to decision-makers the diversity of existing environmental water resource functions and potential impacts on these of changes in water allocation.

The principle of long term planning and precaution. The criterion of sustainable (water use (in terms of quantity and quality) should supplant short term expediency. In terms of quantity, sustainability requires that current water abstractions should not impose costs upon future generations. The quantity of water that is available for use in any particular period is equal to effective runoff, i.e., the difference between total precipitation and the amount lost through evapotranspiration, plus the stock of freshwater (water stored on the surface or underground). The sustainability rule (at least at the national level) is that water demand should be met out of effective runoff only (Dubourg, 1992). From the quality perspective, sustainability requires that: water quality is non-declining over time. However, the concept of desirable water quality is complex, ambiguous and varies between time and place, making this rule difficult to operationalize. Hence, except in cases where effluent levels exceed critical loads, sustainability arguments cannot be used categorically as justification for improving water quality.

The principle of inclusion. Interactive, participatory and inclusive approaches involving decision-makers, experts and other stakeholders help ensure that decisions focus on real world problems, and that possible solutions are elicited using the combined knowledge and experiences of decision-makers, experts, interest groups and the lay public. They also assist in identifying distributional concerns and increase the chance of consensus being reached on proposed solutions.

In summary, a transparent appraisal of water related projects, programmes or courses of action require a comprehensive assessment of water resources and supporting ecosystems. Based on appropriate scales of analysis, the drivers, pressures, states, impacts and resources (DPSIR) auditing and scoping framework is deployed to highlight the main causal mechanisms that underlie the pressure that is being placed on water resources. Scenario analysis can play a useful role in sustainability planning and recognition of policy options. An explicit focus is required on the distributional consequences of water allocation, together with 'coping' strategies for greater stakeholder inclusion in the decision-making process. At the project, policy or programme level, economic appraisal, suitability modified by ecological sustainability principles, need to be applied in a rigorous fashion to assist in the identification of the preferred policy options. Finally, adequate resources need to be put into monitoring and feedback systems to guide the evolution of policy/management options.

Chapter 1

The role of water in agricultural development

Agriculture has, arguably, been very successful at capturing the major share of the world's exploitable water resources. However, the environmental and socio-economic rationale for this capture by the sector is now being questioned. This review presents a framework and a suite of techniques for analysing these issues and making the rationale explicit and transparent. It is not a field manual but rather an 'advocacy' brief. It sets out to bring together economic and ecological evidence and argumentation in support of the need to challenge and change the fundamentals of the prevailing technocentric view of water resources exploitation. A new and more suitable approach to water resources allocation is necessary if the world's population is to be adequately fed, without further degradation and destruction of the planet's critical ecosystem services. Water productivity needs to be enhanced considerably, and economic cost–benefit analysis and pricing regimes can play a significant role in such a process. However, these economic measures will not be sufficient on their own. They will need to be buttressed by technological innovation and institutional changes in order to encourage a more equitable distribution of resources and to mitigate potential international conflicts across 'shared' water basins.

Water has unique characteristics that determine both its allocation and use as a resource by agriculture. Agricultural use of water for irrigation is itself contingent on land resources. An overview of economic characteristics of water and their implications is presented below. The case for improved allocation of water to the agriculture sector and improved allocation within the agriculture sector is then presented. In a situation of growing water scarcity and rising demands for non-agricultural (household and industrial) use of water, reassessment of sectoral allocations of water are inevitable. In developing countries, irrigated agriculture plays a vital role in contributing towards domestic food security and poverty alleviation. Therefore, achievement of these objectives is dependent on adequate allocations of water to agriculture. Justification of such allocations requires that irrigated agriculture be a cost-effective means of achieving stated political or social objectives, such as food security or poverty alleviation, and that all externalities be taken into account in the pricing mechanism. Improved allocation of irrigation water is required within the agriculture sectors of developing countries in order to achieve greater efficiency in the use of irrigation water and existing irrigation infrastructure. Reallocation is also required in order to reduce waterlogging and salinization of irrigated land, to decrease the negative environmental impacts and other externalities of irrigation (caused by overextraction of groundwater and depletion and pollution of surface water). The following chapters set out the methods and techniques for achieving improved allocation to and within the agriculture sector. Fundamental to the proposed approach is the adoption of a functional ecosystem perspective for water resources, which underpins water resource management on at least a catchment scale. This is presented at the end of this chapter.

ECONOMIC CHARACTERISTICS OF WATER

Water provides goods (e.g. drinking-water, irrigation water) and services (e.g. hydroelectricity generation, recreation and amenity) that are utilized by agriculture, industry and households.

Provision of many of these goods and services is interrelated, determined by the quantity and quality of available water. Management and allocation of water entails consideration of its unique characteristics as a resource. These are discussed in brief below.

Water used for irrigation can be pumped from reserves of groundwater, or abstracted from rivers or bodies of stored surface water. It is applied to crops by flooding, via channels, as a spray or drips from nozzles. Crops also obtain water from precipitation. Water infiltrates into the soil, evaporates, or runs off as surface water. Of the water that infiltrates the soil, some is taken up by plants (and later lost through transpiration) and some percolates more deeply, recharging groundwater. This water can be polluted with agrochemicals (fertilizers, herbicides and pesticides), with salts leached from the soil and with effluent from animal waste. However, pollution can be attenuated as the water moves through the ground by processes that include sorption, ion exchange, filtration, precipitation and biodegradation. Aquifers can also be sources of pollution. Pollutants can be released into groundwater from pockets of contaminants or natural materials (e.g. sources of fluoride) within the aquifer. When river levels are low and groundwater levels are high, groundwater can recharge the levels of surface water, which creates a two-way linkage between resources of surface and groundwater.

It is not easy to control or prevent water use. Many uses of water involve the withdrawal of water from the hydrological system (known as 'extractive' or 'off-stream' use). Typically, only a small proportion of the water withdrawn is consumed. Water consumption is exclusive in its use. Consumed water is retained in plants, animals, or industrial products, so it is not available for other uses. However, most of the water withdrawn is not consumed and it returns to the water system for reuse at a later time and a different location. Water in return flows can re-enter the surface water system further downstream, can percolate into aquifers, or evaporate, returning to the hydrological system in gaseous form. Therefore, water withdrawals are not exclusive within a broad perspective on water use, but only within a narrow location- and time-specific context. Water can also be used in-stream without removal from the hydrological system (e.g. in hydroelectric power generation or boating). Such uses generally entail little or no consumption of water but do affect the location and time at which water is available for consumption by other uses (Young, 1996).

Water is a 'bulky' resource. This means that its economic value per unit weight or volume tends to be relatively low. Therefore, its conveyance entails a high cost per unit of volume and is often not economically viable over long distances unless a high marginal value can be obtained. The costs of abstraction, storage and any conveyance tend to be high relative to the low economic value that is placed on the use of an additional unit of water. This can create values for water that are location specific (Young, 1996). A further characteristic of water is that the quantity of supply cannot be readily specified; it is determined by various processes: the flow of water; evaporation from the surface; and percolation into the ground. In the case of surface water, supply is determined largely by the climate. Consequently, the quantity supplied is variable and can be unreliable. This can preclude certain uses of water (e.g. the development of water-dependent industries) and affect the value of water in some uses (e.g. irrigation). The quality of water (i.e. the nature and concentrations of pollutants) can exclude certain uses (e.g. drinking-water for household use), but have no impact on others (e.g. hydroelectric power generation).

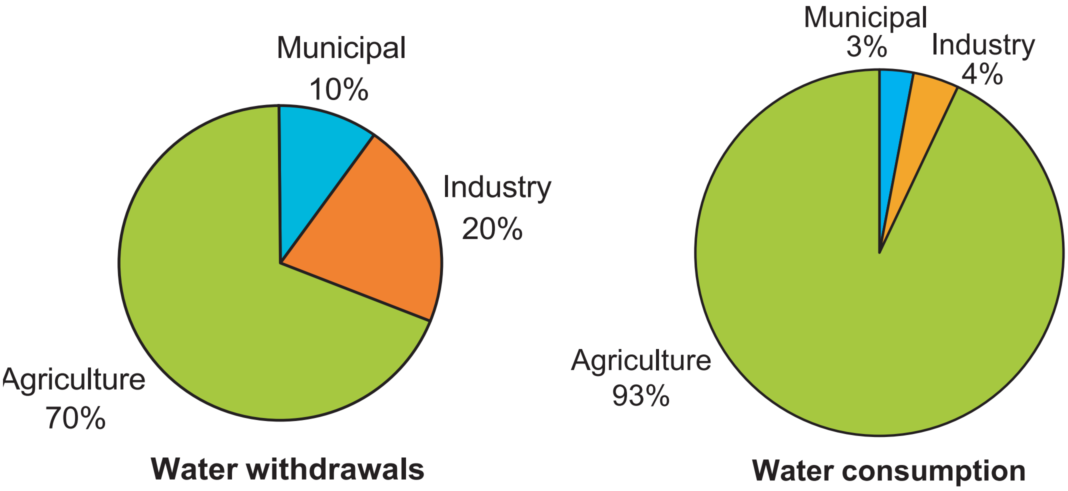
Characteristics of demand for water for irrigation relate to quantity, location, timing and quality. Irrigation generally requires large volumes of water, which can be low in quality. This is in contrast to household use of water, for example, which requires low quantities of water of high quality. The large volumes of water required for irrigation usually have to be transported over some distance to the field. For surface water, canals and pipes can enable conveyance; in the case of groundwater, extraction is provided via tubewells. In terms of timing, demand for irrigation water can extend through the growing season and, where adequate supplies are available, extend into the dry season for multiple cropping. Peak demand for irrigation water does not usually coincide with peak flows of surface water. This creates the need for storage capacity, which naturally occurring waterbodies (lakes, wetlands and aquifers) or specially constructed dams may provide. Although the quality of water required for irrigation is low, high levels of salinity preclude its use for irrigation, and contaminated supplies can reduce the quality of produce (e.g. contamination of horticultural produce with pathogens in polluted water supplies). Agriculture is implicated in issues that concern water quality. Leaching of effluent from animal wastes, especially from intensive livestock production, can pose a serious water pollution risk. Both return flows of irrigation water and precipitation runoff from arable land can pollute surface water with nutrients, herbicides, pesticides, salts leached from the soil, and sediment.

THE DOMINANCE OF AGRICULTURAL WATER USE

Irrigation is a vital component of agricultural production in many developing countries. In 1997–99, irrigated land provided two-fifths of crop production in developing countries, and accounted for about one-fifth of the cultivated area. The divergence in these statistics reflects the high crop yields and multiple cropping that are achieved through irrigation (FAO, 2002a). Developing countries are particularly dependent on irrigation: in 1997-99, 59 percent of cereal production in developing countries was irrigated (Bruinsma, 2003). Food production in developing countries is increasing in response to the demands of an expanding population and rising prosperity. Some of this demand will be met by increased productivity of rainfed agriculture, some by increased imports, but irrigated agriculture will be a major contributor.

- Agriculture is the largest user of water in all regions of the world except Europe and North America (FAO, 2002b). In 2000, agriculture accounted for 70 percent of water withdrawals and 93 percent of water consumption worldwide, where consumption refers to withdrawals net of returns flows and evaporation (Figure 1). This is in contrast to industry, which accounted for 20 percent of withdrawals and 4 percent of consumption worldwide in 2000, and household use, which accounted for 10 percent of withdrawals and 3 percent of consumption (FAO 2004 (AQUASTAT-database) FAO, 2002b). The water requirements

FIGURE 1
Water withdrawals and consumption



of agriculture are large relative to water requirements for other human needs. The human body needs about 3 litres of water per day;

- For domestic uses people use approximately 30 – 300 litres of water per person per day;
- To grow their daily food needs people require 3000 litres of water per person per day. (FAO 2003)

However, the agriculture sector is often criticized for high wastage and inefficient use of water at the point of consumption (i.e. at farm level) encouraged by subsidized low charges for water use or low energy tariffs for pumping.

It is often claimed that the charges made for irrigation water, fail to signal the scarcity of the resource to farmers. This situation may persist because of entrenched interests, political problems associated with price reform, practical difficulties in measuring and monitoring water use, and social norms, e.g. perception of water as a free good and access to water as a basic right (Rosegrant, Cai and Cline, 2002). These low charges can have an adverse impact on the effectiveness of irrigation systems and water use. They result in poor maintenance and consequent inefficient operation of existing irrigation systems, limited capacity for improvements or investment in new infrastructure, and waste of water at the farm level. Furthermore it is claimed that the subsidies provided for irrigation water tend to favour the wealthy and thereby exacerbate inequalities in resource access and wealth distribution in rural areas (De Moor and Calamai, 1997).

Water used for irrigation comes from surface water or groundwater. The use of groundwater for irrigation enables the extension of irrigated area beyond that which surface water alone can support. In addition, it assists with drainage of the soil (by lowering the groundwater table and providing drainage of soil water into tubewells). Groundwater can supplement surface water during periods of low flow, making surface water available for alternative uses. It is also used as a sole source of irrigation water. For example, in India, more than half of irrigated land is supplied with groundwater, providing one-third of the country's food production (Roy and Shah, 2003). Groundwater has various advantages over surface water: it can be stored in aquifers for years with little or no evaporative loss; the percolation of aquifer recharge water through the ground attenuates pollution levels (making groundwater particularly suitable as a source of drinking-water, especially in areas with no water treatment facilities); groundwater can be withdrawn near the point of use; and it is available immediately on demand, which enables more timely applications of irrigation water. However, groundwater contains dissolved salts that can be toxic to plants and result in soil salinization. Groundwater can be combined with surface water to dilute salt concentrations to levels suitable for use in irrigation.

Surface water for irrigation is stored either in natural storage capacity (lakes and wetlands) or artificial capacity created through the construction of dams. Dams are usually constructed for the purposes of water storage for irrigation, hydroelectric power generation, flood control, or any combination of these. However, in the case of dual-purpose dams designed to store water for irrigation and hydroelectric power generation, conflicts can arise because increases in demand for irrigation water in the dry season exceed demand for power. This creates difficulties in the specification of the required storage capacity and the timing of water releases. The situation is yet more complex for dams also designed to provide flood protection. Effective provision of flood control requires storage capacity that is empty, but effective storage of water for hydroelectric power generation and irrigation requires storage capacity that is kept as full as possible (though seasonal flooding and flood prediction can limit these conflicts). Despite potential for conflict, provision of storage capacity for irrigation combined with other uses can have advantages. The combined value of storage capacity for multiple purposes may be required in order to make large dam developments economically viable. Moreover, the provision of storage capacity for non-agricultural uses can provide contingency against failure of irrigation schemes to meet predicted uptake and economic returns, e.g. through potential to develop further power generating capacity.

The design and implementation of irrigation projects has traditionally been the domain of engineers and agronomists. In response to a commitment to a more developed approach to water management, a broader multidisciplinary perspective on irrigation is evolving (FAO, 2003b). This approach incorporates social, cultural, environmental and wider economic impacts of irrigation projects. Nevertheless, implementation of this perspective on the ground in the development and management of irrigation projects and programmes remains a persistent challenge. However, this challenge can begin to be addressed by the appropriate deployment of the functional approach to water management advocated here.

Pressures on the supply of water for irrigation

Supply of bulk water for irrigation is under pressure from the demands of other water-using sectors, constraints on further water resource development and is compounded by poor maintenance of existing irrigation infrastructure.

Demand for water for non-agricultural uses is increasing in response to economic growth, rising populations and increased urbanization. Rising urban demands for water (for household and industrial use) pose a particular threat to agriculture because urban demands take priority over rural demands in situations of potential conflict. This is because existing urban supplies are usually polluted, they can be associated with high health risks (such as the risks of epidemic diseases), new urban supplies have to come from increasingly distant sources (owing to scarcity in supplies), and the economic benefits of urban water supplies exceed those of rural supplies. Worldwide, withdrawals of water for household and industrial use quadrupled between 1950 and 1995, while withdrawals for irrigation only doubled in the same period (FAO, 2003c). In terms of future demand in developing countries, non-agricultural demand for water is forecast to increase by 100 percent between 1995 and 2025 and agricultural demand to rise by only 12 percent (given prevailing trends). Rosegrant, Cai and Cline (2002) observe that this is the "first time in world history" that absolute growth in non-agricultural demand for water will exceed growth in agricultural demand. It will result in a fall in agriculture's share of total water consumption in developing countries from 86 percent in 1995 to 76 percent in 2025.

Increases in non-agricultural demands for water are coinciding with constraints on further development of new water sources. In combination, these two factors are creating increased water scarcity and they will result inevitably in the transfer of water from agricultural use to higher value household and industrial uses. Urban areas can and do appropriate water supplies from rural areas, resulting in depletion and pollution of surface water resources used by farmers and rural households. In areas of India and the Philippines, water supplies have been diverted from large irrigated areas, seasonally or permanently, to meet urban demand, without any payment of compensation to farmers for resultant losses in crop production (IWMI, 2000). Increases in household and industrial demand for water are expected to result in increases in the scarcity of water for irrigation

IRRIGATION AND AGRICULTURAL DEVELOPMENT OBJECTIVES

Governments and donors have traditionally justified allocation of water to agriculture on grounds of food security and rural development. These are examined below, followed by a brief overview of relevant aspects of the international consensus that has emerged in water management policy.

Food security

Irrigation enables greater agricultural production than is achieved with rainfed agriculture. The additional food production obtained with irrigation is essential for food security on a global level, and on a national level for some countries. National food security is attained either through the pursuit of self-sufficiency in food (i.e. meeting demand through domestic production) or through a combination of domestic production and imports. Food self-sufficiency was once a widespread objective and some nations still aspire to it. It creates savings in foreign exchange, protects domestic producers and consumers from the fluctuations of world markets, ensures rural food supplies and contributes to a political sense of national security. However, it has disadvantages. In arid countries, a self-sufficiency policy can increase allocations of water to agriculture at the expense of industrial and household water use, and can contribute to the overextraction of groundwater resources. Moreover, food supplies are vulnerable to extreme weather events, and shortfalls in supply then have to be met through imports, which eat into limited resources of foreign exchange. In response to various factors, which include increased water scarcity, reduced availability of agricultural land, and industrial growth, many countries have moved towards an objective of food security partly enabled by imports (FAO, 2002a). However, successful pursuit of such an objective is reliant on adequate regulation of world trade in foodstuffs, to provide assured imports under fair terms of trade.

Global demand for food is increasing as the population continues to grow and increase in prosperity. Demand pressure is concentrated in developing countries, where demand for agricultural products is forecast to increase at an average rate of 2 percent per year from 1999 to 2030 (FAO, 2002b). Food demand is also affected by a shift in diets, which is occurring in developing countries as a result of increased prosperity, urbanization and changing preferences. Populations in developing countries are tending to consume more livestock products, more fruit and vegetables, and fewer cereals than in the past. Meat consumption in developing countries is projected to increase by 44 percent per capita from 1997/99 to 2030 (Bruinsma, 2003). Combined with a general shift in animal production from extensive (i.e. grazing) to intensive (i.e. cereal-fed) systems and the low efficiency of meat production, this is creating increased demand for cereals (such as maize) for animal feed. Cereals for animal feed account for half of the projected 70-percent increase in demand for cereals forecast to occur in developing countries between 1997/99 and 2030. Irrigation is used particularly important to produce cereals. For example, almost 60 percent of the cereal production in developing countries in 1997/99 comes from irrigated land (FAO, 2003c). However, it also contributes to meeting increased demand for other foods.

Increased demand for food in developing countries will be offset at a national level, to various extents, by increased agricultural production. A 61-percent increase in annual cereal production is expected to occur in the period 1997/99–2030 (Bruinsma, 2003). With the exceptions of sub-Saharan Africa and Latin America (where rainfed agriculture has greater significance), irrigated agriculture will provide much of this increase. In developing countries collectively, irrigated agriculture will provide 57 percent of the additional 256 million tonnes of cereals that will be produced in 2025 relative to 1995. Irrigation increases agricultural production through both the expansion of cultivable area beyond that possible under rainfed agriculture and higher crop yields. FAO (2002b) predicts that 70 percent of the increase in agricultural production that is forecast to occur in developing countries from 2000 to 2030 will come through increased yields, 20 percent through expansion of crop area and 10 percent through increased cropping intensity (multiple cropping and reduced fallow). Irrigation increases yields not only through reduction or prevention of crop water stress, but also through complementary benefits of combined use of irrigation with high yielding varieties, fertilizers and pesticides ('green revolution' technology). Yields for cereals produced with irrigation exceeded rainfed yields by 115 percent in developing countries collectively and by 150 percent in sub-Saharan

Africa and West Asia/North Africa in 1995. Although yields for irrigated cereal production in developing countries are increasing by 1.2 percent per year, it is at a reduced rate relative to 1982–1995 (1.9 percent per year).

Increases in yields for irrigated cereals in developing countries are expected to be of a similar proportion to increases in yields for rainfed cereals in the period 1997/99–2030 (annual increases of 0.9 and 0.8 percent, respectively). However, higher initial yields for irrigated cereals will result in greater absolute increases over this period. For developing countries collectively, average weighted yields for irrigated cereal production are expected to increase by 1.4 tonnes/ha, compared with an increase of 0.5 tonnes/ha for rainfed cereals between 1997/99 and 2030 (Bruinsma, 2003). Irrigated agriculture is thereby forecast to contribute significantly to increased future food production through both high and increasing crop yields.

In addition to increasing productivity, irrigation also enables expansion of the area under cultivation. In 1997/99, irrigation was used on 21 percent of arable land in developing countries collectively, though this was subject to considerable regional variation. In South and East Asia, irrigation was used on 39 and 31 percent of arable land, in the Near East and North Africa, 30 percent of arable land was irrigated, and in sub-Saharan Africa and Latin America (including the Caribbean), irrigation was used on only 2 and 9 percent of the arable area, respectively (Bruinsma, 2003). Expansion of the area under irrigation is expected to be concentrated in developing countries. Absolute increases in irrigated arable area for the period 1997/99–2030 are forecast to be greatest in Asia (an increase of 14 million ha in each of South and East Asia). In sub-Saharan Africa and Latin America, expansion of the irrigated arable area is expected to be low in absolute terms (an additional 2 and 4 million ha, respectively), though these represent large proportionate increases (of 40 and 22 percent) (FAO, 2003c). In the period 1962–1998, the area under irrigation in developing countries increased at an average rate of 2 percent per year, adding a total of 100 million ha to the area under cultivation (FAO, 2002a). However, the net increase in irrigated area in developing countries from 2000 to 2030 is expected to be 60 percent less than the net increase achieved for the period 1960–2000 (FAO, 2003c). The forecast growth rate in irrigated area (0.6 percent per year) is one-third of that achieved in the period 1960–2000. In developing countries collectively, the slowdown in the development of irrigated arable land will be countered to some extent by expansion in the arable area under rainfed crop production. Consequently, the share of total cereal area under irrigation in 2030 will remain relatively unchanged from 1997/99. In developing countries collectively, 22 percent of the arable area will be irrigated (FAO, 2003c).

Climate change is expected to affect agricultural production in developing countries, particularly through increases in temperature in arid regions (which will reduce the potential for crop production) and greater variability in the climate (which will cause increases in the frequency and duration of crop water stress). It will tend to increase local fluctuations in crop production and food supplies, particularly affecting food supplies and the incomes of poor people, and to increase national vulnerability to food insecurity (FAO, 2003c). In certain regions, the effects could be significant even in the next few decades. For example, climate change could cause a 2–3-percent decline in cereal production in Africa by 2020 or 2030. Assuming that other factors remain constant, this would increase the number of people at risk of hunger by 10 million (FAO, 2003c).

Demand for food is not met solely by domestic production in many developing countries; imports of food are required to varying extents. In 1997/99, cereal production represented 91 percent of demand for cereals (a total of 1 026 million tonnes) in developing countries (FAO, 2003c). However, this aggregation hides regional extremes. In the Near East and North Africa, domestic cereal production represented 63 percent of demand. In sub-Saharan Africa and Latin America (including the Caribbean), it represented 82 and 88 percent of demand, respectively, and in East and South Asia, production met 95 and 102 percent of demand. Reliance on imports is forecast to increase. In 1997/99, cereal imports accounted for 9 percent of demand in developing countries collectively and they are predicted to grow to 14 percent of demand by 2030 (Bruinsma, 2003).

Poverty alleviation

In an appropriate environment and with suitable planning (e.g. provision of training and credit), investment in irrigation schemes can alleviate poverty both directly and indirectly through stimulation of the rural economy. Indeed, the purpose of many large scale schemes associated with the Green Revolution in Asia was more to do with addressing food security and poverty targets rather than direct commercial returns. (Plusquellec, 2002). This nootion and practice persists. The IFAD "Report on Rural Poverty 2001" is clear in stating that irrigation schemes have direct benefits for poor people, given the required policy and institutional environment (IFAD, 2001). Even if irrigation is not specifically targeted at poor beneficiaries, irrigation stimulates the agriculture sector of the rural economy indirectly through increased demand for agricultural inputs (including agricultural labour, services of local artisans who manufacture tools and equipment, seed and fertilizer) and the marketing of additional produce. Increased incomes in farming communities can create demand for non-agricultural goods and services (e.g. meat, processed foods, clothes, and repair of bicycles), many of which are marketed only locally and can be supplied by resource-poor individuals. The resultant stimulation of non-farm incomes can help to reduce absolute poverty in rural areas in the long term (Bruinsma, 2003), and it can reduce relative poverty as long as the prevailing asset distribution is not too skewed.

Increased food production from irrigated agriculture can confer nutritional benefits for farmers, their families and the local population (through increased food supplies). Irrigation can enable multiple cropping, which can smooth seasonal shortfalls in food supply and encourage the production of crops that contribute towards a more varied and nutritious diet. Improved nutrition can enhance quality of life, reduce illness, increase labour productivity, and improve the performance of children at school (FAO, 2003c). Irrigated agriculture can also benefit the urban poor by keeping food prices low despite growing demand from increasing populations (IWMI, 2000). Indeed, continuation of the current decline in irrigation investment could eventually cause an increase in world cereal prices food prices, which would affect the poor in particular as a large proportion of their income goes on food.

However, irrigation can have a negative impact on the health of rural households through exposure to parasitic infections and to diseases transmitted by water-related vectors such as malaria (associated particularly with canal distribution systems and flood irrigation). Moreover, in an inappropriate environment, e.g. where land is not evenly distributed, economic benefits of irrigation may be received predominantly by wealthy farmers and reinforce inequalities in the distribution of resources and wealth. The policy and institutional environments play critical roles in determining whether irrigation has positive impacts for poor people (FAO, 2003).

International consensus in water policy: water as an economic good

An international consensus in water management has emerged, based on growing concerns about efficiency in the use of government and donor resources, disappointing outcomes from past efforts, and greater awareness of environmental issues (European Commission, 1998). These concerns are manifest in for example, the water policy of the European Community (or the so-called Water Framework Directive), which promotes the use of water pricing and charging as a means of enhancing the sustainability of water resources, and on integrating economics into planning and decision-making. The policy consensus has also been shaped by a reorientation of the development cooperation agenda that has resulted, among other issues, in greater focus on institutional reform, participation, and involvement of civil society and the private sector.

Three agreements lie at the core of the consensus concerning water policy: (i) a set of key recommendations (known as the "Dublin Principles") agreed at the International Conference on Water and the Environment (1992); (ii) Chapter 18 (on freshwater resources) of Agenda 21, the action plan agreed upon at the United Nations Conference on Environment and Development (UN, 1992) held in Rio de Janeiro in 1992 and incorporating adoption of the Dublin Principles for water resources management in rural contexts; and (iii) the World Summit on Sustainable Development (UN, 2002) held in Johannesburg in 2002, which reaffirmed the 1992 "Dublin Principles" and highlighted water availability as a key concern and objective.

The consensus adopts an integrated approach to water resources and a multisectoral view of water use on at least a catchment scale. Water management is considered in relation to issues of economic efficiency, environmental protection, sustainability, and the needs of marginalized and poor people. Decision-making should involve the participation of users, particularly women, and should be driven by the needs of the community. Investments in the water sector are required to be economically efficient, socially acceptable and financially sustainable.

Despite the consensus on water policy, there is considerable debate on the practical implementation of any reforms. For example, while reforms in economic pricing of irrigation water have been proposed, the political economy of pricing policy reforms suggests a rather complex process in evidence (see Chapter 3). It is recognized that the main management challenge is not a vision of integrated water resources management but a "pragmatic but principled" approach that respects principles of efficiency, equity and sustainability, but recognizes that water resources management is intensely political, and that reform requires the articulation of prioritized, sequenced, practical and patient interventions (World Bank, 2003).

As indicated above, sustainability is a key aspect of water management decisions. However, the term sustainability is open to different interpretations, and these affect how it may be operationalized. The differences arise through use of a flexible or stringent interpretation of sustainability, described as weak and strong sustainability, respectively (Turner, 1993).

Sustainability requires that the stock of capital that is available for future generations be equivalent to that available at present. Here, the term capital refers to the overall stock of materials and information that generates goods and services that enhance social welfare. Capital can be subdivided according to whether it is depleted by the production of goods and services, as follows:

- Capital caused by human activities (e.g. factories, roads and houses). This can be increased or decreased at discretion.
- Critical natural capital (e.g. ozone layer, biodiversity and water). This is essential to human life and cannot be replaced by or substituted for with human-induced capital.
- Non-critical natural capital, which includes some renewable natural resources and some finite mineral resources. This can be wholly or partly replaced or substituted by human-induced capital.

Weak sustainability requires that the total stock of capital, human-induced and natural, be maintained, and it assumes substitutability between the two types of capital. As a natural resource becomes depleted, the price increases; this encourages more efficient resource use, substitution with other goods, and technological advancement. However, complete substitution is not necessarily practicable or possible, for example, because of the absence of substitutes for some forms of capital (e.g. critical natural capital), and inadequacy of substitutes (e.g. for complex ecosystems).

Strong sustainability requires that the total stock of natural capital not be depleted. Natural and human-induced capital are regarded as complements not substitutes (Daly, 1995) and stocks of both must be maintained. Consequently, activities are required to conserve the natural environment, or to ensure that any losses incurred are replaced or compensated for fully in physical terms through 'shadow projects' (Barbier, Markandya and Pearce, 1990). The use of a criterion of strong sustainability is likely to result in the wholesale rejection of development projects as most of these impinge to some degree on the environment. However, this rejection can be overcome by employing suites of projects that are designed to have elements that generate net environmental benefits (Pearce, Markandya and Barbier, 1989). Adoption of such an approach enables market-oriented decision-making to persist even under stringent sustainability requirements. The wetland mitigation policy of the United States of America provides an example of a strong sustainability requirement (Marsh, Porter and Salvesen, 1996). The policy requires that any loss of wetland be compensated for by an alternative wetland of equal physical quality. However, a number of problems have been encountered in implementing the policy. These include the definition of a suitable measure of the physical quality of wetlands (McCrain, 1992), and issues that relate to the locality and interactions with the landscape (Ledoux *et al.,* 2000).

The emerging approach to water governance is seeking to adopt a stronger sustainability approach, one guided by principles of stewardship, equity and accountability. The result will be to constrain the mindset and market mechanisms that treat water as a commodity in its various functions and seek to establish an efficient allocation of water among competing end uses. Efficiency is a necessary but not sufficient condition for sustainability, but exactly how constraining sustainability standards ought to be remains an open scientific and policy question. The methods and techniques reviewed in this report can provide a decision-support toolbox to assist in the answering of the composite sustainability questions and challenges.

Chapter 2

A framework for interdisciplinary analysis of water resources: a functional perspective

The interdisciplinary analytical framework proposed in this report examines the value of water resources based on the linkage between water resource structures and processes and the goods and services that they provide at the necessary temporal and spatial scale. After a discussion of the general nature and problem of environmental valuation, there follows a brief review of studies that have attempted to provide a valuation framework for water resources. The proposed functional perspective is then presented, followed by an overview of functions provided by water resources. This framework and perspective are in line with the general principles of sustainability discussed in Chapter 1.

THE NATURE AND PROBLEM OF ENVIRONMENTAL VALUATION

Although water resources perform many functions and are potentially very valuable, these values have often been ignored, with the result that depletion and degradation of the resource occur. The debate over what the value of water is, or of the environment and nature more generally, has highlighted the fact that the core concept is complex and multidimensional. An economic perspective on water portrays it as a natural asset providing a flow of goods and services, physical as well as aesthetic, intrinsic and moral. The main problem when including the full range of environmental services in economic choices is that many of these water-related services are not valued on markets. There is a gap between market valuation and the economic value of many water functions. The non-marketed gaps must first be identified and then monetized where possible. In the case of many of the functions, the identification of economically relevant services is of special importance as over time those services not allocated by the market have gained continuously in importance.

In considering environmental values, economists have generally settled for a taxonomy, the components of which add up to total economic value (TEV). The key distinction made is between use values and a remainder called non-use value. The latter component reflects value in addition to that which arises from usage. Thus, individuals may have little or no use for a given environmental asset or attribute but would nevertheless feel a 'loss' if such things were to disappear. However, the boundaries of the non-use category are not clear cut and some human motivations that may underlie the position that the asset should be conserved 'in its own right', and labelled existence value, are arguably outside the scope of conventional economic thought. In practice, the issue is whether it is meaningful to say that individuals can assign a quantified value to the environmental asset, reflecting what they consider to be intrinsic value.

Economic valuation, as discussed in Chapter 4, can be combined with an ecosystem function (and related goods and service outputs) approach to water valuation. What is therefore being valued is not the water ecosystem per se, but rather independent elements of ecological services provided by water. The aggregation of the main function-based values provided by a given water ecosystem has been labelled TEV. However, the aggregate TEV of the functions of a given ecosystem, or combinations of such systems at the landscape level, may not be equivalent to the total system value. The ability to value water ecosystem services is constrained by the complexity of the water ecosystem itself. The "production function" of water ecosystems is so complex, and little understood in many instances, that reliable estimates of all services are not possible. An aspect of this complexity is that joint products are inherent in most water ecosystem processes. Accounting for value must recognize all of these joint product values.

Previous studies

Young and Gray (1972) made an early attempt to provide a framework for understanding and analysing values of water in different uses. Gibbons (1986) later extended and updated their work. These studies aimed to provide understanding of the multiple uses that constitute water demand, determinants of that demand, and methods for estimating the value of water empirically. Gibbons (1986) examined water use in a number of sectors (municipal, agricultural, industrial, waste assimilation, navigation, hydropower, recreation and aesthetics), using a variety of techniques to estimate values for water use in each sector. The results, which were inexact, were intended to illustrate use of the valuation techniques and indicate possible ranges in values. However, sector-by-sector comparison of results was not possible owing to differences in the definitions, time frames and procedures employed in the analysis. The framework did not integrate the physical and economic aspects of water use, and external impacts between sectors were not considered fully.

The hydrological, physical and economic aspects of water resources were integrated in a more recent framework developed for economic evaluations of groundwater use. This framework is detailed in Bergstrom *et al.* (1996) and National Research Council (1997). The framework links changes in groundwater quality and quantity to changes in the services provided and, thereby, to the value placed by society on resultant changes in groundwater use. The framework describes the value of services provided by groundwater as the outcome of three sets of functional relationships between:

- human interventions and groundwater quantity/quality;
- groundwater quantity/quality and the stream of services provided by groundwater;
- the stream of services provided by groundwater and its economic value.

The value of groundwater is given by the present value of the stream of services that it provides. The framework is interdisciplinary. It requires information on a variety of hydrological, physical, biological and economic processes, and cooperation between disciplines is needed to establish the various linkages necessary for valuation. Although interactions between groundwater and surface water are recognized, the framework focuses only on the services provided by groundwater. Therefore, it stops short of the appropriately scaled and comprehensive analysis of both surface and groundwater that is required for thorough analysis of irrigation water use.

THE FUNCTIONAL PERSPECTIVE AT A CATCHMENT SCALE

As previously proposed (e.g. Young, 1996), economic valuation at the catchment scale can be used to enhance welfare through investments that capture, store, deliver and treat new water supplies, and through reallocation of water supplies among water-using sectors. However, the functional perspective enables more effective consideration of water not just in terms of water supply but also with regard to other dimensions, including water quality and supply reliability. Furthermore, the use of this approach within the context of the catchment system allows better evaluation of in-stream versus extractive uses, in particular with respect to return flows, and the implications of withdrawals or depletion in considering values of water resources.

Figure 2 depicts an overall framework for the water valuation problem. It can be used to increase transparency and hence the legitimacy in the monetary estimation of water values and their use in appraisal. Human activities exert pressure on groundwater resources, affecting the quantity and quality of the water and thereby changing the stream of services it can provide. This affects human welfare through its influence on stakeholders. Not all effects can be translated meaningfully and reliably into economic value because of limited knowledge and information. The shaded areas in Figure 2 represent this limitation, the darker shading indicates increased difficulty in application of valuation techniques.

Water resources are components of a more extensive set of interrelated systems encompassed within catchment (or wider) boundaries. More efficient management of water and related measures that protect the supporting ecosystems are all vital components of sustainable development. Given the latter generic policy goal, management agencies should seek to maintain the resilience of systems in terms of their ability to cope with stress and shock.

Maintenance and enhancement of system resilience is linked to the ecological concept of functional diversity and the social science analogue, functional value diversity. Therefore, management of water resources at the catchment scale is connected intimately with an appreciation of the full functioning of the hydrological, ecological and other systems and the total range of structures and processes and functional outputs of goods and services provided. Therefore, water management and pricing must be based on a relatively wide (at least catchment scale) appreciation of the landscape ecological processes present, together with the relevant environmental and socio-economic driving forces. Such a management strategy needs to be underpinned by a scientifically credible but also pragmatic environmental decision-support system, i.e. a toolbox of evaluation methods and techniques, which is complemented by a set of environmental change indicators and an enabling analytical framework.

The decision-support system used requires a number of steps or 'decision rules' in order to operationalize the analytical framework in a given catchment. The main steps are:

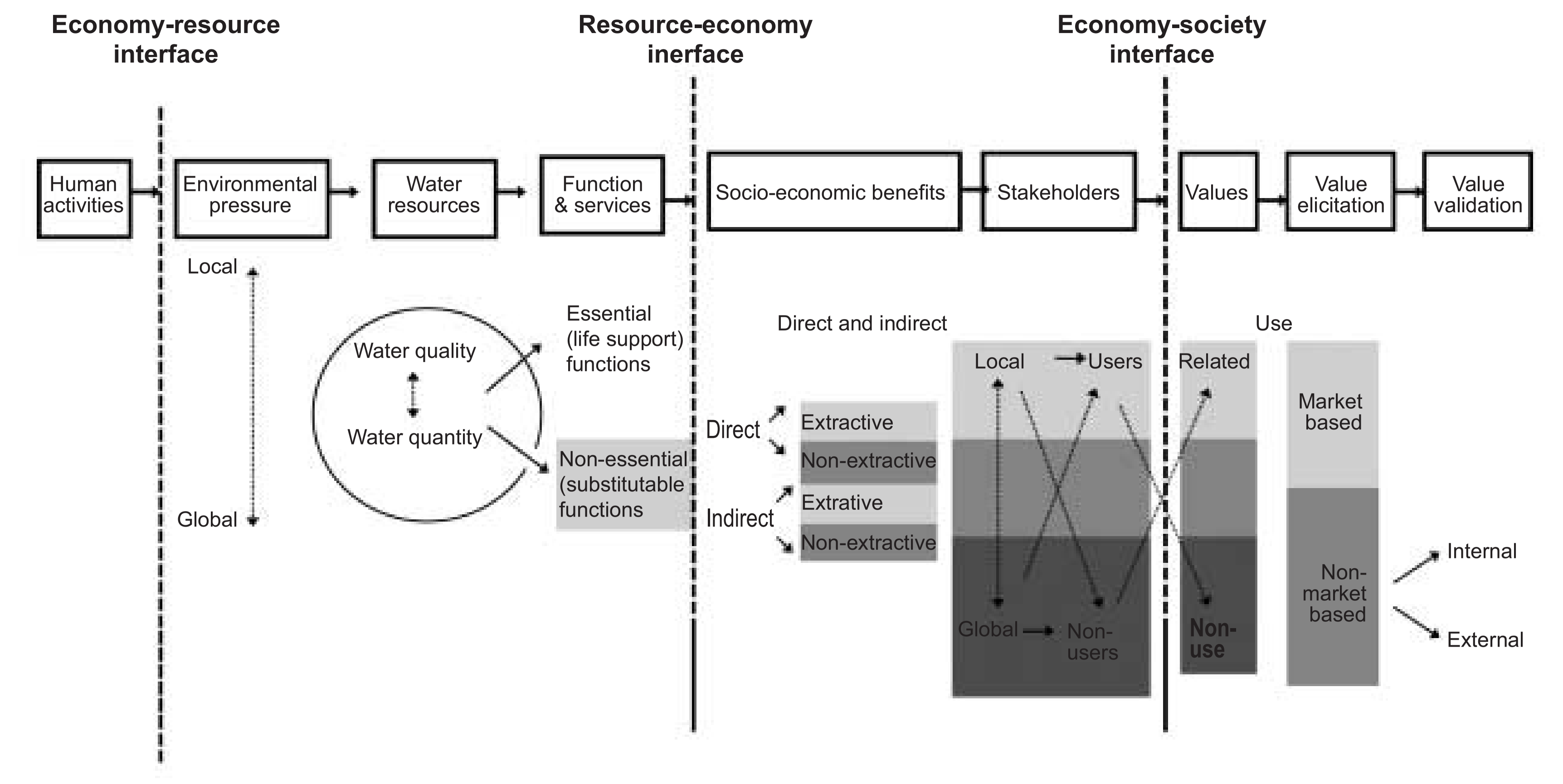
- scoping and auditing – this stage determines the nature, scope and scale of the problem and the relevant causes and consequences;
- identification, selection and coupling of analytical methods and techniques – such as a geographical information system (GIS), natural science models, and economic analysis;
- data collection and monitoring via indicators of change;
- evaluation of project, policy or programme options – using methods such as stakeholder analysis, cost effectiveness, cost–benefit analysis, and multicriteria analysis.

THE NEED FOR ANALYSIS AT THE CATCHMENT SCALE

Groundwater and surface water systems are of major socio-economic and biophysical importance. Much of their development and management has been piecemeal, often without regard for the natural processes that occur in the system as a whole, and in ignorance of the long-term effects of human activities on the system. This situation has arisen partly as a result of the differing interests of users and local, regional and national administrative and institutional bodies.

Policy-makers have recognized the importance of and need to protect water resources and to approach human activity and water resources in an integrated manner, for example, at the

FIGURE 2
A simple general framework for monetary valuation of water resources



Source: Turner, Brouwer and Georgiou (2001).

European level as laid down in the recent Framework Directive in the field of water policy (Directive 2000/60/EC). The "ecological principle" articulated in the Dublin Statement (Dublin Statement, 1992) also contains a requirement for the holistic management of water. Mitchell (1990) has argued that efforts towards a more integrated water resources management regime should seek to combine three related dimensions:

- in systems ecology terms, i.e. how each component of the water system (at the catchment scale) influences other components;
- in wider hydrological, biogeochemical and physical systems terms, i.e. the interactions that occur between water and other natural systems;
- in socio-economic, socio-cultural and political terms, i.e. the linkage of water management to relevant policy networks and economic and social systems (with attendant culture and history) so that chances of achieving a cooperative solution or mitigation strategy are maximized.

A critical requirement of integrated water catchment management is the introduction of water planning and management mechanisms that fit the catchment scale at least. A management strategy based on the principle of sustainable water resource utilization should have at its core the objective of catchment ecosystem integrity maintenance, i.e. the maintenance of ecosystem components, interactions among them and the resultant behaviour or dynamic of the system. Integrity is best protected when efforts are made to secure a diverse range of water system functions and their asset values, i.e. functional value diversity. This encompasses the variety of spatial and temporal scales on which organisms react to each other and to the environment (Steele, 1991). The onus is on analysts and managers to take a wider perspective and examine changes in large-scale hydrological and ecological processes, together with the relevant environmental and socio-economic driving forces. Groundwater and surface water resources are viewed as integral and management is considered from a wider ecosystem perspective rather than a more narrowly focused sectoral view. Protection of as diverse a range of functions as is practicable contributes to overall system resilience and the capacity to cope with stress and shock, allowing adaptation to both physical and social vulnerability (Adger, 1999). A policy objective of maximum diversity maintenance also serves to ensure the maximum amount of functional value in terms of goods and services provision. Such a management strategy requires the practical coupling of economic, hydrological and ecological models.

In order to manage water catchments holistically, one of the primary issues is whether the scale of administrative structures and appropriately refined scientific support equate with the scale of catchment processes. Management of water systems is too often focused on a sectoral basis, and constrained by political and institutional considerations. The proprietorial interests shown by communities towards their localities in catchments are extremely powerful forces, which democratic systems often find difficult to accommodate. However, water systems are driven by hydrological and ecological processes that transcend the local scale and the short term. These linked hydrological-ecological systems provide a wide range of benefits and services that are often ignored or undervalued in water use planning, leading to their long-term loss. Under a catchmentwide perspective, interrelationships, e.g. between upstream and downstream water use, are made explicit. They then provide an important basis for decision-making involving multiple water users, including agriculture. For example, water abstraction or water pollution upstream may have severe consequences downstream. The important issue of the distribution of costs and benefits of (changes in) water use only becomes visible if considered at their appropriate scale in time and space. For water systems, this is the catchment level, without which, it will be difficult to trace the impact of any upstream user's decision on the downstream beneficiaries of the service. Thus, it is difficult to allocate the value of the service and include it in the decision-making process. As they rely heavily for their productive capacity upon the water system (water being an essential input in agriculture), for agriculture to be sustainable from an economic, environmental and social perspective, this also has to be evaluated from a catchmentwide perspective. This is because farmers' practices and other socio-economic water use, either in the same subcatchment or dispersed throughout the whole catchment, will eventually, directly or indirectly, affect the aggregate viability of farming businesses throughout the whole catchment in which they reside. Furthermore, many water values are only attainable if a minimum of upstream users take the catchment perspective into account in their decision. For example, in a given area, a minimum amount of land users may have to agree to maintain riparian buffer strips in order to guarantee a certain water quality for domestic use for a downstream city, which makes negotiations complex. In cases where land uses have a noticeable impact on downstream water values, it will be just as important to take the land property rights into account in valuation exercises as the water property rights. Moreover, human intervention in these complex and large-scale systems can have results that are not understood fully at present (Turner, 2000).

ECOSYSTEM FUNCTIONING AND THE FUNCTIONS OF WATER RESOURCES

Ecologists refer to ecosystem functioning as the habitat, biological or system properties or processes of ecosystems. A variety of system processes are critical to the sustained functioning of natural ecosystems, such as the flux and transfer of water. Demand for the goods and services provided by catchments forms the link between catchment ecosystem functioning and the functional value of the catchment. This demand comprises use and non-use values for goods and services, both of which are dependent on the essential structure of the catchment ecosystems and the functions they perform. The term "function" is used, in socio-economic terms, to refer to the provision of goods and services that satisfy human needs and wants. It provides the link between water resource structures and processes and the provision of goods and services that are of value to society. Thereby, it creates an interdependent perspective of the ecological and economic systems. The economic value of water resources (regardless of the typology adopted) is contingent on the structures and processes performing functions that society perceives as valuable. Therefore, ecosystem structures and processes in themselves are not necessarily of economic value; such values derive from the satisfaction of human needs and wants by the goods and services they provide. Thus, it is important to identify the potential demand for these goods and services, rather than simply the degree to which they are provided. A number of these can be valued in economic terms, while others cannot because of uncertainty and complexity conditions.

Water resource ecosystems provide a wide range of goods and services of significant value to society, such as pollution attenuation, flood alleviation, recreation and aesthetic services. 'Valuing' the ecosystem consists of valuing the characteristics of the system, and capturing these values in an economic value framework. However, because the component parts of a system are contingent on the existence and continued proper functioning of the whole, it is quite a complicated matter to place an aggregate value on ecosystems.

The use of a functional approach has various benefits (adapted from Maltby, 1999):

- It should allow more efficient use of scarce resources by determining such relationships as the compatibility of water use activities with water resource structures and processes, the capacity of water resources to tolerate impacts, and their resilience to human disturbance.
- The approach recognizes a wide range of environmental interactions and is not restricted to a narrow view of conservation of assets.

- The dynamics of water resources can be translated more easily into economic terms, which are usually more understandable than ethical and scientific arguments to the public and politicians.
- A functional approach encompasses improvements in water use, environmental quality, human health and social welfare, which makes it more suited to the political agenda.
- It allows scope for policy innovation.
- It makes it possible to target more precisely the systems responsible for particular benefits, which should lead to more effective environmental protection. Effectiveness is increased through improved use of limited financial resources and better identification of priority areas for protection, rehabilitation and restoration.

MAINTENANCE OF FUNCTIONAL DIVERSITY

In order to manage water resources in a sustainable way, management strategies should aim to maintain catchment ecosystem integrity. This is best protected when a diverse range of environmental functions and their asset values are secured. From an ecological stance, functional diversity creates variety in responses to environmental change, in particular, variety in the spatial and temporal scales over which organisms react to each other and to the environment. From a social science perspective, a policy objective of maximum diversity maintenance serves to ensure maximum functional capacity and associated functional value in terms of the provision of goods and services. Implementation of this objective requires the practical coupling of economic, hydrological and ecological models. The first step is to compile a complete list of all the relevant boundary conditions for a catchment. These are the characteristic properties that describe the area in the simplest and most objective terms possible. Examples of such characteristics include hydrological, biological, chemical and physical features that describe a catchment, e.g. size, shape, depth, climate and other natural processes. These characteristics, singly or in combination, give rise via processes to benefits, which may be realized currently or be latent.

The economic worth of catchment ecosystem structure (the plants, animals, soil, air and water stocks and flows of which it is composed) is generally appreciated more easily than that of ecosystem processes. Evaluating processes such as nitrogen fixation, nutrient retention, pollution absorption and others for any given segment of catchment pushes scientific knowledge to its limits. Therefore, a precautionary approach is required in any catchment management strategy. It is also evident that there are strong linkages between the types of benefits. For example, the sound functioning of the catchment ecosystem through efficient nutrient, sediment and contaminant removal is necessary to ensure clean water. Although each of these benefits provides a distinct positive value within the overall system, the need to avoid double counting cannot be overstated.

The diversity of the functions provided by water resources is dependent on the complexity and diversity of their structures and processes. These provide stability, resistance and recovery from disturbance and change. Functional diversity provides capacity for environmental-economic systems to maintain functions under stresses and shocks, building on concepts of ecosystem integrity and resilience. In this context, integrity can be defined as the maintenance of system components, the interactions between them, and the resultant behaviour of the system (King, 1993). Resilience is the capability of the system to maintain stability in the presence of disturbances (often human-induced), determined by its stability and adaptability. The maintenance of functional diversity secures a range of water resource structures and processes, which offers the best protection of the integrity of the water resources and is therefore consistent with sustainable management. The diversity concept also encourages analysts to adopt an extended geographical perspective in the valuation of water resources: to encompass changes in large-scale processes (hydrological processes of both surface and groundwater, ecological processes, etc.) together with the socio-economic driving forces that cause or ameliorate environmental degradation.

The use of the concept of functional diversity highlights the importance of the deterministic relationship between the structures and processes of a water resource and the functions that it provides. The structures and processes of water resources can be divided into categories to enable analysis of the functions provided. According to de Groot (1992), the following environmental characteristics are relevant:

- bedrock characteristics and geological processes;
- atmospheric properties and climatological processes;
- geomorphological processes and properties;
- hydrological processes and properties;
- soil processes and properties;
- vegetation and habitat characteristics;
- species properties and population dynamics;
- life-community properties and food-chain interactions;
- integrated ecosystem characteristics.

The functions provided by water resources can also be categorized. De Groot (1992) describes them as follows:

- Regulation functions: the capacity of water resources to regulate ecological processes and life support systems. These contribute to the maintenance of a healthy environment.
- Carrier functions: provision of space and a suitable substrate or medium for human activities such as fisheries and recreation.
- Production functions: provision of resources, such as water, food, industrial raw materials, energy and genetic material.
- Information functions: the contribution to maintenance of mental health through the provision of opportunities for reflection, spiritual enrichment, cognitive development and aesthetic experience. In addition, there are unknown functions that are not yet recognized but may have considerable (potential) benefits to human society.

The quantity and quality of the surface water and groundwater available affect the functions provided by water resources. The volume of available surface water and groundwater determines the quantity of water available in the short term. In the long term, it is also influenced by rates of surface and groundwater recharge and discharge and rates of abstraction. Water quality is determined in the short term by pollution with natural and artificial contaminants. In the long term, it is also influenced by environmental processes (such as the attenuation of pollutants by groundwater processes).

In determining the value of water resource functions there are several issues to consider. These include:

- The spatial and temporal scale. Water resource processes operate over a range of spatial and temporal scales; the scales that are appropriate to study the management of one process may not be suitable for other processes.
- The persistence of the functions of a water resource is dependent on the complexity and diversity of its structures and processes. The diversity provides resistance and recovery from

disturbances and capacity for long-term adaptation, as well as being a sensitive indicator of environmental change.

- Water resources are dynamic in space and time. Change is the normal course of events. Natural or human-induced disturbances create an interrelated mosaic of change. This influences water resource processes at large spatial scales.
- Uncertainty and surprise are inevitable. There is much that is not understood about water resources. Progress will yield some new knowledge, but the complexity and interactions of non-linear processes means that certain elements of water resources will always be difficult to predict and that surprise outcomes are inevitable.

The valuation of the functions of water resources implies full knowledge of the goods and services provided and their worth to society. Table 1 presents a list of goods and services provided by surface and groundwater, though this is by no means comprehensive. These are divided into *in situ* and extractive uses of water, following the classification used by the National Research Council (1997). Some uses are attributed directly to either surface water (e.g. transport, recreation) or groundwater (e.g. attenuation of pollutants). However, many of the uses, such as irrigation and drinking-water, are common to both surface and groundwater owing to discharge/recharge interactions between the two.

As highlighted earlier, the value of water resource structures is generally appreciated more easily than that of the processes, but even the structures are incompletely known. Valuation of the species in a catchment, when many of these species have never been described taxonomically,

TABLE 1
A selection of goods and services provided by surface and groundwater

Surface water	Groundwater
In-situ uses:	
Flood and flow control	
Water quality maintenance	
Water storage	
Medium for wastes and other by-products of human economic activity	
Non-use services (e.g. existence or bequest motivation)	
On-site observation or study of wildlife and plants for leisure, educational and scientific purposes	Prevention of land subsidence
Recreational swimming, boating, canoeing, fishing, hunting, trapping, and plant gathering	Mitigation of saltwater intrusion
Informal recreation (non-contact activities along a river corridor)	
Amenity	
Commercial fishing, hunting, trapping, and plant gathering	
Habitat for plants, animals and micro-organisms (biodiversity)	
Food web support	
Climate stabilization / regulation through support of plants	
Transport	
Hydroelectric power generation,	
Storm protection / windbreak	
Shoreline stabilization	
Extractive uses:	
Agricultural: use in irrigation and for livestock	
Household: drinking-water, bathing and cleaning	
Industrial: use as a coolant, as steam, and as an input to production process e.g. processing and manufacturing	
Horticultural: use in irrigation of gardens and turf	
Discharge / recharge:	
Groundwater recharge	Contribution to stream flow
Improved water quality through support of living organisms	Attenuation of contaminants in surface water

exceeds available knowledge (Westman, 1985). The valuation of processes such as nutrient retention and pollutant attenuation pushes present scientific knowledge beyond its bounds. However, the preservation of catchment processes is as important a goal for conservation as is the preservation of catchment structure. The science of ecology has elucidated water resource processes to the extent that some management principles are evident, yet much research on water resource structures and processes is still needed.

STRUCTURES, PROCESSES AND FUNCTIONS OF WATER RESOURCES

The proposed analytical framework employs the concept of functions to link water resource structures and processes with the goods and services that they provide. Therefore, functions have environmental, ecological and economic components. The following sections (and Table 2) provide an overview of some of the more economically significant outputs provided by water resources.

Hydrological functions

Floodwater control

The floodwater control function of water resources is determined by three sets of variables: the potential for flooding downstream (which is environmental), the extent to which water

TABLE 2
A selection of catchment ecosystem functions and associated socio-economic benefits

Ecosystem structures and processes that provide the function	→	Function	→	Socio-economic benefits of the function	Threats to the function
		Hydrological			
Short- and long-term storage of over bank floodwater and detention of surface water runoff	→	Floodwater retention	→	Natural flood protection, reduced damage to infrastructure (e.g. roads), property and crops	Conversion of land use, drainage, reduction of storage capacity, removal of vegetation
Infiltration of water into the ground followed by percolation to aquifer	→	Groundwater recharge	→	Water supply	Reduction in recharge rates, overextraction, pollution
Retention of sediment carried in suspension by water from over bank flooding or surface runoff	→	Sediment retention and deposition	→	Improved water quality downstream, increased soil fertility on site	Channellization, excess reduction of sediment throughput
		Biogeochemical			
Uptake of nutrients (applied as fertilizers) by plants (N and P), storage of nutrients in the soil (as organic matter and through absorption)	→	Nutrient retention	→	Improved water quality	Removal of vegetation, cultivation of soil
Flushing through water system and gaseous export of N	→	Nutrient export	→	Improved water quality, waste disposal	Removal of vegetation, flow barriers.
		Ecological			
Provision of sites for invertebrates, fish, reptiles, birds, mammals and landscape structural diversity	→	Habitats for species (biodiversity)	→	Fishing, hunting, recreational amenities, tourism	Overexploitation, overcrowding and congestion, disturbance of wildlife pollution, inadequate management
Biomass production, biomass import and export via physical and biological processes	→	Food web support	→	Agricultural production	Conversion of land use, excessive use of inputs (pollution)

Source: Modified from Turner *et al.* (1997) and Burbridge (1994).

resources influence flooding (also environmental), and the damage caused to resources and structures by potential flooding (economic). The potential for flooding downstream is a product of the hydrological system: the capacity of the system to transport and absorb increases in water volume, e.g. through storage in waterbodies. The likelihood of flooding is indicated by a history of flooding, evidence of past or present flood management, an absence of significant human activity (buildings and cultivation) adjacent to the river, among other factors.

The extent to which water resources influence flooding downstream is determined by their hydrological characteristics. Key factors include available additional storage capacity, the significance of the storage capacity relative to the discharge rate, and the significance of the reduction in discharge relative to the level of flooding downstream. The storage capacity may be limited; once this threshold is exceeded, flooding occurs downstream. However, any water storage that has been provided reduces the magnitude of this flooding. The extent of flood control is also determined by sequencing with floodwaters from other tributaries. For example, delay in the discharge of floodwater may exacerbate flooding downstream owing to synchronization with other tributaries. Large-scale processes also affect flood control. Although an individual water resource may provide significant flood control, effective flood control is more commonly provided by a series of catchments (Sather and Smith, 1984).

The economic component of the flood control function concerns the extent of damage due to the potential flooding that is prevented by flood control. The flood control function is of value only if potential flooding would threaten goods and services of value to society. Therefore, the value is determined by goods and services provided by the land and river system in areas of potential flooding. For example, if flooding is likely to affect forested areas and wetlands, the damage may be minimal. However, if urban or intensive agricultural land uses are under threat, damage costs could be considerable and have longer-term implications. Consequently, the value of flood control is affected by the location, area, depth, timing and duration of any potential flooding.

The flood control function can also have benefits in terms of control of bank erosion caused by peak river discharges. This is achieved through the retention and delayed gradual release of water. Some water resources reduce the velocity of surface water flows continually, not only during high discharge episodes, further limiting erosion downstream. The value of erosion control is determined by the extent of potential erosion and its impact on social welfare. For example, were erosion of a riverbank to result in loss of marginal grazing land, the value of its control would be low, but if it were to undermine the foundations of a building, the value would be higher.

Groundwater recharge

The subterranean hydrological system determines the recharge of groundwater by surface water resources. The extent of this process depends, among other factors, on whether there is a shortage of groundwater, whether the rate of groundwater extraction exceeds the rate of recharge, and the contribution that surface water makes to the quantity and quality of groundwater. As a consequence of the complexities involved, hydrological investigation of the groundwater system may be required to determine the extent of the recharge function.

Groundwater recharge can have direct and indirect benefits to society, which determine the value of this function. Direct benefits include provision of groundwater for domestic or agricultural use. Indirect benefits include maintenance of the water table, prevention of salinization of groundwater, and attenuation of pollutants. Recharge can also have non-use value in terms of maintenance of groundwater resources for future generations.

Generation of surface water

Surface water resources provide water for on-site abstraction and sources of seasonal or continual downstream flow of water. The generation of the surface water function is determined by the hydrological system, the benefits generated on- and off-site, and the impact that these have on human welfare. On-site, surface water provides habitats that are reliant on inundation and resultant anaerobic conditions. It also provides for on-site abstraction of water for domestic, agricultural and industrial use. Sustainable abstraction requires consideration of the minimum water requirement for persistence of the water resource and associated habitats. Abstraction of water beyond this threshold has uncertain consequences and could potentially result in irreversible damage. The application of safe minimum standards and sustainability constraints can reduce the likelihood of such an outcome (see Chapter 4). Off-site benefits of surface water generation are varied. They include maintenance of downstream habitats and species, aesthetic and recreational benefits, and provision of water for abstraction.

An important aspect of the benefits of surface water abstraction is the degree to which the system is able to support this activity without suffering damage. There is a minimum requirement for water in the system if it is to retain its essential ecosystem characteristics and continue to perform a range of other functions. Economic valuation should take into account the sustainability of any such consumptive use of water resources and the likely time frame over which these resources (and possibly, as a result, other functions) might be exhausted.

Biogeochemical functions

Nutrient retention and export

The nutrient retention and export functions of water resources are determined by:

- the location and nature of any adverse effects caused by potential increases in nutrient concentrations in the water;
- the extent to which increases in nutrient levels are limited by nutrient retention and export by water resources;
- the impacts that potential increases in nutrient levels have on social welfare (e.g. through eutrophication of waterbodies, pollution of drinking-water, and damage to fisheries).

Water resources can be involved in both the retention and export of nutrients. They have a limited capacity to retain nutrients. If subsequent export of nutrients does not occur, a threshold can be reached beyond which further retention of nutrients may cease. If the capacity for retention becomes degraded, this can result in greater levels of nutrient release. Where nutrient retention dominates without subsequent export, the use of critical loads, safe minimum standards and sustainability constraints can contribute towards management of this function. In contrast to nutrient retention, export involves the permanent removal of nutrients from the ecosystem. This can create externalities for the recipient site.

The retention and export of nutrients ameliorates pollution of water with nutrients. This affects the quality of surface water, and of groundwater through any recharge. The resulting improvements in water quality can have benefits for the following (Freeman, 1982):

- recreation (e.g. fishing, boating, hiking, and aesthetic appreciation of a view);
- domestic, agricultural and industrial water use (e.g. resultant impacts on human health and water treatment costs);
- fisheries;
- non-use benefits (associated with the knowledge that water quality and ecosystems are maintained).

The divergence between perceived and measured assessments of water quality complicates valuation of the benefits of nutrient retention and export. Public perceptions of water quality are determined by more obvious aesthetic characteristics of water, such as discoloration, turbidity, floating matter, oil on the surface, and odour. These do not necessarily correspond with chemical and biological measures of water quality. House and Sangster (1991) found that public assessments of water quality in the United Kingdom were more likely to be influenced by indicators of 'bad' quality (e.g. protruding rubbish, foam on the surface, unusual smell or colour) than indicators of 'good' quality (such as the presence of many fish, or the ability to see the river bed).

Sediment retention

Surface water carries a sediment load of soil particles eroded by runoff from land and from the banks and beds of watercourses. The sediment is deposited within the surface water system at points of low flow velocity. On-site, sediment retention can impose costs on the structures and processes of water resources. Off-site, it confers benefits through reduced sediment loads in surface water downstream. In-stream, reduced sediment loads can affect the survival of habitats and species, fisheries, recreation, amenity, and the values of residential property adjacent to watercourses. It also confers benefits on the capacity of water storage facilities (e.g. reservoirs) and navigability of waterways.

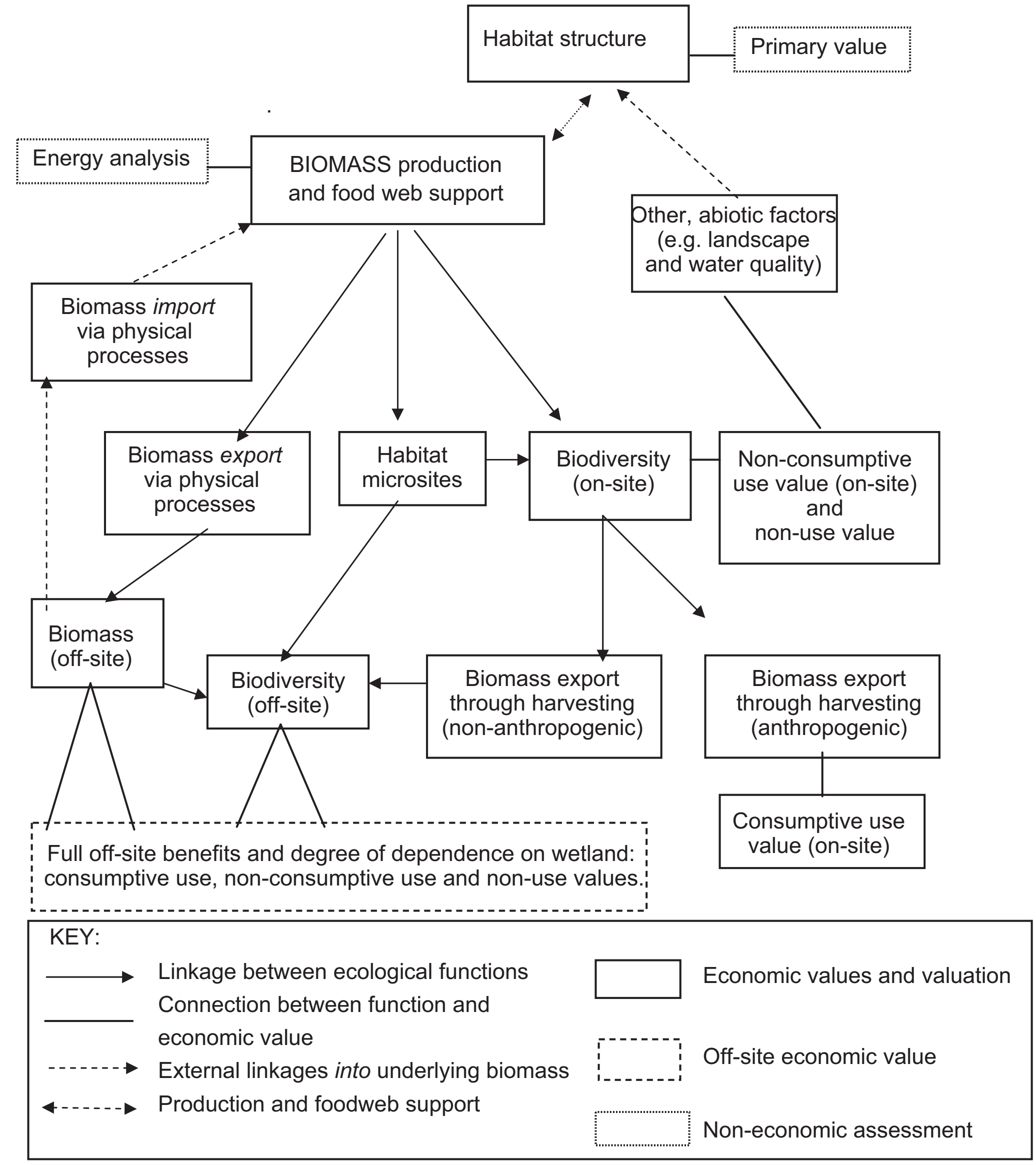
For extractive water uses, sediment retention reduces the costs of water treatment for household and industrial use. In irrigated agriculture, it reduces the costs imposed by sediment load on drainage ditches (through siltation) and irrigation systems (through siltation of canals and damage to equipment). It also reduces smothering of crops by sediment and sealing of the surface of the soil by silt particles. Other off-stream benefits include the retention of capacity to mitigate downstream flooding. However, sediment retention also results in the loss of positive externalities. Examples include the gains to agricultural productivity from deposition of fertile sediment and the added cooling capacity provided by sediment load in the use of water as a coolant for thermal power generation.

Ecological functions

The function of ecosystem maintenance is composed of three processes: provision of overall habitat structural diversity; provision of microsites; and provision of plant and habitat diversity. However, it is only through contact with, or concern for, the biological organisms that make up an ecosystem that economic value is generally derived from ecological functions. Thus, biodiversity maintenance and anthropogenic export of this biodiversity form the basis for the valuation of ecological functions. Although biodiversity may derive ultimately from the processes of biomass production and food web support, and it may be dependent on overall ecosystem health and habitat structure, these processes are not in themselves of value to society.

Ecological functions relate primarily to the habitats and species that are associated with water resources. The habitats and species do not themselves have a direct impact on social welfare, but they do have an effect through the goods and services that they provide. This is usually through contact with or concern about species associated with water resources. Figure 3 illustrates typical ecological functions of water resources. Only two of the ecological functions usually have significant economic value: biomass export through anthropogenic harvesting, and biodiversity maintenance.

FIGURE 3
Ecological functions and economic value



Biomass export through anthropogenic harvesting

The export of biomass through anthropogenic harvesting includes commercial extraction of resources (e.g. fisheries), harvesting for subsistence (e.g. harvesting berries and reeds), and recreational activities (e.g. hunting). Sustainability is an important consideration in the analysis of anthropogenic harvesting. Overharvesting affects the capacity to harvest in the future and other water resource functions. It can have consequences for future generations. This can be addressed through the use of sustainability constraints and safe minimum standards.

Maintenance of biodiversity

Biodiversity maintenance has benefits in terms of consumptive and non-consumptive use and non-use. Consumptive use of biodiversity is included in export of biomass through anthropogenic harvesting, described above. Non-consumptive uses of biodiversity include aesthetic benefits such as bird watching and enjoyment of scenic beauty. In terms of non-use values, society may value the existence of a water resource, or unique habitats or endangered species that are associated with the water resource. Value may be placed on the current existence of these or their preservation for future generations. Such non-use value can be indicated by an official designation as a protected area. Similarly, evidence of current or past projects to enhance or protect ecological features can indicate use or non-use value.

The dependence of biodiversity on the water resource determines the extent to which the value of biodiversity maintenance can be attributed to a water resource. Species may be only partially reliant on the habitats provided. There is uncertainty particularly concerning the consequences of loss of biodiversity. Loss of habitats and species may be irreversible, and the consequences for ecosystem stability and provision of functions in the present and in the future unknown. Threats to biodiversity also raise moral and ethical issues relating to intergenerational equity. Therefore, management of biodiversity entails considerations of sustainability constraints, preservation of critical natural capital, and the maintenance of safe minimum standards for species and habitats.

AN INTEGRATED APPROACH TO ASSESSMENT

As well as economic consequences, resource allocation decisions have social, cultural and political consequences for society. Similarly, the actions of individuals are determined not only by economic factors, but also by peer expectations, social and cultural norms and political pressures. Therefore, thorough evaluation of water allocation options involves consideration of the full impacts, both non-economic and economic. This requires a multidisciplinary approach. This can be achieved through the use of a framework for integrated assessment. The framework proposed here provides assessment from multiple perspectives (e.g. environmental, economic and social) and also offers synergistic benefits from the combined efforts of experts of different disciplines, decision-makers and other stakeholders. Integrated assessment is particularly suited to complex problems that offer a number of interrelated options. Rotmans *et al.* (1996) describe integrated assessment as: "an interdisciplinary process of combining, interpreting and communicating knowledge from diverse scientific disciplines in such a way that the whole cause–effect chain of a problem can be evaluated from a synoptic perspective with two characteristics: (i) integrated assessment should have value added compared to single disciplinary oriented assessment; (ii) integrated assessment should provide useful information to decision makers."

There are three characteristics, highlighted above, that are essential to integrated environmental assessment (IEA). First, integrated assessment is a team-based process undertaken by experts, decision-makers, and in its most inclusionary form, other stakeholders. This adds to the demands of the assessment (Turner, 2000). Second, successful integrated assessment is reliant on effective communication. In addition to communication between experts of different disciplines, effective communication is required between experts, decision-makers and other stakeholders involved in the assessment. Decision-makers should be involved continually in this process so that any assessment is scoped appropriately. Furthermore, any assessment process involves some subjective judgements. If these judgements influence outcomes in a major way, they should be made transparent to the users of the evaluation. In addition, most complex decision contexts are beset by inevitable scientific uncertainties and risks, and the involvement of lay decision-makers in discussions about these uncertainties and risks can help in the formation of coping strategies such as the adoption of the precautionary principle approach, or use of safe minimum standards (see Chapter 4).

Adoption right from the start of an interactive, participatory and more inclusionary bottom-up approach that involves decision-makers, experts and other stakeholders is beneficial for a number of reasons:

- It helps to elicit public perception of problems and possible solutions, which may contrast with expert judgement, and therefore ensures that decisions focus on real world problems and misconceptions. IEA can also be seen as a dialogue bringing together the knowledge and experiences of decision-makers, experts, interest groups and lay public.
- Proper involvement of all stakeholders facilitates social learning, identifying *inter alia* the distributional impacts and thereby maximizing the chances of eventual consensus.

Such a participatory approach is also in line with the requirements of the 'institutional principle' articulated in the Dublin Statement (1992). It is also a core component of the prevailing international consensus over policy for water resources management (ICWE, 1992). In summary, IEA is a continuous process that is conditioned by a policy and/or management context and characterized by its cyclical nature with multiple feedback effects and requirements. The process is enabled via team-based interdisciplinary/multidisciplinary research, utilizing a toolbox of complementary analytical methods and techniques. Evaluations are best carried out on a mixed methodological basis (Brouwer, Turner and Georgiou, 2001). Although it is important that the different contributing disciplines have some knowledge about the methodology and approaches to scientific investigation of one another, this is not a critical issue. The more significant issue is that all contributors to IEA maximize their knowledge of the policy/management context at issue (Harremoës and Turner, 2001). Each contributor should also be prepared to contribute consciously to the dialogues that must take place if IEA is to be socially relevant (Figure 4).

In order to succeed in the real world, integration needs to be less a process of comprehensively including all possible parameters and more a focused process seeking to identify, quantify, evaluate and monitor key parameters (Harremoës and Turner, 2001). It also is a process that puts a premium on the efficient collection, monitoring and analysis of relevant and appropriately scaled data (Figure 5).

FIGURE 4
IEA as a continuous process and dialogue

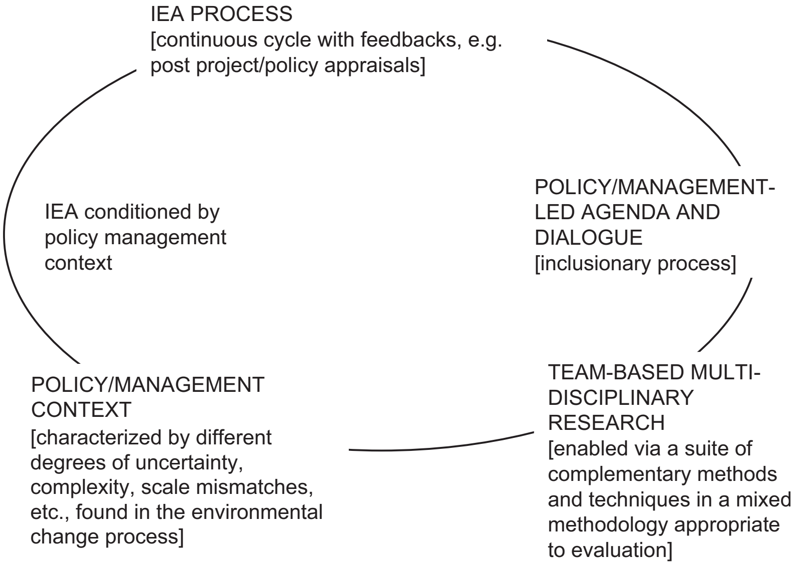
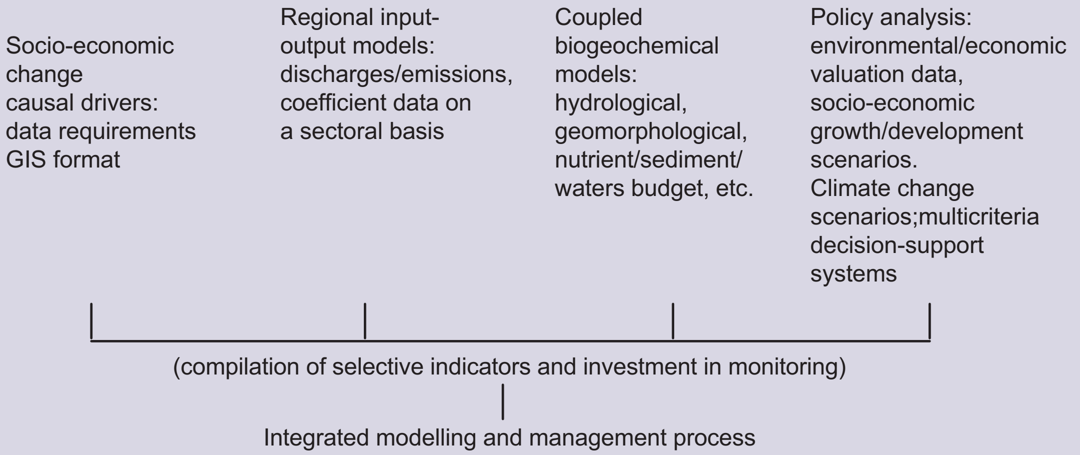


FIGURE 5
Towards integrated models and analysis



In order to fully achieve integrated assessment, the analyst has to undertake the following steps:

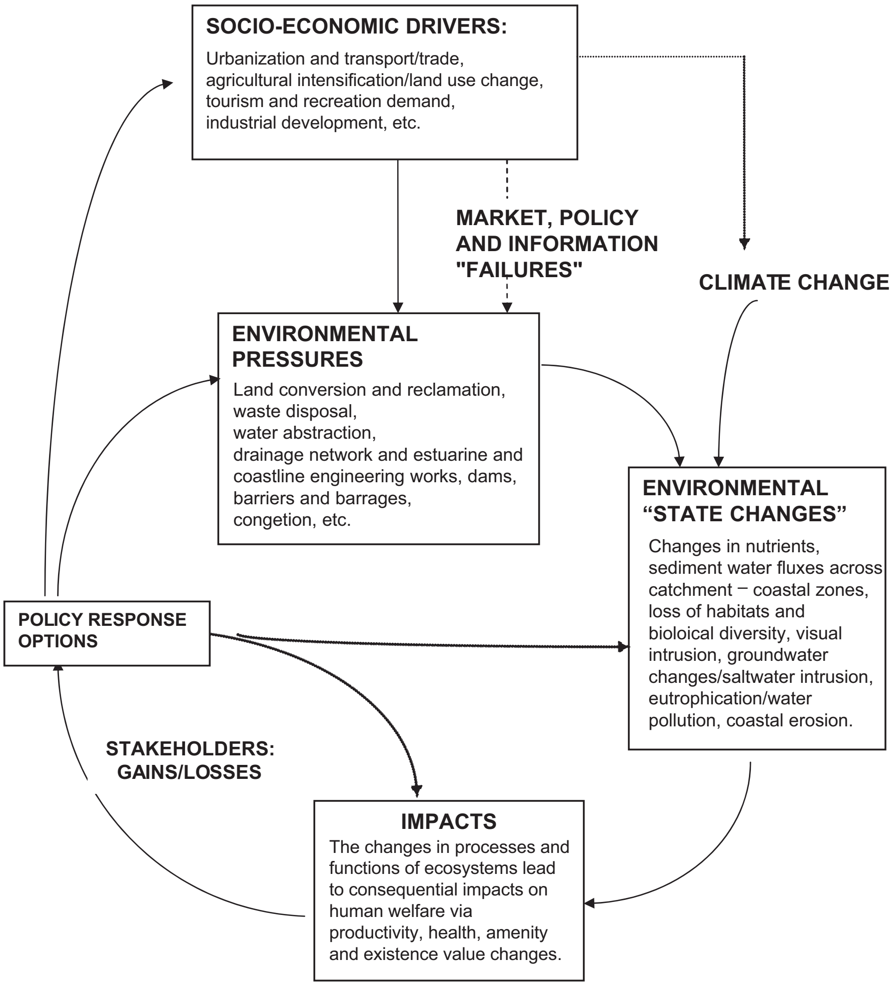
1. On at least the catchment scale, determine the causes of water and ecosystem degradation/ loss in order to improve understanding of socio-economic impacts on ecosystem processes and attributes, e.g. with the aid of the auditing framework of drivers, pressures, states, impacts and responses (DPSIR).
2. Assess the full ecological damage caused by water and ecosystem quality decline and/or loss.
3. Assess the human welfare significance of such changes, via determination of changes in the composition of the water resource and ecosystem, evaluation of ecosystem functions, provision of potential benefits of these functions in terms of goods and services, and consequent impacts on the well-being of humans who derive use or non-use benefits from such a provision.
4. Formulate practicable indicators of environmental change and sustainable utilization of water resources and associated ecosystems (within the DPSIR framework).
5. Carry out evaluation analysis using monetary and non-monetary indicators (via a range of methods and techniques, including systems analysis) of alternative water usage and ecosystem change scenarios.
6. Assess alternative water uses and ecosystem conversions/developments together with conservation management policies.
7. Present resource managers and policy-makers with the relevant policy response options.

The steps presented here encompass the provision of transparent, meaningful and useful information. This system can support and link decision-making at different spatial and time scales with the objective of fostering the protection and sustainable management of natural resources.

Scoping and problem auditing

A complete appraisal of water-related projects, programmes or courses of action requires a comprehensive assessment of water resources and supporting ecosystems. The DPSIR auditing

FIGURE 6
DPSIR framework: continuous feedback process



framework (see Figure 6) is recommended as the basis for any such assessment in either its full or 'reduced' form. This framework provides a conceptual connection between ecosystem change and the driving forces of such change, together with the effects of change (impacts and their distribution) on human welfare. Policy-response feedback effects can also be incorporated into the framework. The formulation of such a framework is a useful scoping procedure even where data sets are deficient.

Identification of appropriate evaluation criteria

Managed ecosystems are in an almost constant state of flux as the natural processes and systems react to human management interventions, which in turn, subject to various lags, produce more human interventions, i.e. a coevolutionary process characterized by continuous feedback effects. Therefore, it is important to be able to assess the impact of alternative sets of management actions or strategies in order to judge their social acceptability against a range of criteria such as environmental effectiveness, economic efficiency and fairness across different stakeholder interests (including different generations). Evaluation methods and techniques have to be matched with the chosen evaluation criteria. The socio-cultural and historical contexts in which environmental assets exist also provide for alternative aspects of environmental value that the market paradigm may not capture. Moreover, if the "deep ecology" worldview is adopted, nature possesses "intrinsic value", which exists regardless of human use or appreciation.

Data collection and monitoring via indicators

The data required for monitoring environmental change can be conveniently classified in terms of three dimensions of value (outlined in Chapter 4): primary/glue value possessed by ecosystems; TEV assigned to ecosystem functions; and the social-cultural, historical and symbolic value inherent in some environmental assets.

Primary value data and indicators

Primary value data collection should be based on the overall system and ecosystem integrity in terms of structure, composition and functioning. Both quantitative and qualitative descriptive indicators of ecosystem integrity are required because of the level of uncertainty that surrounds the scientific understanding of how complex systems work. This lack of knowledge also means that a precautionary approach to ecosystem conservation is recommended, with normative benchmarks to assess the sustainability of systems and management regimes.

The effect of pressures exerted by human activities on ecosystems can be measured by defining the relevant indicator spheres for ecosystem structure, composition and functioning. This breakdown, first proposed in the context of biodiversity assessment techniques, can be used to organize the indicator sets that cover three interrelated aspects of ecosystems: landscape, water regime and biodiversity. This holistic approach focuses on the interdependency and compatibility within and between indicator sets across different scales.

Total economic value data

Both the socio-economic and natural scientific aspects of ecosystem integrity are integral to the approach presented here. The environmental indicators must be analysed and evaluated *vis-à-vis* the social context in which they arise. This context includes the institutional, political, socio-cultural and spatial/temporal scales, as well as the economic circumstances through which environmental change occurs and is monitored.

Key issues and ecological principles relating to the functioning of ecosystems and the assignment of values to ecosystem structure and functions that must be considered include:

- the spatial and temporal scale of ecological processes;
- the structure, complexity and diversity that underlie ecosystem functions;
- the dynamic (in space and time) nature of ecosystems;
- the uncertainty associated with ecosystems.

The essence of an overall socio-economic evaluation is to determine how society is affected by the functions that an ecosystem performs, and by changes in that ecosystem functioning. The key to valuing a change in an ecosystem function is establishing the link between that function and some service flow valued by people. Where that link can be established, then the concept of derived demand can be applied (see Chapter 4). The value of a change in an ecosystem function can be derived from the change in the value of the ecosystem service flow it supports. However, the multifunctional characteristic of ecosystems makes comprehensive estimation of every function and linkages between them difficult. For example, it will be necessary to assess features of socio-economic activities and behaviour, and how these respond to changes in ecosystem functioning.

Socio-cultural, symbolic value data

The task of sustainable management can be defined as sustainable utilization of the multiple goods and services generated by ecosystems, together with the 'socially equitable' distribution of welfare gains and losses inherent in such usage. However, the social welfare account includes not only economic welfare stocks and flows but also changes in properties, such as sense of identity, cultural and historical significance of ecosystem components and overall landscapes. Compiling data values in this context is likely to be more of a qualitative exercise, involving deliberative and inclusionary interest group approaches such as consensus conferences, citizen juries and focus group interviewing. Different cultural views on social relations are then assumed to give rise to different degrees of support for alternative decision-making procedures and the underlying valuations elicited via the social discourse process (O'Riordan and Ward, 1997; Brouwer *et al.*, 1999).

Assessment of the options under consideration by decision-makers

A combination of quantitative and qualitative research methods is advocated in order to generate a blend of different types of policy-relevant information. This applies to both the biophysical assessment of management options and the evaluation of the welfare gains and losses people perceive to be associated with environmental changes and management responses. The main generic approaches that can form the methodological basis for strategic options appraisal are:

- stakeholder analysis;
- cost–effectiveness analysis;
- extended cost–benefit analysis and risk–benefit analysis;
- social discourse analysis;
- multicriteria analysis.

It is recognized that complete adoption of such a procedure requires institutional, financial and scientific capacity that may not be feasible in all countries. Therefore, the aim should be to move iteratively over time from a 'reduced form' procedure towards a comprehensive assessment. However, certain elements are fundamental, i.e. adoption of the catchment as the minimum scale for analysis; recognition of the importance of the functional approach to water resources and water uses; the need for a scoping exercise (DPSIR) which encompasses distributional impacts; and the acceptance of economic principles for water valuation, albeit constrained by cultural, political and other factors.

Box 1 presents several of the more important aspects of any integrated economic assessment of water resources and catchment ecosystems that require consideration in agricultural development project appraisal. Such assessment is suggested as a minimum requirement for enabling a credible and pragmatic decision-support tool.

Core principles for integrated assessment

The framework advocated in this report for the integrated assessment of water allocation options is based on **six principles**. Combined together, these principles provide the foundations for a thorough and powerful analysis of key issues related to agricultural use of water.

The **first principle is that of economic efficiency and cost–benefit analysis**. In an environment of increasing water scarcity, the allocation of water should be at least informed, if not guided (for political reasons) by the full economic value of water in its various uses. When determining the efficiency of water use, as many costs (e.g. destruction of wetlands through

BOX 1

IMPORTANT ASPECTS OF IEA OF WATER RESOURCES AND CATCHMENT ECOSYSTEMS

- Problem orientation – using DPSIR auditing framework: Any analysis should take account of the prevailing political economy context, equity issues and possible 'stakeholders' (i.e. stakeholder mapping). Data inadequacies must be acknowledged and recommendations made conditional upon these limitations.
- Typology: A useful common terminology regards 'functions' as relationships within and between natural systems; 'uses' refer to use and potential use, non-use interactions also occur between humans and natural systems; and 'values' refer to human preferences for a range of natural or non-natural objects and attributes.
- Thresholds and scenarios of ecosystem change: Thresholds relate to the scale and frequency of impacts on ecosystems. Their occurrence can be presented in a simple three-part classification: no discernible effects; discernible effects; discernible effects that influence economic welfare.
- Economic valuation: Three broad settings for understanding the catchment approach are: impact assessment; partial analysis; and total valuation. For each function or impact, a number of techniques exist for attributing economic value to environmental benefits. Systems analysis and multicriteria evaluation methods can be used to complement economic cost-benefit analysis.
- Scale: The catchment should be the preferred spatial unit for assessing physical variables, with possible zoning within this. Nevertheless, catchmentwide management and appraisal is not necessary in all cases. In terms of benefit estimation, the minimum scale is determined by the relevant population affected by any impacts. The temporal scale of analysis is also fundamentally important.
- Transferability (spatial and temporal): Transfer of previous assessment results and benefit estimates is often the most cost-effective and rapid procedure for an assessment. However, transfer of data on scientific results and economic benefits is problematic. Accuracy of benefits transfer may be improved if it is based on scientific variables divided into components according to processes, functions, and 'state variables'.
- Integrated assessment requirement: Integrated assessment is carried out as a continuous ”process”, which is conditioned by a policy and/or management context and characterized by its cyclical nature with multiple feedback effects and requirements. The process is enabled via team-based interdisciplinary/multidisciplinary research, utilizing a toolbox of complementary analytical methods and techniques.

overextraction of water) and benefits (e.g. purification of water through groundwater recharge by using household wastewater for irrigation) of water use as feasible need to be considered. The value of water to a user is the cost of obtaining the water plus the opportunity cost. The latter is given by the willingness to pay for the water in the next best alternative use (in terms of social welfare). For goods and services that are marketed, economic value can be determined using market prices. Methods are available that provide proxy estimates of value for goods and services that are not marketed, although application of many of these is sometimes problematic in the context of developing countries. Water pricing remains a complex process with its own 'political economy' arising from the set of legal, institutional and cultural constraints that condition water resource allocation and management in all countries. Economic efficiency as an objective will often have to be traded off against other decision criteria, but it will gain in significance as the full social costs of water service provision escalate.

The **second principle is that of integrated analysis**. The allocation of water has social, cultural, political and economic impacts on society. Therefore, for it to be sufficient, assessment of water allocation options is required to assess these multiple impacts and interactions between them. This entails a shift away from a more simplistic and narrow sectoral view to a wider, more holistic perspective that encompasses relevant prevailing economic, social, cultural and political processes. Such an approach is provided by the proposed framework for integrated assessment.

The **third principle is that of an extended spatial and temporal perspective**. The volume and quality of water supplies and the functions that they provide are determined by the abstraction of water, recharge of water resources and processes of the hydrological system. The thorough assessment of options for water allocation entails consideration of these processes and, therefore, requires the adoption of an extended geographical perspective. Such a perspective incorporates surface water processes at the catchment scale, groundwater processes at the aquifer scale, interactions between surface water and groundwater, and socio-economic drivers in the wider environment that affect water resources. Sustainability of water resources also requires a longer, i.e. intergenerational, time scale for planning and management, with due regard for precautionary motivations.

The **fourth principle is that of functional diversity maintenance**. Water resources provide many environmental goods and services that are of economic benefit to society (e.g. the amenity and recreational value of wetland sites, maintenance of biodiversity in surface water systems, purification of water through aquifer recharge). Diversity in the environmental functions provided by water resources contributes to the stability of the associated ecosystems and to the capacity of the ecosystems to recover from stresses and shocks and to maintain integrity while allowing the continued provision of goods and services. Therefore, maintenance of functional diversity is key to sustainable water resource management. This is fostered through the adoption of a functional perspective in integrated assessment, which indicates to decision-makers the diversity of existing environmental water resource functions and potential impacts on these of changes in water allocation.

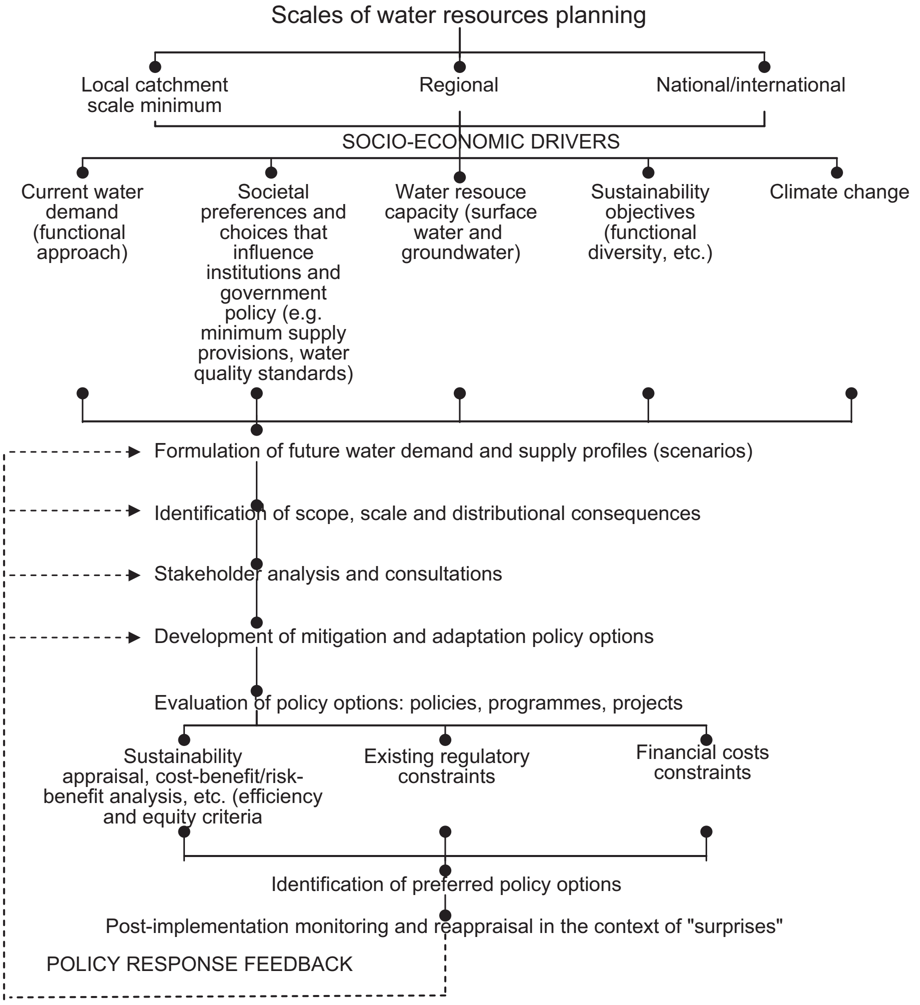
The **fifth principle is that of long-term planning and precaution.** The criterion of sustainable water use (in terms of quantity and quality) should supplant short-term expediency. In terms of quantity, sustainability requires that current water abstractions should not impose costs upon future generations. The quantity of water that is available for use in any particular period is equal to effective runoff, i.e. the difference between total precipitation and the amount lost through evapotranspiration, plus the stock of freshwater (water stored on the surface or underground). The sustainability rule (at least at the national level) is that water demand should be met out of effective runoff only (Dubourg, 1992). From the quality perspective, sustainability requires that water quality be non-declining over time. However, the concept of desirable water quality is complex, ambiguous and varies between time and place, making this rule difficult to operationalize. Hence, except in cases where effluent levels exceed critical loads, sustainability arguments cannot be used as a justification for improving water quality.

The **sixth principle is that of inclusion**. Interactive, participatory and inclusionary approaches involving decision-makers, experts and other stakeholders help ensure that decisions focus on real world problems, and that possible solutions are elicited using the combined knowledge and experiences of decision-makers, experts, interest groups and the lay public. They also assist in identifying distributional concerns and increase the chance of achieving consensus on proposed solutions.

Complete adoption of these principles requires resources and capacity that may not be available. However, a feasible objective is to move gradually from a narrow and reduced form of assessment towards a wider and more comprehensive form. The framework for integrated assessment presented here provides such a decision-support system, which is thorough, credible and pragmatic. Figure 7 sets out the generic stages of an IEA. Based on appropriate scales of analysis, the DPSIR auditing and scoping framework is deployed to highlight the main causal mechanisms that underlie the pressure being placed on water resources.

Scenario analysis can play a useful role in sustainability planning and recognition of policy options. Explicit focus is required on the distributional consequences of water allocations,

FIGURE 7
Strategic decision-support process: an integrated assessment approach



together with "coping" strategies for greater stakeholder inclusion in the decision-making process. At the project, policy or programme level, economic appraisal, suitably modified by ecological sustainability principles, must be applied in a rigorous fashion in order to assist in the identification of the preferred policy options set. Finally, monitoring and feedback systems require adequate resources in order to guide the evolution of policy/management options.

The evaluation framework and decision-support system proposed in this document are consistent with the sustainable water resource management approach advocated by the World Bank (1993). The adoption of this framework facilitates the consideration of relationships between the ecosystem and socio-economic activities on an extended geographical scale. It takes into consideration social, environmental and economic objectives and the views of all stakeholders. The advantages of such an approach are that it:

- provides improved assessment of both short- and long-term demands for water in an economically efficient manner;
- integrates activities and objectives that are not always feasible in separate approaches;
- enhances management of resources in terms of environmental issues;

- reduces costs through economies of scale;
- identifies efficient solutions to water quality and pollution problems;
- facilitates a consensus among the riparians, thereby reducing tensions and conflicts;
- provides a means to assure equity and participation of beneficiaries and those affected by development;
- can adjust to changing priorities;
- can be used to prepare for emergencies such as drought and floods;
- provides a base for research and knowledge accumulation.

Full deployment of such an approach has yet to be undertaken in practice. However, many of its elements (using some of the methods and techniques described in Chapters 3 and 4) have been deployed in a study on at the Maipo river basin in Chile (Rosegrant *et al.*, 2000). The study illustrates how useful such an approach can potentially be in analysing policy and water allocation at the catchment scale, and in delivering improvements in the allocation and efficiency of water use, especially in the agriculture sector. The study introduces an integrated economic–hydrological modelling framework that accounts for the interactions between water allocation, farmer input choice, agricultural productivity, non-agricultural water demand, and resource degradation in order to estimate the social and economic gains from improvement in the allocation and efficiency of water use.

The framework is applied to the Maipo river basin, an area characterized by a very dynamic agriculture sector and rapidly growing industrial and urban sectors. Although agriculture accounts for 64 percent of total withdrawals at the offtake level in the river basin, the irrigated area has been declining gradually owing to increasing domestic and industrial demand for water and land resources. It is hoped to meet the increase in domestic water demand through improved use of existing water rights, the purchase of additional rights from irrigation districts, and additional extraction of groundwater. However, the municipal water company has been unable to purchase sufficient shares from irrigation districts, and both industry and agriculture are competing for groundwater sources at levels above the recharge capacity of local aquifers. Increasing competition for water in the basin has given rise to growing pollution problems, while at the same time room for improvement in the areas of water rights for environmental and hydropower uses has become apparent.

The river basin modelling system incorporates a node–link network, based on linkages between: source nodes, such as rivers, reservoirs, and groundwater aquifers; and demand nodes, such as irrigation fields, industrial plants, and households. The modelling framework includes the following components:

- A hydrologic model based on a previous successfully applied model and adapted to the Chilean context. The major hydrologic relations/processes represented through mathematical expression in the model include: flow transport and balance from river outlets/reservoirs to crop fields or municipal and industrial (M&I) demand sites; salt transport and balance from river outlets/reservoirs to irrigated crop fields; return flows from irrigated and urban areas; interaction between surface water and groundwater; evapotranspiration in irrigated areas, and hydropower generation as well as physical bounds on storage, flows, diversions and salt concentrations.

- An economic optimization model developed in order to estimate the economic returns to water uses, including irrigation, hydropower and M&I uses. The optimization model includes simulation components, in which hydrologic flow and salinity balance and transport are simulated endogenously, while an external cropwater simulation model is used to estimate the crop yield function, with water, salinity and irrigation technology

> as variables. The optimization model considers in-stream water uses, including flows for waste dilution and hydropower generation, as well as off-stream uses, such as water diversion for agriculture and M&I water uses. The valuation of these uses is implemented in a unified economic objective function, constrained by hydrologic, environmental and institutional relations. Water demand is estimated endogenously within the model using empirical agronomic production functions (yield versus water, irrigation technology, and salinity) and an M&I water demand function based on a market inverse demand function. The determination of water supply is given by the hydrological water balance in the river basin with extension to the irrigated crop fields at each irrigation demand site. Water demand and supply are then integrated into an endogenous system and balanced using the maximization of the benefits from water use including irrigation, hydropower and M&I benefits as the economic objective. Water quantity and quality in terms of salinity are both simulated in the model. By explicitly calculating the salt concentration in the return flow from irrigated agriculture, this allows endogenous consideration of this externality with respect to upstream and downstream irrigation districts.

The resultant model is first used to estimate a basin-optimizing (“baseline”) solution in which no water right is set up and where water withdrawals to demand sites depend on their respective demands with the objective of maximizing basin benefits. The model is then extended to allow for a realistic representation and analysis of water markets. In particular: water trading in the basin is constrained by the hydrologic balance in the river basin network; water is traded taking account of the physical and technical constraints of the various demand sites, reflecting their relative profitability in trading prices; water trades reflect the relative seasonal water scarcity in the basin that is influenced by both basin inflows and the cropping pattern in agricultural demand sites; and negative externalities, such as increased salinity in downstream reaches owing to incremental irrigation water withdrawals upstream, are endogenous to the model framework. To extend the model for water trading analysis, a shadow price–water withdrawal relationship is determined for each demand site using regression analysis on water withdrawals and shadow prices derived from the water balance equations. Water rights are allocated proportionally to total inflows based on historical withdrawals for M&I areas and on the harvested (irrigated) area for agricultural demand sites. The water right refers to surface water only. To determine the lower bound for profits from water trade by demand site, the model is solved initially for the case of water rights without trading. The regression relationships of shadow price versus water withdrawal for all agricultural and M&I demand sites, the water rights, and other water trading related constraints are then all finally added to the basin model. The trading price for each demand site is assumed equal to its shadow price for water. Solving the resultant model determines the water trading price and the volume of water bought and sold by demand site. Trades are allowed on a monthly basis and throughout the basin, while transactions costs are assumed to be incurred by both buyer and seller.

Three scenarios are analysed to assess the impacts of water trading. These include: a baseline in which an omniscient decision-maker optimizes benefits for the entire basin; water rights with no trading permitted; and water rights with trading. The model results show the benefits of water rights trading, with water moving into higher valued agricultural and M&I uses. The net profits in irrigated agriculture increase substantially compared to the case of proportional use rights for demand sites. It is found that agricultural production does not decline significantly. Indeed, net benefits for irrigation districts can be even higher than for the basin optimizing case, as farmers reap substantial benefits from selling their unused water rights to M&I areas in months with little or no crop production. Finally, it is found that reducing transaction costs increases both the amount of trading and the benefits therefrom.

Chapter 3
Economics of water allocation

Economics studies the allocation of scarce resources in society as a means of satisfying human wants or desires. In doing so, it takes into account the availability of resources, methods for the production of goods and services, their exchange, and the distribution of income within society. Economics is anthropocentric, and as such provides useful tools that can support decision-making. However, decisions concerning water allocations are guided not only by concerns of economic efficiency but also considerations of equity, environmental protection and social and political factors, to name but a few. This chapter focuses on the issues considered and tools used in the analysis of economic efficiency as the primary objective of water resource allocation.

ECONOMIC APPRAISAL AND ALLOCATION OF WATER

Given its fundamental preoccupation with scarcity, economics defines the conditions required to secure the most efficient allocation of scarce resources in a variety of contexts.

Water resources provide important commodity and environmental benefits to society. Any particular use of water will be associated with opportunity costs, which are the benefits foregone from possible alternative uses of the resource. Decision-makers are faced with balancing, for example, water demands from agricultural irrigation for food production with the desire to preserve wetlands for fish and wildlife habitat. Economics contributes towards improved allocations by informing decision-makers of the full social costs of water use and the full social benefits of the goods and services that water provides.

The main approaches that form the methodological basis for strategic economic appraisal are cost–benefit analysis and cost–effectiveness analysis.

Cost–benefit analysis

Cost–benefit analysis is carried out in order to compare the economic efficiency implication of alternative actions. The benefits from an action are contrasted with the associated costs (including the opportunity costs) within a common analytical framework. The benefits and costs are usually measured physically in widely differing units; comparison is enabled through use of the common numeraire of money. The benefits and costs of each option are determined relative to the common scenario that would prevail if no action were taken. The net benefit of each option is given by the difference between the costs and benefits. The most economically efficient option is that with the highest present value of net benefit, i.e. net present value (NPV); economic efficiency requires selection of the option with maximum NPV. Options are economically viable only where the NPV that they generate is positive.

Cost–benefit analysis provides a rational and systematic framework for assessing alternative management and policy options. It entails identification and economic valuation of all positive and negative effects of alternative options. This involves the translation of all benefits and costs into monetary terms, including where possible, non-marketed environmental, social and other impacts. It is based on the underlying assumption that individual preferences should determine the allocation of resources among competing uses in society.

Selection of cost–benefit analysis as a decision-support tool is at the discretion of analysts and policy- and decision-makers. It is the responsibility of analysts to ensure that the underlying assumptions of a cost–benefit analysis are appropriate to a specific situation and that the results are valid and reliable. Cost–benefit analysis reflects a specific paradigm that is considered more or less appropriate in different domains of decision-making. The appropriateness depends on culturally determined beliefs, norms and values, regarding, for example, the legitimacy of the social–political organization of decision-making, public consultation and the process of value elicitation.

Cost–effectiveness analysis

Cost–effectiveness analysis (also known as least cost analysis) is used to identify the most cost-effective option for achieving a pre-set objective or criterion. The relevant objective is set, options for achieving it are identified, and the most cost-effective option is identified as that with the lowest present value of costs. It is assumed implicitly that the benefits of meeting the goal outweigh the cost and that the action is therefore economically viable.

Cost–effectiveness analysis is suitable for use in situations where valid and reliable estimation of the benefits of alternative options is not feasible. This is particularly relevant to actions that involve environmental change. Instead of attempting to identify and value the benefits, the most cost-effective means of achieving a desired objective is identified. For example, cost–effectiveness analysis is suited to situations where clear and defensible conservation targets or other environmental goals exist that can be measured in terms of biophysical units such as minimum water quality standards. It can also be used to identify the most effective option for a fixed amount of funding that has been allocated to achieve a policy objective. The drawback of cost–effectiveness analysis is that it does not identify the benefits of actions or the willingness of society to pay for improvements in environmental quality, which are important considerations in many decision contexts. For these reasons, cost–benefit analysis is, where practicable, the preferred tool for decision support.

Economically efficient allocation: the theory

The focus on economic efficiency as the primary objective in the development and allocation of water resources is because of its importance as a social objective; efficiency values having viable meaning in resolving conflicts and assessing the opportunity costs of pursuing alternative uses (Young, 1996). Although economically efficient allocation of irrigation water is rarely attained in practice, analysis of economic efficiency provides a useful point of reference for understanding causes of inefficient allocation and mechanisms for improving the overall economic performance of irrigated production.

At the outset, economic efficiency needs to be distinguished from the various technical definitions of efficiencies associated with irrigation (Perry and Kite, 2003; Seckler, Molder and Sakthivadive, 2003). However the two types of efficiency are related in the sense that both seak to maximize the productivity of water in terms of output per cubic metre of water.

Economically efficient allocation of water is desirable to the extent that it maximizes the welfare that society obtains from available water resources. Welfare in this context refers to the economic well-being of society and is determined by the aggregate well-being of its individual citizens. Economically efficient allocation maximizes the value of water across all sectors of the economy. This is achieved through the allocation of water to uses that are of high value to society and away from uses with low value. Efficient allocation occurs in a competitive, freely functioning market when supply is in equilibrium with demand. Under these conditions, the marginal cost of the supply of water (the cost of supplying an additional unit) is equal to the marginal benefit of the use of water (i.e. the benefit of goods and services provided by an additional unit of water). The marginal benefit and marginal cost are the same across all uses and equate with the market price. However, where there are distortionary constraints, such as subsidies or taxes, the maximization procedure will result in a second-best efficient allocation (Tsur and Dinar, 1997).

A feature of economically efficient allocation is that no reallocation can make anyone better off without making at least on person worse off, a condition that is described as "Pareto optimal". The relative efficiency of alternative allocations can be analysed with respect to this, i.e. in terms of whether they provide a "Pareto improvement". A change in allocation is considered desirable if at least one person gains in welfare and no one loses. However, this criterion proves too stringent in practice as few changes can be made in the real world that do not reduce the well-being of others. For this reason, an adaptation is usually employed; this is described as a 'potential Pareto improvement' or the Kaldor-Hicks criterion. A change in allocation is considered desirable if those individuals who gain from the change can hypothetically compensate those who lose and still be better off than they were previously. It is anticipated that compensation does not take place, owing to difficulties of identifying and compensating all necessary individuals. The criterion of potential Pareto improvement forms the basis of cost–benefit analysis, which is used to analyse the relative economic efficiency of alternative courses of action (e.g. water allocations, and new irrigation schemes).

Although economic efficiency is an important factor, there are additional economic issues that decision-makers need to consider. Two of these issues are the distribution of costs and benefits across society and their distribution across generations. In terms of the former, neither the equity implications of an allocation nor the equity of the prevailing distribution of wealth are considered in analysis of economic efficiency (van Kooten and Bulte, 2000). Focusing first on the equity implications of an allocation, costs and benefits are usually specified using values that are representative of the whole of society (based, for example, on a random sample). However, the costs and benefits may not be borne equally by society; they may be concentrated in specific geographical areas. These differences may also correlate with differences in income borne by sections of society: environmental costs (e.g. costs imposed by polluted water supplies) are often borne disproportionately by low-income sections of society (NMI and NOAA, 2001). Such disparities can be incorporated into analysis through studies of costs and benefits for separate sections of society (NMI and NOAA, 2001), though this adds to the information requirements and the demands of the analysis.

The prevailing distribution of wealth is usually assumed to be a given in analysis of economic efficiency. Equal weight is given implicitly to costs and benefits experienced by all members of society. However, circumstances arise where it is socially desirable to alter the distribution of wealth in the pursuit of greater equity. This can be incorporated into the analysis through the use of distributional weights. Weights are assigned to costs and benefits according to the section of society that they accrue to and the desired redistribution of wealth. For example, high weights can be applied to benefits that accrue to poor sections of society and low weights to benefits for the rich. Application of this procedure is challenging because of the difficulties of identifying the distribution of costs and benefits within society and of specifying appropriate weights, which is subjective. In the past, it has usually been considered more appropriate for decision-makers to consider prevailing inequalities separately from analysis of economic efficiency.

In terms of equity in the distribution of costs and benefits over time, it is argued that economic analysis commonly favours consumption in the present at the expense of future generations. Analysis of economic efficiency addresses the distribution of costs and benefits over time through the use of discounting: all costs and benefits are converted into present values using a rate of time preference (discount rate) (discussed further in Chapter 4). The discount rate used is intended to represent society's preference for consumption in the present over the future. The rate is commonly prescribed by government agencies and is typically positive and less than private discount rates. On the one hand, it can be argued that government has a responsibility for the interests of both current and future generations and that it sets the social discount rate accordingly. One the other hand, it is argued that the rates used are too high, placing low weight on consumption in the future and discriminating against future generations (NMI and NOAA, 2001). A further argument concerns the use of a zero discount rate, which would place equal weight on the interests of all generations. However, its application would result in rejection of all use of non-renewable resources (e.g. oil) or any irreversible developments (e.g. construction of dams). It could also result in rejection of investments that might be of great value to future generations, through creation of wealth or new technologies (NMI and NOAA, 2001). Concerns about future generations can be addressed better if they are considered separately from analysis of economic efficiency, through, for example, application of safe minimum standards (Chapter 4).

Reasons for inefficient allocation

Although water resources perform many functions and have important socio-economic values, water is in many respects a classic non-marketed resource. Even in its use as a tradeable commodity, market prices are not generally available. The reasons why water has no price are often related to the historical, socio-cultural and institutional context in which water is used and managed (e.g. the return of water use rights for groundwater or surface water on farmers' land). In addition, although water can be captured and shared, water flows can also be recycled. This often makes it difficult to break water down into marketable proportions.

An important cause of this economically inefficient water use (where costs outweigh benefits) is the failure of institutions involvement with the allocation and management of water. 'Failure' refers here to institutions where 'they induce or favour decisions that lead society away or prevent society from achieving socially optimal resource allocations' (OECD, 1994). Sources of institutional failure include markets, policies, and political and administrative factors. They derive from a fundamental failure of information or lack of understanding of the multitude of values that may be associated with water resources (Turner and Jones, 1991).

Market failure

Although markets can achieve economically efficient allocation, they are commonly unable to do so. Described as market failure, this occurs through an 'inability of the market to lead the economic process towards the social optimum' (OECD, 1994). Market failure can occur through the non-existence of markets (for externalities and public goods), their failure to communicate necessary information (the social discount rate, society's attitude towards risk and uncertainty), restricted operation of markets (under a monopoly), and inadequate institutions or regulations (absence or non-enforcement of property rights).

Activities can impose losses or gains in welfare on individuals other than those engaged in the activities. If these losses or gains go uncompensated or unpaid for, they are described as externalities (negative and positive, respectively). Externalities are not incorporated into market prices, so are not accounted for in market-based allocation. This results in socially suboptimal resource allocation and market failure. Return flows of water are an example where both positive and negative externalities can be generated. Negative externalities arise where pollution from water use imposes additional treatment costs on downstream users. In the context of irrigation, drainage water from fields often carries high levels of agrochemical pollutants, which can lead to losses of aquatic habitats downstream. Optimal allocation of water requires that supply costs be increased to reflect the costs of mitigating the negative externalities. Positive externalities are also generated by return flows, which form a vital element of many hydrologic systems. Irrigation often performs a secondary function in that it recharges aquifer systems. Such external effects can mean that while farm-level water use efficiency may be apparently low, at the catchment level, water use efficiency of irrigation may be much greater. Thus, improvements in efficiency at the farm level may be at a cost of overall efficiency of the hydrological system.

By definition, a public good can be enjoyed without diminishing the supply (i.e. is subject to non-rival consumption) and others cannot be excluded from its use (and consequently it is not traded). As a result of the non-rivalry characteristics, demand for public goods is collective: it is the sum of the separate demands of individuals for the good. Although some uses of water tend towards being rival in consumption, e.g. agricultural, residential or industrial uses, others such as recreational and aesthetic uses are non-rival. Thus, water supply has often been exposed to 'open access' pressures, with a lack of enforceable property rights allowing unrestricted depletion of the resource. Furthermore, even where water resources are privately owned, many of the benefits they provide may be off-site, and may not accrue to the owner (e.g. downstream flood protection). The lack of a market for these benefits limits the incentive to maintain the resource, as the private benefits derived by the owner do not reflect the full benefits to society. Most commonly, the non-traded nature of public goods hides them from market-based decision-making, which results in market failure.

The preference of individuals for consumption in the present rather than the future is understood to usually exceed that of society. Where allocations are determined based on the discount rate of an individual decision-maker, this is likely to give less weight to long-term costs and benefits. Typically, this translates into the selection of courses of action that are of short-term net benefit and rejection of those that are of net benefit only in the longer term. A particular concern is the favourable consideration that is given to courses of action that yield net benefits in the short term, but incur substantial costs on society in the long term.

The supply of irrigation water is often controlled by only one agency, a situation described as a monopoly. Under these conditions, the supply of water is not subject to market competition. The supplier determines the price and quantity of water supplies. This can result in inefficient allocations and is a source of market failure. For example, a monopolistic supplier may elect to allocate water between farmers in a manner that does not make the maximum contribution to social welfare. Similarly, the supplier may set the water supply at a level that exceeds the optimum for society (resulting in overabstraction) in order to maximize profits.

Property rights are the characteristics that define the rights and duties associated with use of a particular source of water (van Kooten and Bulte, 2000). The nature of these property rights can determine the efficiency with which a source of water is used. Particular types of property rights regime result in market failure. Property rights regimes can be considered in terms of four types: private, common, state and open-access.

With private property rights, a private individual owns the resource and has the right to use, benefit from, and sell the resource, subject to a duty to refrain from socially unacceptable activities (such as imposition of negative externalities). These rights are subject to state regulation and protection, which is required for private property to exist and to exclude unentitled individuals from its use. However, the rights can be eroded in circumstances where resources supply public and private goods jointly. In order to maximize profits, the owner of a private resource manages the resource like an asset: its use is allocated over time such that the total present value is maximized. The owner delays use of the resource (if it is economically rational to do so) because of the expectation of being the only beneficiary of the resource in the future.

With common property rights, a group of individuals owns and manages the resource. The individuals in this group have specified rights and duties regarding the resource, and enforced rules exclude other individuals from its use. Common property ownership of resources tends to play a larger role in developing countries than in the industrialized countries (van Kooten and Bulte, 2000). Communities that have the characteristics required for successful common management of resources are more prevalent in developing countries: communities that are small, relatively immobile, close knit, and that have a common ethos and shared beliefs. Moreover, common property resources can have an important role in these communities as they can aid the distribution of wealth and provide a means for reducing the marginalization of poor, e.g. provision for the harvesting of fish and plants from communally owned wetlands by low-income households.

With state property, the state owns the resource. The state may allow individuals to use the resource, but according to its rules and under its regulation.

In an open-access situation, no property rights are assigned to the resource, which results in open access to the resource for all potential users. Water from both underground and surface sources is often an open access resource. Use of the resource is subject to neither exclusion nor regulation. Individuals have complete autonomy in its use.

The property rights of resources are often held in combinations of the above regimes and can alter with a change in situation. The efficiency of resource use under these regimes is based on four determining conditions (Tietenberg, 1992):

- full specification of ownership and entitlement to the resource (universality);
- accrual of all benefits and costs exclusively to the entitled individual (exclusivity);
- exchange of property rights in voluntary transactions (transferability);
- penalties that prevent individuals from encroaching or taking property rights without prior agreement (enforceability).

Table 3 indicates the extent to which the four property rights regimes satisfy these conditions. Economically inefficient resource use is associated particularly with open-access property rights. Open-access characteristics can also arise through poor management or a failure to regulate the use of common-property and state-property resources. The absence or non-enforcement of property rights for resources with open-access characteristics can lead to use of the resource at rates that exceed the social optimum. Described as the “tragedy of the commons”, this occurs where individuals have no incentive to conserve the resource because there is no assurance that other users will do likewise.

Policy and institutional failure

Allocation of water can be socially suboptimal not only through the failure of markets, but also through failure of government policy and associated instiututional arrangements. Policy failure occurs where government regulatory instruments (e.g. taxes and exchange rates) or government policies create market price distortions that make it economically rational for individuals to use resources in a socially suboptimal manner (OECD, 1994). Sectoral policies for agriculture and the environment, and for other sectors such as employment and taxation, can encourage suboptimal resource use and allocation. Moreover, government interventions intended to correct for market failure can result unwittingly in greater degradation and depletion of environmental resources if the regulatory environment is not suitably 'joined up'.

TABLE 3
Property rights regimes and their conditions for efficient resource use

Conditions	Property rights regime			
	Private property	**Common property**	**State property**	**Open access**
Universality	Yes	Yes (for the group)	No	No
Exclusivity	Yes (except for externalities and provision of public goods)	Yes (for the group)	No (although non-nationals are excluded	No
Transferability	Yes	Yes (for the group)	No	No
Enforceability	Yes (legal & social sanctions)	Yes (legal & social sanctions)	Yes (legal & social sanctions)	No
Efficiency	Efficient, but inefficiencies arise in presence of externalities and public goods.	Efficient in many cases, but inherent risk of breakdown.	Usually inefficient, owing to government failure.	Very low, no incentive to conserve.

Source: Pearce, Whittington and Georgiou (1994).

Failure in sectoral policies can arise through inadequate consideration of impacts on other sectors, particularly with regard to the environment (OECD, 1994). Bias in the formulation of policy towards sectors that exercise strong economic and political power can further marginalize the concerns of other sectors. Agriculture provides various examples of policy failure, such as subsidized irrigation and land improvement. A policy of subsidized supplies of irrigation water provides farmers with water at a price that is less than the marginal cost. Farmers respond to the low price by using quantities of water that exceed the social optimum. In an extreme case, this can result in overabstraction of aquifers and waterlogging of the land. An alternative example of agricultural policy failure is the provision of subsidies to drain land and to divert surface water, both of which can contribute to the degradation or destruction of wetland sites.

Political, administrative and other institutional factors can distort market signals in a manner that encourages socially suboptimal resource use. Pressure to gain re-election can lead governments to over-supply state services for example. At the extreme, this can favour excessive economic development at the expense of resource conservation. Political failure can also occur through lack of government intervention, e.g. in response to market failure. Administrative failure refers to a range of problems within the organization of government at the various levels, leading to inadequate policy implementation. Examples include: rigidities due to entrenched traditional divisions of labour within administrative organizations, and insufficient integration between agencies and departments. Other institutional failures include inadequate availability of information for policy-makers, and poor communication between rural electorates and urban-based central government. These policy and institutional failures are generic and could apply to most government interventions. The significance for irrigaton is the scope and depth of government involvement in irrigation (Burke, 2003).

WATER ALLOCATION POLICY

As indicated above, economic efficiency and equity are important considerations in the allocation of water. Greater efficiency is required in the face of increasing water scarcity, and equity is a concern because of the importance of water to the livelihoods and well-being of rural communities in particular. It is possible to derive a broad classification of policy measures that

TABLE 4
Policy measures relevant to resource management

Conditions	Public sector		Private sector	
	LDCs	DCs	LDCs	DCs
Property rights:				
Pricing	P = MC P = MSC	P = MSC	P = MSC	P = MSC
Quantity trading			Possible emissions & resource quota trading	Emissions &resource quota trading
Command & control	Environmental quality objectives	Environmental quality objectives	Environmental quality objectives	Environmental quality objectives
Investment policy	CBA	CBA	EIA	EIA

LDC = least-developed country; DC = developing country; P = price; MC = marginal cost; MSC = marginal social cost; CBA = cost–benefit analysis; EIA = environmental impact assessment.

are relevant to managing resources within the boundaries of a nation. The measures include the redefinition of property rights and investment policies.

One thing to be kept in mind is that many of the large public irrigation schemes that were promoted as part of the green revolution, particularly in Asia, were designed to target poor rural communities and as such were never oriented to maximize economic output, rather to guarantee production of food staples (Pluquellec, 2002).

The proper pricing of inputs (such as raw water) and outputs (such as agricultural irrigation products) can be viewed as a form of property right designation, while command and control measures are also means of defining property rights or modifying existing ones. Table 4 shows the various generic types of policy measures. Once a regime of property rights has been established, the proper pricing of a resource requires that it be priced at least at marginal private costs, and preferably at marginal social cost (especially in the longer term and where output prices are below private production costs). As pricing of water affects the allocation decisions of those with competing wants, then by correctly pricing water, efficient allocation of water is achieved. However, the standard economic efficiency (marginal) cost pricing result is sometimes problematic as regards the specification of production technology. In the water supply sector, inputs to production are often not perfectly divisible. Investments often require large lumps of capital (e.g. for dams and reservoirs). In such cases, marginal cost pricing to achieve economic efficiency requires some form of intervention (Sherman, 1989). Table 4 lists quantity-based measures as a separate policy option although they have similar effects to the price-based measures. Finally, investment policy, which is most usually characterized in terms of cost–benefit analyses, is applicable to all public sector operations (although environmental impact assessments are employed most widely in assessing private sector environmental impacts).

Water allocation systems

Water allocation systems differ in the extent to which they address efficiency and equity iobjectives. The various systems can be compared according to several criteria (Dinar, Rosegrant and Meinzen-Dick, 1997; Howe, Schurmeier and Shaw, 1986; Winpenny, 1994). These criteria include:

- Flexibility in allocation of supplies: allocation requires flexibility such that supplies can be shifted between uses and sectors, as demand changes, so as to achieve efficiency.

- Security of tenure for users: established users require security of tenure if they are to be expected to take the necessary measures to use the resource efficiently. Although this may conflict with flexibility, problems should not arise if sufficient water reserves are available to meet unexpected demands.
- Payment of real opportunity costs of water by users: users should pay the real opportunity costs of their use, so that other demand or external effects are internalized (see Chapter 3).
- Predictability of the allocation outcome: in order to achieve the best allocation and minimize uncertainty minimized, the outcome of the allocation process needs to be predictable.
- Equity in the allocation process: users should perceive the allocation process to be equitable.
- Political and public acceptability: the allocation should serve the various political and public values and objectives, thereby making it acceptable to the groups in society.
- Efficacy in achieving desired policy goals: the form of allocation should change an existing undesirable situation towards one where the desired policy goals are achieved.
- Administrative feasibility and sustainability: the allocation mechanism must be practicable, adaptable and allow an increasing effect of policy.

Water allocation systems range from government-controlled to market-led systems, and combinations of the two. The prevailing institutional frameworks (including laws, regulations, organizations) and the water resources infrastructure (Dinar, Rosegrant and Meinzen-Dick, 1997) influence the precise nature of allocation systems. However, they commonly fall into one of only a small number of categories: public allocation, market-based allocation and user-based allocation.

Public (administrative) allocation of water is determined by the state. It is used for intersectoral allocation of water, as the state usually is the only institution that has jurisdiction over all sectors of the economy (Dinar, Rosegrant and Meinzen-Dick, 1997) and because allocation of water is considered too important to leave to the mercy the market. The state can control allocation within sectors through, for example, granting permits for water abstraction. In agriculture, the state commonly administers allocation of water to large-scale irrigation schemes and to sections within the schemes. Distributions can be based on historical allocations or political influence (Dinar, Rosegrant and Meinzen-Dick, 1997). The state is less commonly involved in allocation at the farm and field levels. Under such allocations, the price of water is usually subsidized, low and charged on a flat-rate (e.g. per hectare) or fixed-charge basis (not according to the amount of water consumed).

Public allocation of water enables pursuit of objectives other than economic efficiency, such as equity and environmental protection. Some aspects of water allocation lend it particularly to state control (and pose challenges to market-based allocation). The economies of scale and the high levels of investment required for infrastructure readily create monopolistic supply and consequently a need for regulation. The joint provision of goods and services by water resources (e.g. provision of water for irrigation, hydroelectric power generating capacity and recreational services) and the provision of public goods (e.g. flood control) also suit state-controlled allocation. Many water resources are open access, so require state regulation of use. The interdependence of surface water and groundwater resources can require regulation of abstractions to prevent depletion of surface water and groundwater supplies. Finally, the essential role of water in meeting basic needs can require state control of allocation under conditions of drought (World Bank, 1993). However, there are problems associated with public allocation of water. These arise through poor management of infrastructure and inadequate development (which result in wastage of water), inadequate implementation of regulations (which can, for example, result in excessive pollution), and subsidized prices (which result in economically inefficient and excessive water use). Public allocation usually precludes user participation, a key objective in the international consensus for water resources policy (as stated in the Dublin Principles). Moreover, the institutions engaged in public allocation are typically sector-oriented, which fosters neither the integrated nor the flexible management required for effective intersectoral allocation. Thus, where public allocation is necessary, efforts are required to limit the potential deficiencies.

User-based allocation of water is undertaken through collective management of water sources, supplying water for either collective or individual use. Examples include farmer-managed irrigation systems and village-managed local water supplies (for example, allocating water to domestic use, irrigation and livestock). User-based allocation requires established rights to water use and an appropriate institutional framework that has the capacity and strength to determine and regulate use. Its effectiveness is determined by the characteristics of the community (size, mobility of the population) and its institutions, and by the extent to which social norms (such as social awareness of efficiency and resource conservation) influence water use. User-based allocations have the advantages that they are informed by knowledge and understanding of the needs of the local population, and can be flexible and responsive. Effectively operated systems can allocate water efficiently and address equity concerns. User-based allocations are sustainable, politically acceptable and are supported by the consensus in international policy (Chapter 1). However, effective allocation is dependent on the existence of a strong and transparent institutional framework, which is not always present (Dinar, Rosegrant and Meinzen-Dick, 1997)

Market-based allocation is determined by transactions in water use, at prices determined by the forces of supply and demand. It encourages greater efficiency in the use of water, and flexible and responsive allocation. Such allocation is reliant on effective operation of the market. Markets for water are often hampered from achieving this by subsidies, few suppliers and inadequate information. Moreover, they are distorted by externalities: uncompensated costs and benefits of water use that are imposed on others. These costs and benefits are not internalized into the price of water, which results in pervasive socially undesirable outcomes (such as the reduction or pollution of surface water flows for downstream users). Where it is judged desirable to establish a market for water, trade in the rights to water use is generally more acceptable than volumetric pricing as farmers view the latter to entail appropriation of their prior rights in water use. Such establishment of a market requires clearly defined rights for water use (usually determined by the state), specification of the initial allocation of rights, the necessary institutional framework and the infrastructure required to enable trade in water. In this sense the basis used for the pricing is an important determinant of the acceptability.

Pricing and cost recovery in the irrigation sector

Irrigation water is commonly priced volumetrically or using a flat rate or fixed charge. A special case of volumetric pricing is marginal cost pricing which requires metering of water use (which makes it suited to pumped water supplies such as tubewells) and the necessary administrative capacity. A review of World Bank policy and practices recommends that for efficient use, irrigation water is priced volumetrically, based on opportunity costs (Julius and Alicbusan, 1989). Where this is not feasible (e.g. for gravity-fed systems and canal irrigation), water can be charged for at a flat rate or a fixed charge. The charges are based not on the amount of water used but on other variables such as the land area, value of landholding, crop output, or non-irrigation inputs (e.g. land improvements). The most common form of charging is based on land area, as this is easy to administer and suited to continuous flow irrigation (Johansson, 2000). However, the actual preview of charging for irrigation water is not necessarily consistent with economic expectations and straightforward notions of price and costs (FAO, 2004).

Nevertheless, farmers place high marginal values on irrigation water, often a number of times higher than the charges actually imposed (Repetto, 1986) and increases in charges may not affect demand where these marginal values are so high. On the other hand, underpricing can be expected to encourage wastage of water, poor maintenance of irrigation systems and inefficient applications of water, resulting in reduced agricultural output.

With regard to private irrigation schemes, while irrigators have to meet the full financial costs of private irrigation schemes (although subsidies reduce the costs in some cases), it can be agreed that they rarely face the opportunity costs of water use (Briscoe, 1996). However, public irrigation schemes throughout the world have been subsidized to such an extent that charges rarely cover even operation and maintenance costs. Recovery of at least these costs is needed to enable the maintenance of irrigation systems, which is crucial to improved irrigation performance. Nevertheless, cost recovery can achieve such improvements only if the associated revenues are applied to improvements in the system. In public schemes, farmers sometimes do face a restricted measure of opportunity costs, which can arise implicitly as a consequence of water rationing. However, this is likely to underestimate the true opportunity costs significantly. Simulation analysis (Maass and Anderson, 1978) has indicated large differences in the economic losses arising from water shortages between market systems (which incorporate opportunity costs) and public allocation systems. Market systems were also found to be greatly superior in terms of the equity of distribution of the losses resulting from water shortages (contrary to the expected doctrine regarding procedures that perform well in terms of allocative efficiency).

There are further lessons that are important to the successful reform of water resource allocation policy (Briscoe, 1997). Although conventional economic wisdom suggests that users should pay the full economic costs of water supply, pursuit of such an aim is impractical and unhelpful in most developing-country contexts. Users commonly resent paying prices for water that exceed financial costs of supply, and object to paying for water supplies that were previously free. In order to be acceptable, tariffs need to be set on a basis that is understandable, transparent, legitimate, and that stimulates accountability. The challenge in irrigated agriculture is to ensure that farmers take into account the opportunity costs of water use (which are often an order of magnitude greater than current charges) and that institutional arrangements are in place to ensure that water moves to higher value uses. The incorporation of opportunity costs into water tariffs is not a straightforward task for a number of reasons: the information requirements are considerable; such charges would be objected to on the grounds that they entail appropriation of current users' 'property rights'; and farmers would have to pay substantially more than the cost of service provision, which may be politically unacceptable. Emerging international experience suggests that the appropriate approach to ensure that users consider the scarcity value of water is to clarify property rights and facilitate the leasing and trading of these rights. “Getting prices right” is important (Kloezen, 2002). Nevertheless, the lessons from experiences with pricing irrigation water suggest that water allocation methods are sensitive to physical, social, institutional and political settings, thus making it necessary to design allocation mechanisms accordingly (Johansson *et al*., 2002).

PRICING, OPPORTUNITY COSTS AND ECONOMIC BENEFITS

As water becomes increasingly scarce, the legitimacy of treating it as a 'free' resource arises. Arguably, the absence of pricing, as well as the lack of cost effective recovery, has been a major determinant of inefficient and excessive agricultural use of water. In response to these problems, many countries and water management agencies are turning to water pricing mechanisms to allocate water (Dinar, 2000). However, economists disagree on the appropriate means and methods for pricing water and on the notion of an optimal water pricing policy. The methods used to price water and the performance of these is dependent on the physical, social, institutional and political context. Nevertheless, as the pricing of water affects the allocation decisions of those with competing wants, then correct pricing can led to efficient allocation. In this context, pricing refers to the introduction of amended financial charges in situations where water was previously free or underpriced, or to the consideration of the economic value of water in decision-making through use of an appraisal and accounting procedure, such as cost–benefit analysis.

Because water resources are often non-marketed, it is extremely important to ensure that, where possible, the 'true' economic value of these resources is accounted for when making investments, or decisions concerning water and environmental policy. 'Accounting' or 'shadow prices', determined through the economic valuation of water resources, are employed in such decision-making in place of market prices. Unless water resources are priced correctly, and those prices internalized in decisions, distortions arise. These bias investment and policy decisions against concerns about water resource depletion and degradation, resulting in misallocation of resources and suboptimal social welfare.

The opportunity costs of water resource use and the economic value of the benefits can be compared in terms of whether the use is economically sustainable or socially optimal.

The characteristics of the agriculture sector and its relationship to the water system require careful consideration when designing instruments to internalize the opportunity costs in water use and/or to change water use behaviour. These include:

- the nature and complexity of water use and/or pollution (including environmental effects);
- geographical/location characteristics;
- characteristics of the target group (e.g. farmers);
- market characteristics.

However, given the criteria discussed earlier for comparing allocation mechanisms, no general guidelines exist as to how to price water. The right design depends upon the specific characteristics of the agriculture sector and the aim one has in mind of pricing water in the first place.

Opportunity costs of resource depletion and degradation

Marginal opportunity cost (MOC) is an important and useful tool for conceptualizing and measuring the physical effects of resource depletion and degradation in economic terms. MOC seeks to measure the full societal cost of an action or policy option that employs a natural resource such as water. Economically efficient resource management requires that the price that users pay for resource use should equate with the MOC. Where the price is less than the MOC, then the resource is overconsumed or overutilized. A price that is higher than the MOC results in the resource being underconsumed or underutilized. Sustainable management is achievable through sustainability pricing, which also includes a premium to cover the costs that accrue from any resource depletion.

The concept of opportunity cost is used to refer to the value of a resource in its best alternative use, i.e. other than the purpose being considered. This is the cost to society of use of the resource. It is considered in terms of a change at the margin, i.e. the MOC, because management decisions usually entail relatively small changes in resource use. MOC comprises three components.

The first component is the direct economic costs of water abstraction, such as the costs of labour, equipment and materials used for abstraction. Such costs require adjustment for any subsidies, taxation and market imperfections in order to reflect true opportunity costs (shadow pricing). These costs vary with the difficulty of extraction.

The second part of MOC is external costs that arise from water use (Chapter 3). This is the net value of any losses and gains in welfare that water use imposes on individuals other than those engaged in the activity. External costs arise because changes in one component of the natural resource base affect other components and the efficiency with which other activities can be conducted. Costs that occur in the future require discounting in order to make them commensurate with present day costs. Although information on marginal external costs is difficult to obtain and often imprecise or incomplete, useful approximations are possible. It is the external costs that arise from unsustainable resource use that are of particular interest.

The final component of MOC is relevant for non-renewable resources. Where such resources (which are fixed in supply, e.g. overabstracted aquifers) experience a positive rate of exploitation, then use of a unit of the resource results in its non-availability for future use. A scarcity premium can be placed on the resource, its magnitude depending on: the size of the resource stock relative to the rate of exploitation; the strength of future demand relative to present demand; the availability and cost of future substitutes; and the discount rate. This scarcity premium is known as the user cost (Conrad and Clark, 1987) and relates to the value of the opportunity foregone by exploiting and using the resource in the present period rather than at sometime in the future. It also incorporates increases in the costs of future resource use and exploitation that occur as a consequence of current use and exploitation (e.g. the increases in costs of future pumping of groundwater that occur owing to the greater difficulty of extraction). Marginal user costs also apply to non-sustainable use of renewable resources.

The user cost of non-renewable water resources is often ignored, especially where water resources are treated as an open-access resource and users behave in an individually competitive manner. This can happen in situations where property rights are ill defined or not enforced (Chapter 3). Use of the water is then governed by the law of capture, on a 'first come, first served' basis. Each user tries to extract as much as possible from the resource in the fear that other users will exploit the resource first, and also in the belief that the amount they themselves use is only a small proportion of the overall stock. The consequences of ignoring the user costs are that the costs of extraction are undervalued, which results in exploitation rates that exceed the optimum. This is in contrast to the situation where a single user has rights to a resource: the user has to take user costs into account because it is the user who faces the increased costs of extracting from a depleted resource in the future.

In summary:

marginal opportunity cost = marginal direct cost + marginal external cost + marginal user cost.

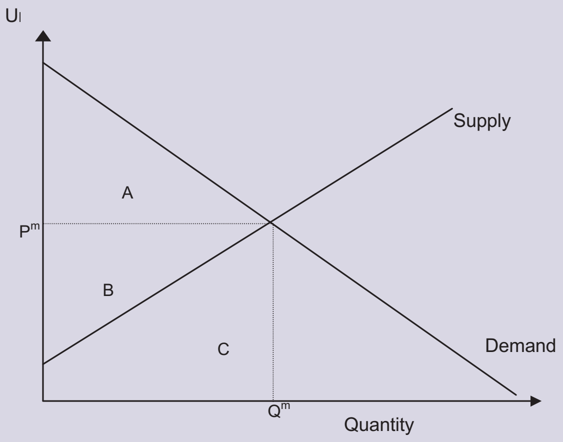
Pricing based on MOC is a useful principle as it forces attention on to the externalities associated with natural resource degradation, and guides pricing policy in providing incentives for allocative efficiency. Water is allocated to high-value uses, and high social costs provide a disincentive against excessive water use (Dinar, Rosegrant and Meinzen-Dick, 1997).

Failure to set water charges for irrigation on the basis of either opportunity costs or user benefits has been a classic cause of inefficiency in the agriculture sector (Repetto, 1986). Therefore, proper valuation of the socio-economic benefits derived from water resources is an important and often necessary condition for efficient and sustainable water resource use.

Economic benefits

Evaluation of the trade-offs necessary to allocate resources between competing wants requires consideration of their economic value. In particular, one of the main principles of efficient and sustainable resource allocation requires knowledge of the marginal value or benefits of the resource in its alternative uses.

FIGURE 8
Economic value, price and consumer surplus



In conventional economic terms, valuation refers to the estimation of individuals' preferences for the conservation or improvement in quality of a resource, as well as individuals' loss of welfare owing to resource depletion or quality decline. Individuals' preferences are measured in terms of how much they are willing to pay, which is also referred to as the economic value or benefit. Willingness to pay and economic value can be discussed in terms of the demand curve for a good or service. The gradient of the demand curve indicates how much an individual is willing to pay for each extra unit of the product (i.e. the marginal benefit). The price of the product gives the amount paid in the marketplace. Some individuals are willing to pay more than this price and so receive an additional benefit over and above the amount paid. This additional benefit the consumer surplus or net willingness to pay. Figure 8 illustrates this for the ordinary Marshallian formulation of welfare measures. Freeman (1993) presents a more precise Hicksian formulation. Economic value to society of a good or service is determined as the aggregate of all individuals' willingness to pay. Therefore, the price of a good or service and its economic value are distinct and can differ greatly: water can have a very high value, but a very low price or no price at all.

An aggregate measure of impact on social welfare does not consider inequalities in the distribution of gains and losses among individuals. Willingness to pay relates essentially to individuals' ability to pay, which determines the relative weights assigned to their preferences. Its use infers acceptance of the prevailing distribution of income. Cost–benefit analyses usually apply equal weighting of gains and losses across all individuals, and assume a socially acceptable prevailing distribution of income. However, distributional and equity weights, which are assigned on a social or political basis, can be used to weight preferences or outcomes that are of particular importance.

Although the economic value of a resource is most commonly determined by willingness to pay for gain or improvement in a resource, it is also theoretically valid to use willingness to accept compensation for loss or degradation of the resource. Theoretically, there should be no significant difference in the value of the two measures. However, empirical evidence suggests that in practice willingness to accept compensation is often substantially greater than willingness to pay (Hammack and Brown, 1974; Olsen, Richards and Scott, 1991; van Kooten and Schmidtz, 1992). Willingness to pay has become the most frequently applied measure of economic value and has been given peer review endorsement through a variety of studies (e.g. Arrow *et al.*, 1993). The specific circumstances and the property rights regime that is associated with the resource use in question determine the appropriate measure of economic value.

The area under the supply and demand curves indicates the aggregate supply and demand respectively for a good or service. In a competitive, freely functioning market, a quantity Qm of the good or service is traded at the market price Pm, which is the price at which demand matches supply. If quantities less than Qm are traded, consumers are willing to pay more than the market price (the demand curve is higher than Pm), suggesting that market price alone is only a minimum estimate of the economic value or benefit derived. The area between the market price and the demand curve (triangle A) is the consumer surplus, or the additional utility gained by consumers above the price paid. Therefore, total social benefits or TEV are the expenditure (areas B + C, or price multiplied by quantity) plus the consumer surplus (area A). The total cost of producing quantity Qm is the area below the supply curve (area C). The area above the supply curve and below the market price the producer surplus; this occurs because producers are willing to sell for less than the market price if the quantity traded is less than Qm (the supply curve is less than Pm). The net social benefit is the consumer surplus (area A) plus the producer surplus (area B).

A further issue related to valuation entails the use of costs as determinants of economic value. The correct measure of economic value is determined based on benefits, as indicated by the area under the demand curve. However, some valuation techniques, such as those based on the damage costs avoided, defensive expenditure, replacement/substitute costs or restoration costs, use costs as a proxy for benefits. This is based on the misplaced assumptions that costs are necessarily a reasonable approximation of social benefits and that the benefits are at least as great as the costs involved in repairing, avoiding or compensating for damage. These techniques are applied widely because of their relative ease of use and availability of the data, but it is important to be aware of the limitations in terms of the information they convey. Such cost-based measures of value are derived from the supply of goods and services and should not be confused with demand-based approaches.

As discussed above, the supply of goods and services entails various elements of costs, including direct, external and user costs. Taken together these elements of cost are akin to the concept of social cost, and when equated with the marginal benefits of use, lead to an efficient, in economic terms, allocation of resources.

Chapter 4

Economic valuation of water resources

VALUATION OF GOODS AND SERVICES PROVIDED BY WATER

Economic valuation here serves as a basis for evaluating the trade-offs involved in the allocation of water resources between competing wants. Given the perspective outlined in Chapter 1, the focus is particularly on valuation of changes in functions provided by water resources under different allocation options. For the purposes of cost–benefit analysis, the impacts of alternative options for water resource use or management are specified in terms of the economic value using the common numeraire of money. Economic value is determined by the impact on social welfare, which is given by the aggregate impact on the utility of individuals in society. The utility to individuals is determined by their preferences, which individuals express in the amount that they are willing to pay for goods and services. In addition to considering the economic value of water in terms of the common numeraire of money, the value of water also needs to be commensurable in terms of place, form and time. Water is a 'bulky' resource with high conveyance costs and, hence, its value may differ with location. Demand for water can also vary greatly over time (e.g. differences in demand for irrigation water in winter and summer). Thus, comparisons of value should ideally be in terms of raw water supplies at a specified point of diversion (Young, 1996).

Total economic value: linking functions and service flows

Water resources are natural assets that create flows of goods and services over time. As outlined in Chapter 1, the key to valuation of water resources is to establish the functions that they provide, i.e. the link between the structures and processes of water resources and the goods and services they provide that are valued by society. If that link can be established, then the concept of derived demand can be applied. The value of a change in the functions provided by a water resource can be derived from the change in the value of the stream of goods and services provided. The goods and services can be categorized in various ways, for example, in terms of whether they are extractive or *in situ*. They are influenced by extraction and return flows, which affect the quantity and quality of water stocks and flows. These influences relate in an intertemporal way to the stream of goods and services provided, and require incorporation into any meaningful valuation analysis.

Table 5 provides a selection of the various classification systems used to describe the different types of values associated with the goods and services provided by water resources.

Rogers, Bhatia and Huber (1997) consider the value of water to be divided into economic value and intrinsic value. Turner and Postle (1994) consider the economic value of water resources and aquatic ecosystems in terms of four separate components, and Young (1996) distinguishes between five categories of water-related economic values and also considers the possibility of certain other value types. De Groot (1992) categorizes the components of ecosystem value according to the impact on welfare, using a broad definition that encompasses environmental, physical and mental health, employment and social contacts as well as material prosperity.

TABLE 5
Selected classifications of the value of water

Rogers, Bhatia and Huber (1997)	Turner and Postle (1994)	Young (1996)	De Groot (1992)
Value of water use comprises economic and intrinsic value: Economic value of water: • Value to water users. Value of water in industrial and agricultural use and willingness to pay for its domestic use. • Net benefits of return flows. Recognizes the vital role played by return flows in many hydrological systems, e.g. recharge of groundwater. • Net benefits from indirect use. For example, the benefits associated with improvements in income and in health that can accompany schemes that provide water for irrigation, domestic and livestock use. • Adjustments for social objectives such as poverty alleviation, employment generation and food security. Intrinsic value of water: Intrinsic value of water includes the stewardship, bequest, and pure existence value.	The use and, therefore, value of water resources and associated ecosystems are divided into four categories: • Abstraction of water: for irrigation and other agricultural uses, domestic water supply, and water for industrial production. • Fisheries: commercial fish and shell fisheries, non-commercial "heritage" and recreational fisheries. • Recreation: in-stream recreation (canoeing, sailing and bathing) and out-of-stream recreation (such as walking, picnicking, bird watching). • Biodiversity and related landscape conservation: from river corridor to catchment scale. The categories are also sources of non-use or bequest value and all apart from the first category may provide existence value.	Water-related economic values are divided into the following classes: • Commodity benefits. These are derived from personal drinking, cooking and sanitation, and from productive economic activity, e.g. agriculture. • Public and private aesthetic and recreational values. These are becoming increasingly important as incomes and leisure time increase. • Waste assimilation benefits. These result from the sink function of waterbodies that carries away residuals from processes of human production and consumption. • Dis-benefits or damages. These are found in connection with evaluations of floodplain and water quality management. • Non-use values from knowing that a good exists, even though no direct experience is had of the good. Possible other values include intrinsic, ecosystem preservation and socio-cultural.	Value is categorized in terms of the nature of the contribution made to human welfare (defined broadly): • Ecological value: includes conservation and existence values. Usually only described qualitatively as valuation is limited, though it may be described using quantitative indicators (e.g. number of species). • Social value: includes health and option values. It may be quantified through use of minimum standards for resource availability (e.g. to ensure sustainable harvesting). Economic values: includes consumptive use, productive use and employment value. Described in terms of quantities (e.g. volume of a resource harvested), monetary units (e.g. value of the resource harvested), or the number of people employed in activities dependent on the given function.

The approach advocated here is to describe the components of the value of water using the conventional categories of TEV (Figures 9 and 10). There are two main categories, use values and non-use values:

- Direct use values arise from direct interaction with water resources. They may be consumptive, such as use of water for irrigation or the harvesting of fish, or they may be non-consumptive such as recreational swimming, or the aesthetic value of enjoying a view. It is also possible that 'distant use' value can be derived through the media (e.g. television and magazines), although the extent to which this is attributable to a specific site, and the extent to which it is actually a use value, are unclear.
- Indirect use values are associated with services provided by water resources but that do not entail direct interaction. For example, they are derived from flood protection provided by wetlands or the removal of pollutants by aquifer recharge.

Non-use values are derived from the knowledge that a resource is maintained. By definition, they are not associated with use of the resource or tangible benefits that can be derived from it (though resource users may derive non-use values). Non-use values are linked to ethical concerns and altruistic preferences, although it can be argued that these ultimately stem from self-interest. They can be divided into three types of value (which can overlap): existence value, bequest value and philanthropic value. Existence value is the satisfaction derived from knowledge that a feature of a water resource continues to exist, regardless of whether or not it might be of benefit to others. Bequest value is derived from the knowledge that a feature of a water resource will be passed on to future generations so that they will have the opportunity to enjoy it. Philanthropic value is the satisfaction gained from ensuring that resources are available to contemporaries in the current generation.

There are two further types of value that are not categorized as either use or non-use values. These are option value and quasi-option value:

- Option value is the satisfaction that an individual derives from the ensuring that a resource is available for the future given that the future availability of the resource is uncertain. It can be regarded as insurance for possible future demand for the resource.
- Quasi-option value is derived from the potential benefits of waiting for improved information prior to giving up the option to preserve a resource for the future. This is based on a desire to take advantage of the prospect of improved information in the future and act on subsequent revision of preferences. It is the value placed on retaining flexibility, and on avoiding irreversible damage that might prove to be undesirable in the light of future information. An example is the value placed on conservation of a wetland until further information is available on the value of the species that are found within it.

TEV is determined as the sum of the components in Figure 9. In practical terms, this is limited to those components that it is feasible to quantify. Use of TEV in the analysis of alternative allocations ensures that the full social benefit of goods and services provided by water is taken into account. This is necessary to indicate to decision-makers the welfare improvement that is offered by alternative allocations. However, TEV does not provide an exhaustive assessment of the value of water resources to society. It measures the extent to which goods and services provided by water touch on the welfare of society, as direct determinants of individuals' well-being or via production processes. It represents two fundamental sets of values: individual values and production values. Individual values include recreational and amenity values, as well as non-use values (existence, bequest and philanthropic values) of goods and services provided by water. Production values occur through the influence of water on the production and cost functions of other marketed goods and services (such as use of water as an intermediate good

FIGURE 9
Components of the total economic value of water resources

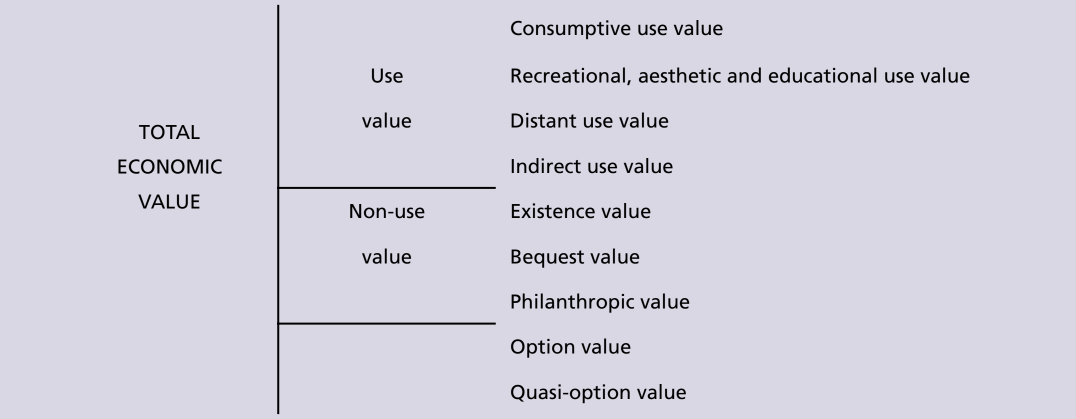
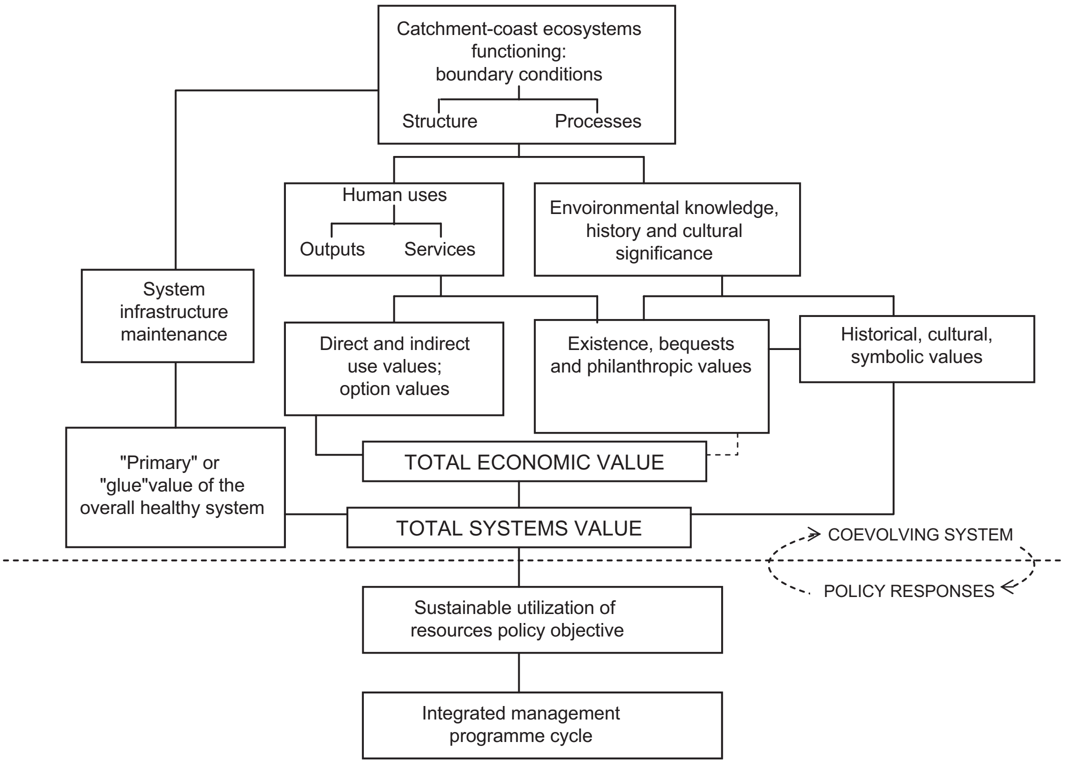


FIGURE 10
Functional and other dimensions of water catchment values



Source: adapted from Turner, Bateman and Adger (2001).

in irrigated crop production). The effects of this influence on the prices of other inputs and marketed goods and services translate into changes in individuals' welfare.

However, as indicated in Figure 10, another set of values is supplementary to TEV. This represents the role of water resources in natural systems. It includes the value of services that stabilize natural systems and perform protective and supportive roles for economic systems. These values are more usually presented in relation to biodiversity, but are similarly applicable to water resources. They include the following (somewhat overlapping) categories of value:

- inherent value: the value of those services without which there would not be the goods and services provided by the system (Farnworth *et al.*, 1981);
- contributory value: this represents the economic–ecological importance of species diversity. Species that are not of use to humans are important because they contribute to increased diversity, which itself contributes to the generation of more species (Norton, 1986);
- indirect use value: this is related to the support and protection provided to economic activity by regulatory environmental services (Barbier, 1994);
- primary value: incorporates the fact that existence of the catchment structure is prior to the range of function/good and service values (Turner and Pearce, 1993);
- infrastructure value: this relates to a minimum level of ecosystem 'infrastructure' as a contributor to its total value (Costanza *et al.*, 1997).

These values build on three important aspects of the ecology of natural systems:

- Complementary relationships. Species coexist within natural systems, defined by complex relationships of interaction and interdependence. Survival of one species depends on the existence of other species, which in turn depend on others. This 'contributory value' focuses on the survival of species within the web of interactive relationships with each species contributing to the survival of others. Contributory value is based on the limited substitutability of species. This occurs because every species performs very specific duties within the ecological system. The role of contributory values is not usually taken into account explicitly, because the required knowledge (on ecological interrelationships) is unavailable, but it can be incorporated through adoption of a precautionary approach to resource management.

- Keystone species. The persistence of natural systems in their current existing states may be dependent on a limited number of biotic and physical processes. These processes are directed by groups of species with complementary functions, known as 'keystone species'. Other species are redundant, although they can become keystone species under a change in environmental conditions. As long as species can substitute for each other under changing conditions, the balance of processes within the system can remain intact. However, reductions in the diversity of species in the system diminish the possibilities for substitutions under a change in conditions. This limits the capacity of the system to persist in its current state in the face of stresses and shocks.
- Goods and services provided by a natural system are dependent on the structure and functioning of the systems. The goods and services provided are connected inherently to the integrity of the natural system and the totality of the structure and functioning of the system (Farnworth *et al.*, 1981). This can be understood in terms of the concepts of primary and secondary value (Gren *et al.*, 1994). The primary value describes the system characteristics: the self-organizing capacity of the system including its dynamic evolutionary processes and capacity to absorb external disturbances. It relates to the aspects of the system that "hold everything together" and is consequently also referred to as "glue value". Secondary value refers to the renewable flow of goods and services generated by the natural system. It is dependent on the continued operation, maintenance and 'health' of the system as a whole.

TEV does not give credit to this set of values and, therefore, is not exhaustive. Such values are particularly relevant to single function natural systems, the contributory value of which can only be addressed properly when the site is viewed within the context of the larger catchment system. The recognition of complementary relationships implies that the total value of catchment systems is infinite. This is similar to the consideration of water resources as a form of 'critical' natural capital (Dubourg, 1997). Here again, the value of water is infinite and the usual measures of value (market price and willingness to pay) do not reflect the true economic value of the resource. As a basis of human life, complementary relationships with water resources are indispensable under realistic technological and economic conditions. However, apparently marginal decisions (as perceived by different stakeholders) are important in the real world and, therefore, need to be considered. The problem is that knowledge about the consequences of resultant infringements on natural systems is incomplete. There is an unbridgeable gap in knowledge about natural system interrelationships and regularities. The benefits of protection will often only become apparent once the natural system has been disturbed or lost.

The task of sustainable management can be defined as sustainable utilization of the multiple goods and services generated by natural systems, together with "socially equitable" distribution of welfare gains and losses inherent in such usage. However, social welfare is affected both by changes in economic welfare and also changes in properties of natural resources that are associated with people's sense of identity, their culture and which are of historical significance. Such properties are particularly important in the case of water resources, given the essential role of water for human life. The compilation of data for such properties is a qualitative exercise, involving more deliberative and inclusionary interest group approaches, such as consensus conferences, citizen juries and focus group interviewing. Different cultural views on social relations are assumed to give rise to different degrees of support for alternative decision-making procedures and for the underlying valuations elicited via the social discourse process (O'Riordan and Ward, 1997; Brouwer *et al.*, 1999). This has similarities to the so-called 'approved process' approach (Morgan and Henrion, 1990) in which all relevant parties observe a specified set of procedures or concept of due process to make a decision that balances conflicting values at the political level.

Some environmental analysts claim that natural systems also have non-anthropocentric intrinsic value and that non-human species possess moral interests or rights, or that although all values are anthropocentric and usually instrumental, the economic approach to valuation is only partial. These environmentalist positions lead to the advocacy of environmental sustainability standards or constraints, which to some extent obviate the need for valuation of specific components of the environment. However, it is still necessary to quantify the opportunity costs of such standards, or to quantify the costs of current, and prospective environmental protection and maintenance measures. Nevertheless, some commentators view it as feasible and desirable to manage the environment without prices. For example, O'Neil (1997) found that in other arenas such as forestry and biodiversity management, issues concerning conflicts in value are resolved through pragmatic methods of argument between botanists, ornithologists, zoologists, landscape managers, members of the local community, and farmers.

A growing body of evidence suggests that some of the conventional economic axioms are violated systematically by humans in controlled experiments and in everyday life. To take just one issue, it seems likely that individuals recognize 'social interest' and hold social preferences separate from self-interested private preferences. The origin of this social interest may be explained by theories of reciprocal altruism, mutual coercion, or by sociobiological factors. Therefore, the distinction between the individual as a citizen and as a consumer is not an 'either/or' issue, but is more properly interpreted as the adoption of multidimensional roles by individuals.

As citizens, individuals are influenced by held values, attitudes, and beliefs about public goods and their provision. In this context, property rights (actual and perceived), social choices and moral concerns can all be involved in the conflict between conservation and development of natural resources. The polar view to the conventional economic approach holds that the very treatment of ecological assets such as biodiversity in terms of commercial norms is itself part of the environmental crisis. The argument becomes one of the 'proper' extent of market influences and commodification. Advocates of this perspective argue that market boundaries should not cover as many environmental assets as possible. Instead, society should give greater consideration to the nature of deliberative institutions for resolving environmental problems and the social and economic framework that sustains them (O'Neil, 1997). A counterbalancing argument is that some environmental goods and services that have mixed public and private good characteristics (e.g. forests, catchments, areas with ecotourism potential and some aspects of biodiversity services) could be privatized or securitized (shares issued). In this way, self-interest and the profit motive can be made to work in favour of environmental conservation (Chichilnisky and Heal, 1998).

USE OF ECONOMIC VALUES IN THE MANAGEMENT OF WATER RESOURCES

The quantification of the economic value of water resources and the identification of those instrumental values that it is not possible to quantify is of importance to the management of water resources for the five reasons (Georgiou *et al.*, 1997) presented below.

The importance of water in national development strategies

The depletion and degradation of water resources imposes costs on nations, some of which affect the gross national product (GNP). Typically, the degradation of water resources contributes towards a reduction in GNP, whereas resource depletion contributes towards increases in GNP. However, GNP accounts do not include the costs imposed on society by resource depletion and degradation; although they would be included if GNP reflected more comprehensive measures of aggregate well-being. Although the empirical investigation of water resource depletion and degradation is in its infancy, the evidence available suggests that the costs of resource depletion and degradation are appreciable. Such estimates of resource costs estimates can play a useful role in assessing development priorities. As the costs of resource depletion and degradation are increasingly recorded and accorded greater significance, planners have greater incentives to prioritize these issues in their development plans.

Modification of national accounts

As mentioned above, national accounts are deficient in the treatment given to environmental resources, such as water. Measures of economic activity ignore the resource flows that take place in the economy. These fail to record important activities that affect the sustainability of the economy and of well-being. Thus, there is a need to modify national accounts such that they record "stocks" and "flows" of natural resources. GNP should account for depreciation of resource stocks (including water resources) in the same manner that it incorporates depreciation of human-induced capital (net national income = gross national income - estimated depreciation of human-induced capital). This would provide a measure of the 'draw down' on water 'capital' and the losses that accrue to human well-being from the use of goods and services provided by water resources (e.g. through pollution of returns flows of water). Both adjustments involve economic valuation, although national accountants have not agreed how best to make the appropriate adjustments.

The setting of national and sectoral priorities

Information on the economic value of changes in water policy can assist governments in setting policy and sectoral priorities. A comparison of the benefits and of the costs of planned changes in policy is required in order to establish whether they are potentially worthwhile. Valuation can be used to influence the allocation of irrigation water, ensuring that water is directed towards priority areas (in addition to its role in efficiency pricing). For example, decision-makers can use it as an aid in the allocation of water between hydroelectric power generation and storage for irrigated agriculture. There is a particular need to review sectoral priorities in terms of economic benefits and costs, which has perhaps even greater force in the developing countries where government income is at a premium.

Project, programme and policy evaluation

Environmental resource damage and benefit estimation falls conventionally under the remit of project appraisal. Extension of project appraisal to account for impacts of water resource degradation and depletion presents no conceptual problem for the benefit–cost approaches that are used. It is important that the environmental implications of projects and programmes be evaluated. Indeed, the overall returns to development programmes should be assessed with reference to environmental enhancement components. Investments in water resources are important components of public infrastructure budgets, and include irrigation, hydropower, urban and rural water supply, sanitation and flood control. Valuation is also employed in the assessment and implementation of policies that are used to monitor and manage water resource depletion and degradation. The policies can include standards (set by regulatory agencies) that require the polluter to bear costs in meeting the standard that are equal to the minimum estimated value of the damage that the pollution would cause. Valuation is also an important guide in the setting of environmental 'prices' in the form of taxes, charges or tradable permits. However, the accuracy and reliability requirements of monetary valuation results are much stricter for this purpose. Large estimation errors are usually unacceptable in view of the political sensitivity and potential consequences if tariff setting does not achieve the intended effect because it is based on the wrong information.

Economic valuation and sustainable development

Economically efficient use of water resources is not necessarily sustainable. For example, the optimal rate at which a finite non-renewable resource is depleted requires a positive rate of extraction. In the absence of discovery of further identical resources, the resource must be exhausted eventually. Every unit of resource used today is at the cost of foregone use of a unit tomorrow. This is relevant to overextracted reserves of groundwater and poses the question of how much groundwater to pump now and how much to save for future needs. On the other hand, sustainability can be interpreted as a requirement that human well-being does not decline through time. Therefore, adoption of sustainable development as a goal creates a need for economic valuation to establish that human well-being does not decline through time. With 'weak' interpretation of the concept, sustainability can be defined such that the primary condition is for the aggregate stock of capital not to decline. This requires valuation of the capital stock to establish the extent of the stock and to monitor whether it is in decline. Thus, valuation can support pursuit of sustainability at the very least by helping to focus policy-maker and public attention on threatened resources.

However, the economic valuation of water resources is a crude and inexact science. The value of water varies widely according to factors such as the use it is put to, the socio-economic characteristics of users, its availability in space and time, as well as the quality and reliability of supply. It is not proposed that technocratic decisions on allocation should be made solely on their basis of estimates, or that they should be made in a routine fashion. Rather, it is proposed that the estimates obtained are useful for highlighting more general themes in water use that have major implications for policy (Briscoe, 1996).

PRACTICAL ISSUES CONCERNING ECONOMIC VALUATION

Scale

The issue that is under investigation determines the scale of evaluation. For a specific isolated external impact, evaluation may be restricted to a limited number of affected variables. Where broader changes are involved (e.g. a change in land use in a catchment), partial analysis of a number of integrated parameters may be required. Because of the costs and effort involved, full valuations are usually avoided unless they are absolutely necessary, e.g. a situation where an entire catchment is under threat.

The geographical scale (or accounting stance) of a study is determined by the extent of the population affected by the impact under investigation. The accounting stance should be as encompassing in this respect as possible. Where the impact incurs only changes in direct uses of a water resource, the affected population consists of existing and potential resource users. However, this population does not necessarily live in close proximity to the resource as they may travel considerable distances to use it. Indirect use values may not be site specific in terms of those who benefit, e.g. interception of floodwaters by irrigation may yield benefits far downstream. Non-use benefits are derived over a wide geographical area, but are likely to be subject to 'distance decay' away from the site. In practice, a pragmatic accounting stance has to be adopted in specifying the scale, where the gains in accuracy are balanced against the costs of spreading the scale wider.

The temporal scale, combined with the discount rate, influences the present value of the streams of costs and benefits. The calculation of expected future costs and benefits involves estimating future demand. This is necessarily unknown but a range of possible values can be obtained through the assessment of likely scenarios and application of sensitivity analysis. The temporal scale also determines the trade-off between considering long-run versus short-run values. Decisions are more constrained and responses quite different in short-run contexts. Most public policy contexts relate to the longer term, although there are some circumstances, such as drought planning, for which short-run values are more appropriate.

Aggregation and double counting

This report advocates adoption of a functional approach to water resources. This involves considering the goods and services provided by water resources in relation to environmental structures and processes. However, it does raise issues that require attention in the aggregation of data on the benefits provided:

- Attention is required to avoid the double counting of benefits. For example, if nutrient retention is integral to the maintenance of biodiversity, its value is "captured" in the value of the latter. Aggregation of the values of the two functions would result in double counting of the value of nutrient retention (Barbier, 1994).
- Some functions of water resources may be mutually exclusive and, therefore, cannot be aggregated. For example, aggregation of the values for both extraction of surface water and recharge of groundwater would overestimate the benefits that could feasibly be derived from a water resource.
- Interactions can occur between functions. For example, conservation goals may require alteration to the harvesting regime employed for reed beds, which reduces the gross margins of the beds. Some functions may be complementary, e.g. nutrient retention can promote biomass production.

In practice, the multiple functions of water resources make comprehensive estimation and aggregation of every function and linkage between them a formidable task. In particular, the ability to use water repeatedly or simultaneously for different uses means that competition and complementarity are important considerations in valuing water resources. Water resource allocation and management would ideally be considered under a general equilibrium framework, although this is extremely difficult in practice. This also means that total valuation (estimation of the full value of a water resource) is undertaken only when necessary. Management decisions are more commonly assessed using impact analysis (which assess the damage arising only from a particular impact) or partial valuation, based on a sectoral approach or on specific functions of a water resource. Such a partial approach means that a number of considerations must be taken into account. First, the different ways of calculating values may result in fundamentally different definitions of value, for example, which are specific to certain time frames that differ between the uses considered. Second, values may be based on average or marginal concepts, which are quite different concepts. Use of marginal values is required for the purposes of efficient allocation.

Allocation over time

It is frequently necessary to choose between options that differ in temporal patterns of costs and benefits, or that differ in their duration. Discounting provides a common matrix that enables comparison of costs and benefits that occur at different points in time. Use of discounting is integral to cost–benefit analysis and cost–effectiveness analysis.

Discounting converts the stream of costs and benefits over time into a stream of 'present' values. The difference between the value of the discounted benefits and costs is referred to as the NPV. A management or policy option is economically viable only if NPV is positive, as described in Equation 1:

$$NPV = \sum_t \frac{(B_t - C_t)}{(1 + r)^t} > 0 \qquad (1)$$

where B_t and C_t are benefits and costs in year t respectively, and r is the discount rate.

The rationale for discounting is that costs and benefits that occur in the future are not valued as highly as those that occur in the present. There are two explanations for this:

- Time preference (or the “consumption rate of interest”). Individuals prefer consumption in the present to consumption in the future. Reasons for this include:
  - the risks involved in delayed consumption;
  - anticipation of increased wealth in the future, which reduces the relative worth of postponed consumption (i.e. decreasing marginal utility of consumption);
  - 'pure' time preference or myopia.
- The opportunity cost of capital. Financial capital that is not consumed in the present can be invested and expected to increase in value by the rate of interest. Therefore, there is an opportunity cost associated with present consumption of financial capital, which is the return that could be derived from its investment (as indicated by the rate of interest).

The choice of discount rate can have a significant effect on economic viability of management options and their relative economic ranking. It signals the rate at which future consumption is to be traded against consumption in the present. Use of a high discount rate discriminates against the future. It discriminates against options that involve high initial costs and a stream of benefits that extends far into the future (e.g. creation or restoration of a wetland). Instead, it favours options that have immediate benefits and a lag in incurring costs. This has been described as the 'tyranny' of discounting (Pearce, Markandya and Barbier, 1989).

High discount rates tend to be justified based on the opportunity cost of capital, although to be correct this is relevant only for financial analysis, which is not the examined here. In general, they are likely to encourage depletion of non-renewable natural resources and exploitation of renewable natural resources, reducing the inheritance of natural capital for future generations. Low discount rates favour the future but could discriminate against and hamper immediate economic development. They encourage investments which would otherwise not have been viable and which could be associated with an even more rapid depletion of natural resources (Fisher and Krutilla, 1975). Therefore, the impact that the discount rate has on the environment is ambiguous, and it is not clear that the call for use of lower discount rates to incorporate environmental concerns is generally valid.

A social rate of discount is used to evaluate the impact of management options on intergenerational welfare. Such evaluations take intergenerational welfare into consideration. The maintenance of future welfare can be regarded as a public good, in which private individuals will tend to underinvest. As a result, the social discount rate is lower than the equivalent rate of discount for individuals. The social discount rate is measured either as the social rate of time preference or the social opportunity cost of capital. Care has to be taken in developing-country contexts, where the use of consumption rates of interest (which are likely to exceed 4–6 percent) may not account adequately for concerns about the inheritance of environmental problems by future generations.

The social discount rate can also be adjusted to reflect temporal trends in the net benefits of environmental preservation and development. The net benefits of such preservation are likely to increase over time as demand for environmental services rises under conditions of limited or declining supply. Conversely, the net benefits of development projects are expected to decline over time due to technological advancement. These trends can be incorporated into economic evaluation through appropriate adjustment of the social discount rate, e.g. by decreasing the discount rate applied to preservation benefits and increasing the rate applied to development benefits (Hanley and Craig, 1991).

Risk and uncertainty

In the case of risk, meaningful probabilities can be assigned to the likely outcomes. In the case of uncertainty, probabilities are entirely unknown. Risk can be incorporated into an evaluation by attributing probabilities to possible outcomes, thereby estimating directly the expected value of future costs and benefits (Boadway and Bruce, 1984) or their 'certainty equivalents' (Markandya and Pearce, 1988). A premium for risk can be incorporated into the discount rate used for the analysis. However, such adjustment is not recommended as it is arbitrary, often subjective and attributes a strict (and unlikely) time profile to the treatment of risk.

In an economic evaluation, uncertainty is associated with physical outcomes and their economic consequences. For water resources, the necessary assessment of possible outcomes and the likelihood of perturbations to what is a highly complex system is inevitably fraught with difficulty. However, this is a necessary component of an economic evaluation. For each management or policy option under consideration, the range of possible impacts needs to be identified and quantified as far as possible. A particularly important issue relating to uncertainty in physical effects is the possible existence of thresholds beyond which disproportional and irreversible effects can occur.

There is also uncertainty that relates to the physical and economic conditions that will prevail in the future. For example, a change in regulations concerning agricultural production could cause farmers to respond with a change in land use. In turn, this could affect nutrient concentrations in runoff and thereby affect the value of the nutrient retention function provided by a wetland. Similarly, individuals can alter their behaviour in response to changes in water resource functions. For example, farmers might respond to an increase in flooding with a change in cropping patterns. Such uncertainties can influence projected benefits and so also need to be incorporated into any evaluation of options.

Uncertainty is incorporated into economic evaluations through the use of sensitivity analysis or scenario analysis. In sensitivity analysis, various possible values are used for key variables in the evaluation, such as the discount rate, the extent of functions, and economic values. This provides a range of estimates within which the true result can be expected to fall. It can create ambiguity, but is a necessary component of any economic evaluation. Scenario analysis can also be used to incorporate uncertainty through comparison of results using parameter values that represent different possible future scenarios.

Costanza (1994) points out that 'most important environmental problems suffer from true uncertainty, not merely risk.' In an economic sense, such pure uncertainty can be considered as 'social uncertainty' or 'natural uncertainty' (Bishop, 1978). Social uncertainty derives from factors such as future incomes and technology, which influence whether or not a resource is regarded as valuable in the future. Natural uncertainty is associated with imperfect knowledge of the environment and whether it has unknown features that may yet prove to be of value. This may be particularly relevant to ecosystems for which the multitude of functions that are performed have historically been unappreciated. A practical means of dealing with such complete uncertainty is to complement the use of a cost–benefit criterion based purely upon monetary valuation with a safe minimum standards decision rule (discussed below).

Irreversible change

The standard procedures for economic evaluation do not account for irreversible impacts, such as the extinction of species or exhaustion of minerals. Under such circumstances, account needs to be taken of the uncertain future losses that might be associated with potential irreversible change. Some protection to the interests of future generations can be offered through the imposition of the safe minimum standards decision rule (Ciriacy-Wantrup, 1952; Bishop, 1978; Crowards, 1996).

The safe minimum standards decision rule recommends that conservation be adopted when a development activity that has an impact on the environment threatens to breach an irreversible threshold (unless the costs of foregoing the development are regarded as 'unacceptably large'). It is based on a modified principle of minimizing the maximum possible loss. Therefore, it differs from routine trade-offs, which are based on maximizing expected gains, e.g. cost–benefit and risk analysis. However, activities that result in potential irreversible change are not rejected if the associated costs are regarded as intolerably high.

A critical aspect in the application of the safe minimum standards decision rule is specification of the threshold for unacceptable costs of foregoing development. The degree of sacrifice is determined through full cost–benefit assessment of the development option, including estimable costs of damage to the environment. The decision as to whether conservation of natural resources can be justified (and rejection of the development activity) is political, constrained by society’s various goals. In this sense, safe minimum standards provide a mechanism for incorporating the precautionary principle into decision-making. Even in the absence of proof that damage will occur, society may choose to conserve in order to limit potential costs in the future (Crowards, 1997).

The concept of safe minimum standards has usually been applied to endangered species. However, it could equally be applied to irreversible impacts that threaten water resources. Where thresholds of water resource processes are threatened with irreversible change, the use of safe minimum standards provides a decision framework that gives more weight to concerns of future generations. It promotes a more sustainable approach to current development and can provide an appropriate supplement to standard analysis of economic efficiency.

Safe minimum standards are closely related to sustainability considerations (Pearce and Turner, 1990). Sustainability essentially requires that the stock of natural capital available in the future is equivalent to that available at present. The concept of sustainability has been partitioned into two approaches: weak sustainability and strong sustainability (Turner, 1993). Weak sustainability requires that the total stock of capital, whether human-induced or natural, be maintained. It rests upon the assumption of substitutability between these two types of capital. Economic theory suggests that decreases in supplies of natural resources cause their prices to increase, which encourages more efficient use of natural resources, substitution with other goods, and technological advancement. However, complete substitution is not always possible because of physical limits on the efficiency and availability of opportunities for substitution, the question of whether human-induced capital can compensate fully for all the functions provided by complex ecosystems, and the existence of “critical” natural capital and thresholds beyond which reversal is not possible. The more stringent interpretation of strong sustainability requires that the total stock of natural capital be non-declining. Under this criterion, projects should either conserve the natural environment or ensure that losses incurred are replaced or compensated fully for in physical terms by the implementation of 'shadow projects' (Barbier, Markandya and Pearce, 1990).

An alternative way of for accounting for potential irreversibility in the analysis of discrete development–conservation choices (e.g. if a development entails exploitation of a water resource to exhaustion) is to include the preservation benefits foregone as opportunity costs in the cost–benefit analysis. Future development benefits that occur as a result of relative price effects and technology changes are discounted and also included in the analysis. This approach is known as the Krutilla-Fisher algorithm (Krutilla and Fisher, 1985). Irreversible change can also be incorporated into the evaluation through adjustment of the social discount rate to allow for temporal trends in the benefits of preservation (discussed above).

Data limitations

It is inevitable that some of the data required for an economic evaluation will not be readily available. Budgetary constraints often limit extensive collection of original data. Where data are limited, this should be acknowledged and the measures taken in response to this limitation specified clearly. The results and recommendations should be made explicitly conditional on these limitations.

The various techniques used to value non-marketed goods and services are each associated with specific data limitations. These limitations are included in the discussion of each of the techniques presented below. They can be particularly acute in applications in developing countries.

ECONOMIC VALUATION TECHNIQUES

The various techniques presented here include the estimation of demand curves and the area beneath them, analysis of market-like transactions, use of production approaches that consider the contribution of water resources to the production process, estimation of the costs of providing alternative sources of water, as well as other techniques used to estimate environmental resources more generally. The techniques reflect the extent to which the goods and services provided by water resources touch on the welfare of society either as direct determinants of individuals’ well-being (e.g. as consumer goods) or via production processes (e.g. as intermediate goods). They are grouped here according to whether the techniques rely on observed market behaviour to infer users’ value of water resource functions (indirect techniques), or on whether they use survey methods to obtain valuation information directly from households (direct techniques).

Some of the techniques require the analyst to undertake primary and secondary data collection, econometric analysis, discounted cash flow analysis and optimization analysis. The aim here is to provide a brief overview (Table 6). Further details of the underlying theory and practical implementation of the techniques is provided in general texts including Braden and Kolstad (1991), Freeman (1993), Pearce, Whittington and Georgiou (1994), Georgiou *et al.*, (1997). In addition, Young (1996) provides a more detailed procedural handbook for field practitioners on the evaluation of some of the more common functions of water resources, such as water supply.

TABLE 6
Summary of economic valuation techniques relating to water resources

Valuation method	Description	Direct use values	Indirect use values[1]	Non-use values
Market analysis & market-based transactions	Used where market prices of outputs (and inputs) are available. Marginal productivity net of human effort/cost. Could also be approximated using market price of close substitute. Includes transactions in water rights. May require shadow pricing.	√	√	
Derived demand functions	Derive value from the household's or firm's inverse demand function based on observations on water use behaviour.	√	√	
Residual imputation and variants	Budget analysis used to estimate return attributable to water. Water treated as one input into the production of a good. The total returns are calculated; all non-water expenses are subtracted. Change in net return from marketed goods: a form of (dose–response) market analysis.	√	√	
Hedonic price method	Derive an implicit price for an environmental good from analysis of goods for which markets exist and which incorporate particular environmental characteristics.	√	√	
Travel cost method	Costs incurred in reaching a recreation site as a proxy for the value of recreation. Expenses differ between sites (or for the same site over time) with different environmental attributes.	√	√	
Contingent valuation method	Construction of a hypothetical market by direct surveying of a sample of individuals and aggregation to encompass the relevant population. Problems of potential biases.	√	√	√
Contingent ranking	Individuals are asked to rank several alternatives rather than express a willingness to pay. Alternatives tend to differ according to some risk characteristic and price.	√	√	√
Damage costs avoided	The costs that would be incurred if the catchment function were not present, e.g. flood prevention.	√	√	
Avertive behaviour & defensive expenditures	Costs incurred in mitigating the effects of reduced environmental quality. Represents a minimum value for the environmental function.	√	√	
Replacement/ cost savings	Potential expenditures incurred in replacing/ restoring the function that is lost; for instance by the use of substitute facilities or "shadow projects". A total value approach; important ecological, temporal and cultural dimensions.	√	√	√[1]
Dose–response	Dose–response: takes physical and ecological links between pollution ("dose") and impact ("response") and values the final impact at a market or shadow price.	√	√	

[1] Perfect restoration of the ecosystem or creation of a perfectly substitutable 'shadow project' ecosystem, which maintains key features of the original, might have the potential to provide the same non-use benefits as the original. However, cultural and historical aspects as well as a desire for 'authenticity' may limit the extent to which non-use values can be 'transferred' in this manner to newer versions of the original; this is in addition to spatial and temporal complexities involved in the physical location of the new catchment or the time frame for restoration.

Indirect approaches

Indirect approaches rely on observed market behaviour to deduce values. They include: observations based on market transactions, derived demand functions, the travel cost method, hedonic pricing approach, averting behaviour method, residual imputation approaches, replacement cost/cost savings methods, income multiplier approach, and dose–response technique.

Observations of market-based transactions in water

The economic value of marketed goods and services is indicated by the market price, adjusted for any distortions. Market prices are adjusted to allow for any subsidies, taxes and trade distortions, converting them to 'shadow prices' that reflect the true economic value to society. Observations of transactions in water rights offer potential to provide relatively simple means of determining economic value. The use of market analysis techniques is outlined in Young and Haveman (1985) with references to studies where each method has been applied. Market transactions have been observed, for example, when considering the demand for drinking-water by municipal users. Studies of such transactions have been conducted in the southwestern states of the United States of America (Saliba and Bush, 1987), and elsewhere in the world (Easter and Hearne, 1995).

Derived demand functions

A household's or firm's inverse demand function can be employed to estimate the user's willingness to pay for water. Transactions concerning water are observed between water utility suppliers and individual water users, usually involving a 'take it or leave it' price schedule. Despite the usual monopolistic nature of supply, because the buyer can buy as much as desired at the price schedule, it is possible to derive inferences on willingness to pay and demand, provided sufficient observations are observed across variations in real price. The data are obtained preferably from observations on water use behaviour of individual households. As this can be costly, aggregate data from suppliers is often used. Statistical regression analysis is employed to estimate the parameters of the demand equation.

Travel cost method

Many natural resources, such as lakes and rivers, are used extensively for the purpose of recreation. It is often difficult to value these resources because no prices exist for them from which demand functions can be estimated. To enable valuation, the travel cost approach takes advantage of costs of travel that are incurred by individuals in visits made to recreational sites. The costs of travel (the costs of transport plus the value of time) are used as implicit prices to value the service provided and changes in its quality. Travel costs measure only the use value of sites and are usually limited to recreational use values; the option and existence value of the sites are measured using other techniques.

There are two variants of the simple travel cost visitation model. The first can be used to estimate (representative) individuals' recreation demand functions. The visitation rate of individuals who make trips to a recreational site are observed, as a function of the travel cost. The value of the recreation site to the person is measured from the area under the individual's demand curve: the total recreation (use) value of a site is the area under each demand curve summed over all individuals. This 'individual' travel cost model requires that there be variation in the number of trips that individuals make to the recreational site in order to estimate their demand functions. A particular problem associated with this model is that such variation is not always observed, especially as not all individuals make a positive number of trips to a recreational site. Indeed, some individuals do not make any. Where the data analysis makes use of standard statistical techniques such as ordinary least squares, non-participants are excluded from the data sets. This exaggerates participation rates and results in the loss of potentially useful information about the participation decision. However, inclusion of data on individuals in the sampling area requires use of more complex statistical methods – in particular, discrete choice models.

The second variant, known as the 'zonal' travel cost model, estimates aggregate or market demand for a site using standard statistical techniques. The unit of observation is the “zone” as opposed to the individual. Zones are specified as areas with similar travel costs; the region surrounding a site is divided into zones of increasing travel cost. The method entails observation of the number of visits to the recreational site per capita of population for each zone. Data are again collected through a survey of visitors to the site.

The individual travel cost model is generally preferred to the zonal variant. The latter is statistically inefficient as it aggregates data from a large number of observations into a few zonal observations. Moreover, it assumes that the cost of travel to the site for all individuals within each zone is equal, which is often not the case.

For both variants, the demand curve is estimated by the regression of the visit rate against socio-economic factors (such as income), the travel cost of visiting the site and some indicator of site quality. Therefore, the data requirements are considerable. For the individual model, data is required on each individual’s socio-economic characteristics. In the case of the zonal model, these data are required for the population of each zone. Data are also required on the nature of each trip to the site, the distance travelled, time taken and cost of travel. The data are usually gained from existing or specially commissioned surveys. The method also requires a measure of site quality, which can be an intangible variable. A measure of site quality can range from angling catch rates to biochemical indicators such as concentrations of dissolved oxygen. The key issue is that the measures of site quality used be robust in relation to measures that individuals perceive as relevant.

Unless the site that is being valued is unique, individuals have access to substitute sites that they can use for the same or similar recreational activities. Omission of substitute sites from the analysis creates a source of bias in the analysis. However, there is no simple means of incorporating substitute sites into the individual and zonal travel cost models presented here. Multisite models can be used. These vary in their complexity and their ability to explain substitute behaviour. Judgement on the part of the analyst is required to determine which substitute sites to include. Restrictions are often placed on site characteristics (some studies are limited to 'typical' sites) or demand equations (such as the use of 'pooled' models). Morey’s (1984, 1985) 'share' model considers the allocation of an individual’s fixed time budget between sites. This accounts for site substitution, but at the expense of explaining the total amount of time allocated to recreation.

The travel cost method is a technically well-developed valuation approach, which has been employed widely in the past two decades. Its strength is that, in theory, it is based on observed behaviour. However, the technical and data requirements should not be underestimated. Travel cost is unlikely to be a low cost approach to valuation of non-marketed services.

Hedonic pricing

Hedonic pricing employs differences in the prices of marketed goods to derive the value of environmental characteristics. Marketed goods can be viewed as comprising a bundle of characteristics; for some goods, these include environmental characteristics. The differential prices that individuals pay for such goods reflect their preferences for environmental quality. Statistical analysis of the prices and characteristics of the goods is employed to derive an implicit value for environmental quality.

Taking housing as an example, hedonic pricing assumes that the expected stream of benefits of living in a property is capitalized into the market value of the property. For example, two properties in areas popular for water-based recreation that differ only in respect of water quality have different market values, owing to people's preferences for the difference in water quality. Hedonic pricing uses this difference in value as the implicit price of the difference in water quality. With adequate data and analytical skills, it is possible to determine the implicit price for environmental quality for properties that differ in not just one but a number of factors.

Hedonic pricing requires data that can be used to relate house prices to relevant characteristics of individual properties (characteristics of the house, e.g. number of rooms and type of neighbourhood, and environmental characteristics, e.g. noise, and water quality). Data on sale prices for actual market transactions are preferred over individual's own valuations of their property. The data are used to estimate a hedonic price function, which describes all points of equilibrium in the housing market between sellers' offers and buyers' bids for the environmental characteristic of interest. The implicit price of the environmental characteristic is given by the responsiveness of property prices to change in the characteristic, as specified by the partial differential of the hedonic price function. A functional form for the hedonic price function is identified that best fits the data. This determines the functional form of the marginal implicit price function. The price is not necessarily constant, it might fall with increases in the characteristic, or it might be dependent on the level of another property characteristic.

To obtain a value for changes in the environmental characteristic of interest, its implicit price (as indicated by the hedonic price function) is regressed against physical and socio-economic variables that are thought to influence demand for housing. The supply of housing is assumed fixed in the short run in order to enable identification of the demand or bid function, which is required for benefit estimation. Identification of a bid function is problematic. All consumers within a housing market face the same equilibrium price schedule, or hedonic price function. Hence, the observation of a single consumer's behaviour provides only one point on that consumer's bid function. Other marginal prices are observed only for other individuals, so they provide no indication of the likely reaction of the original consumer to varying prices. A number of solutions to the identification problem have been proposed. One option is to restrict variables or functional forms so that they are different between estimation of the hedonic price function and estimation of the bid function. The preferred alternative is to use data from spatially- or temporally-separated markets so that individuals do not face the same hedonic price function. However, this requires that consumers be similar between these separate markets.

Hedonic pricing rests on a number of stringent assumptions. It assumes a freely functioning and efficient property market, and that individuals have perfect information and mobility. These conditions need to be met for individuals to buy the property and the associated characteristics that they desire and so reveal their demand for environmental quality. In reality, a large part of the housing stock may be in the public sector, and so subject to price controls. The market may be segmented, resulting in restrictions in mobility between areas. Individuals may not be fully informed about the environmental characteristics of properties prior to purchase. The market may not be in equilibrium, resulting in implicit prices that represent upper or lower boundary estimates of the true price. In many developing countries, the property market is administered, preventing free operation of the price mechanism. Even where markets operate freely, records of transactions are not usually kept in any detail, severely restricting availability of data. For this reason, hedonic pricing is rarely applied in developing countries.

A further assumption is that the measure used for the environmental characteristic in hedonic pricing reflects individuals' perceptions. Although an objective quantitative measure is required for the analysis, it may be that people perceive the environmental characteristic qualitatively. A broader measure of environmental quality may be needed if individuals do not discern changes in an individual variable. A further complication arises in the statistical analysis. If correlation occurs between variables, a trade-off has to be made between multicollinearity and bias owing to the omission of significant explanatory variables.

Hedonic pricing has a sound theoretical basis and is capable of producing valid estimates of benefits as long as individuals can perceive the environmental change of interest. Hedonic pricing has been employed to produce reliable estimates of the values of actual environmental changes such as improved water supply.

Averting behaviour and defensive expenditures

Perfect substitutability provides the basis for the averting behaviour and defensive expenditures technique. This technique focuses on averting inputs as substitutes for changes in environmental characteristics. For example, expenditures on sound insulation can be used to indicate householders' valuations of noise reduction; and expenditure on liming might reflect the value of reduced water acidification. The approach requires data on change in an environmental characteristic of interest and its associated substitution effects. Fairly crude approximations can be found by looking directly at changes in expenditure on a substitute good that arise as a result of some environmental change. Alternatively, the value per unit change in an environmental characteristic can be determined. This involves determining the marginal rate of substitution between the environmental characteristic and the substitute good, using known or observed technical consumption data. The marginal rate of substitution is multiplied by the price of the substitute good to give the value per unit change in the environmental characteristic.

Where observed averting behaviour is not between two perfect substitutes, the value of the environmental characteristic is underestimated. For example, if there is an increase in environmental quality, the benefit of this change is given by the reduction in spending on the substitute market good required to keep the individual at their original level of welfare. However, when the change in quality takes place, the individual does not reduce spending (in order to stay at the original level of welfare). Income effects cause reallocation of expenditure between all goods with a positive income elasticity of demand. Consequently, the reduction in spending on the substitute for environmental quality does not capture all of the benefits of the increase in quality.

Further problems with the approach are that individuals may undertake more than one form of averting behaviour in response to an environmental change, and that the averting behaviour may have other beneficial effects that are not considered explicitly (for example, the purchase of bottled water to avoid the risk of consuming polluted supplies may also provide added taste benefits). Furthermore, averting behaviour is often not a continuous decision but a discrete one, e.g. a water filter is either purchased or not. In this case, the technique again gives an underestimate of benefits unless discrete choice models for averting behaviour are used.

Therefore, simple avertive behaviour models can give incorrect estimates of value where they fail to incorporate the technical and behavioural alternatives to individuals' responses to change in environmental quality. Nevertheless, although the technique has rarely been used, it is a potentially important source of valuation estimates as it gives theoretically correct estimates that are gained from actual expenditures and which thus have high criterion validity.

Residual imputation approach and variants

The use of water in a production process can be determined using the residual imputation approach. This is a form of a budget analysis technique that seeks to find the maximum return attributable to the use of water by calculating the total returns to production and subtracting all non-water related expenses. The value of the product is allocated among the range of marketed inputs that go into its production. The residual value is assumed to equal the returns to water and represents the maximum amount the producer would be willing to pay for water and still cover input costs (Naeser and Bennett, 1998). If only variable input costs are subtracted, then a short-run measure of the value of water is derived. If the costs of all non-water inputs are subtracted (including a normal rate of return on capital), then a long-run value is obtained. The validity of the approach requires: (i) that profit maximizing producers employ productive inputs up to the point at which marginal product is equal to the opportunity cost; and (ii) that the total value of the product can be divided, so each input can be 'paid' according to its marginal productivity and the total value of product is thereby exhausted. The approach is sometimes categorized as a farm crop budget technique in applications to agriculture. A difficulty is that the residual return (after subtraction of the costs of all measured non-water inputs) is the return to water plus all unmeasured inputs, and hence will result in overstatement of the value of water. The approach is also extremely sensitive to small variations in assumptions concerning the nature of the production function or prices. Thus, it is most suitable for use in cases where the residual input contributes significantly to output. Calculation of residual values requires considerable information and accuracy in allocating contributions among the range of resource inputs.

Variants of the residual imputation approach include: yield comparison, and optimization models.

In its application to irrigated agriculture, the yield comparison approach values irrigation water as the difference in per acre returns between irrigated and non-irrigated land, using observed farm budget data. It is assumed that the additional net returns obtained from the use of irrigation in the production process represent the maximum amount that the producer would be willing to pay for use of irrigation water. However, the approach assumes homogeneity in land, crops, husbandry, quality of produce and price between irrigated and non-irrigated production. The heterogeneity that occurs in these factors in reality brings into question use of the difference in net returns as the net willingness to pay for irrigation water.

Optimization models are used to provide mathematical solutions to problems that entail maximization or minimization of an economic objective subject to specified constraints to the economic objective. In generating the optimal solution to the problem, the models reveal the associated economic value of all inputs. Two types of optimization model are discussed here: mathematical programming models and dynamic optimization models.

Mathematical programming models tend to be static one-period models. They model economic problems in which the economic agent (consumer, central planner, or firm) seeks to optimize (maximize or minimize) a single objective function (e.g. surplus, costs, profit or revenue) over a specific time period, while facing constraints that restrict choice to certain levels of inputs or outputs. The models can determine marginal or non-marginal values for use of water as an input. Water enters mathematical programming models as an input constraint, such that its marginal value is found by relaxing the water constraint by adding a unit to the water available for production and calculating the difference between the optimal value before and after relaxing the constraint. This marginal value of water is also known as the 'shadow value' of water. Non-marginal changes can be evaluated similarly, and also changes in the shadow value of water can be calculated for exogenous changes in output prices, input prices, or constraints. Mathematical programming models are often used to determine the value of irrigation water and groundwater in situations where detailed data are available for a few representative agents.

Dynamic optimization models are used to indicate the optimal outcomes for separate periods in frameworks that involve multiple time periods. In a similar manner to mathematical programming models, they can determine marginal and non-marginal values for water and the impacts of changes in other variables on the value of water. Dynamic optimization models have been used to measure the value of water in allocation schemes, irrigation policies, and water quality projects.

Replacement cost/cost savings methods

The replacement cost estimates the benefits of an environmental asset based on the costs of replacement or restoration. The replaced or restored asset is assumed to provide a direct substitute for the original. The technique is used widely because the data required are usually readily available from actual expenditures or estimated costings. The underlying assumption is that the costs of replacement equal the benefits that society derives from the asset. However, the benefits derived from the asset could substantially outweigh the costs of renovation or restoration, in which case the technique will underestimate the value of the asset. Thus, the replacement cost is a valid measure of economic value only in situations where the remedial work is required to comply with an economically determined environmental standard. Use of the replacement cost assumes that complete replacement or restoration is feasible. In the case of environmental assets, this often is not the case. There are also temporal issues as replacement or restoration of an alternative water resource, e.g. a wetland, may not coincide directly with the damage or loss of the original resource. Because of the potential for confusion between costs and benefits, the replacement cost technique should be used with care, and only where benefits cannot be estimated easily.

The cost savings method is similar to the replacement cost, but it determines the value of water in terms of the savings in costs made through use of a good or service provided by water versus the next best (cheapest) alternative source of the good or service. The method is commonly employed to value use of water for transportation, and it can also be applied to other uses of water. The value of using water as a means of transporting goods is measured in terms of the cost savings that result from not transporting the same goods via an alternative means, typically by train. The approach does not allow for the large differences in time costs between different transport modes (Gibbons, 1986). The method has also been used to value hydroelectric power generation by estimating the difference between the cost of generating hydroelectric power and the next cheapest alternative method of power generation (e.g. coal). As with replacement costs, the approach equates cost savings with value. Hence, it can be criticized on the grounds that it assumes implicitly that demand will be unresponsive to changes in costs.

Dose–response functions

In certain instances, dose–response functions can be established between changes in environmental variables (the dose) and the resultant impact on marketed goods and services (the response). Where this is the case, a dose–response function can provide the basis for valuation of the environmental variable of interest; this is the main technique used to derive economic values for air pollution. Valuation is carried out by multiplying the physical dose–response function by the price or value per unit of the impact (usually some form of physical damage) to give a 'monetary damage function'. The latter is equivalent to the change in consumer surplus plus producer surplus caused by the impact.

Where the impact predicted by the dose–response function is marginal, it may be possible to value the impact using relevant market prices, adjusted for any government interventions and market imperfections. For larger impacts, a modelling approach is likely to be required, to predict the resultant changes in prices and behaviour on both the supply and demand sides of the relevant markets. For example, in the case of an impact on a production process, a producer might respond to an impact by changing the quantity of other inputs used, which would alter the costs of production and thereby change the producer surplus. A change in the output price will change consumers' consumption patterns, and thereby the consumer surplus. Prediction of such market responses is complicated. Individuals will often make complex changes in their behaviour to protect themselves against undesirable impacts. For example, farmers might switch to crop varieties that are resistant to pollution. A large number of markets might be involved, and modelling such an interrelated system can be extremely sophisticated. However, simple models can provide useful estimates, provided their shortcomings are recognized.

The specification of the dose–response function is crucial to the accuracy of the approach. The pollutant responsible for the damage needs to be identified as well as all possible variables affected. Large quantities of data can be required. It may be possible to record the impact of change in the environmental variable using variables that are easy to observe and measure (e.g. leaf drop and discoloration of vegetation). However, some impacts (e.g. reduced plant vigour and reduced pest resilience) are difficult to observe directly. In such cases, an 'instrumental variable', which is easily measurable and provides an indicator of the impact of interest, can be used as a measure of the impact. As an alternative to empirical data, dose–response functions can also be specified using suitably validated simulation models, such as fishery models, crop yield models, and biological growth models.

The use of dose–response functions is theoretically sound. Any uncertainty surrounding their use resides in the specification of the function itself and in predicting any behavioural responses that might occur. Dose–response functions are suitable for use in instances where the relationship between change in an environmental variable and the resultant impact on a good or service can be established (it cannot be used to estimate non-use values). It can be a costly technique to use where manipulation of large databases for physical and economic modelling is required. However, where the necessary dose–response functions already exist and impacts are marginal, the method can be very inexpensive to use with low demands on time, providing reasonable first approximations of true economic value.

Direct approaches

Direct valuation techniques seek to elicit preferences directly through the questioning of individuals on their willingness to pay for a good or a service. These techniques include the contingent valuation method, contingent ranking and conjoint analysis.

Contingent valuation method

The contingent valuation method can be useful for eliciting the value of several aspects of water resources including water quality, recreation and biodiversity. It can be employed to calculate both use and non-use values including option and existence values. A survey instrument is used to measure individuals' maximum willingness to pay for an aspect of a water resource, presented to them in a hypothetical market with a proposed improvement (Hanley and Spash, 1993). The contingent valuation method can also be used to measure what people are willing to accept by way of compensation for a deterioration in quality of a water resource.

Bateman *et al.* (2002) provide details of the procedures involved in contingent valuation. In general, a survey is conducted in which people are asked questions regarding the amount of money they would be willing to pay for an improvement in an environmental good or service. This may be conducted through face-to-face interviews, telephone or mail surveys.

In developing countries, face-to-face interviews are considered the most appropriate (because of high rates of illiteracy and defective telephone networks). The design of the questionnaire is important and typically comprises three components. First, the questionnaire provides an explanation of the environmental issue of interest together with information on the change in quality. Second, it includes questions regarding willingness to pay or willingness to accept. The third part of the questionnaire comprises questions about the socio-economic characteristics of the interviewee, which enable analysis and verification of the validity of responses on willingness to pay or willingness to accept given by respondents.

A respondent's choice or preference can be elicited in a number of ways. The simplest is to ask a direct question about how much the respondent would be willing to pay for the good or service (known as continuous or open-ended questions). High rates of non-responses can be a problem with this approach. Alternatively, respondents can be asked whether they would want to purchase the service if it cost a specified amount. These are known as discrete or dichotomous choice questions, and may be favoured because they do not give the respondent any incentive to answer untruthfully, i.e. the approach is 'incentive compatible'. A hybrid approach is the 'bidding game', where respondents are asked a series of questions to iterate towards a best estimate of their valuation. Alternatively, respondents may be shown a list of possible answers – a 'payment card' – and asked to indicate their choice, though this requires a careful determination of the range of possible answers. Each approach implies particular requirements in terms of statistical methods, and the appropriate choice for a specific problem is a matter of judgement on the part of the analyst.

One of the problems with the contingent valuation method is that it is subject to biases. The problem of strategic bias has long worried economists. The likelihood of the occurrence of strategic behaviour depends on respondents' perceived payment obligation and their expectation about the provision of the good. Where individuals believe that they will actually have to pay their reported willingness to pay, but that their personal valuation will not affect whether the good is provided or not, there is a temptation to understate the true value in the hope to 'free-ride', i.e. that others will pay. However, if the price to be charged for the good is not tied to an individual's willingness to pay response, but provision of the good is, then overreporting of willingness to pay might occur in order to ensure provision. Incentive compatible payment methods might minimize the risk of strategic behaviour. Overall, the large amount of empirical investigation into the question has not substantiated fears of strategic bias problems.

There are further sources of bias in contingent valuation method data. The hypothetical nature of the contingent valuation market causes hypothetical bias. It occurs because respondents' answers could be meaningless if their declared intentions cannot be taken as an accurate guide for their actual behaviour. This is most likely to occur where respondents are very unfamiliar with the scenario presented to them. A careful and believable description of the good or service and its context can help in this instance. A survey of experimental tests, which compared hypothetical bids with those obtained in simulated markets where real money transactions take place, suggests that hypothetical bias can be reduced significantly if willingness to pay formats are used instead of willingness to accept. This is because respondents have more practical experience with payment than with compensation scenarios (Hanley, 1990).

Analysts may wish to summarize respondents' valuation estimates in terms of the mean willingness to pay for the good or service, or to develop an aggregate benefit estimate for a community or region. 'Aggregation bias' can arise through this owing to sampling errors or insufficient sample size. Sampling errors can arise where survey non-responses occur for certain types of individuals who are not distributed randomly in the population, resulting in a non-random survey sample. Similarly, where the sample size is small, there is a risk that the characteristics of the sample will not be representative of the general population.

A number of studies have found evidence of 'payment vehicle bias', where willingness to pay depends upon the choice of the method of payment, for example, between an increase in taxes or entrance fees. Controversial payment vehicles should be avoided in favour of those most likely to be employed in real life to elicit payment for the good in question. However, dependence of respondents’ answers on the way in which they are asked to pay for the hypothetical good or service should be expected. This should not be a source of concern because preference for one payment vehicle over another may be perfectly reasonable. In this sense, the term 'bias' is misplaced.

Starting point bias arises when the initial value suggested at the beginning of a bidding game has a significant impact upon the final bid reported by the respondent. The use of starting points can reduce valuation variance and the number of non-responses in open-ended type questionnaires. However, this can be at the possible expense of respondents not giving serious thought to their answers and taking cognitive 'short cuts' in arriving at their decision. One solution is to use a 'payment card', with a range of numbers from which respondents can select their bid. However, this can result in an “anchoring” of bids within the range presented. It has been argued that an optimal range of prices should include a low price that results in almost all respondents accepting it, and a high price that results in almost all respondents rejecting it. Within this range, prices offered should reflect the distribution of bids so that, ideally, each bid interval reflects the same proportion of the population (Bateman *et al.*, 1992).

Perhaps most controversy has centred on the so-called 'embedding effect'. A few studies have found that individuals’ contingent valuation responses often do not vary significantly with changes in the scope and coverage of the environmental good being valued (Kahneman and Knetsch, 1992; Desvousges *et al.*, 1992). In these studies, respondents appeared not to discriminate between the particular environmental good under consideration and the general class of environmental goods it belonged to. A number of explanations have been advanced for this phenomenon. Some have argued that it occurs because individuals do not possess strongly articulated preferences for environmental goods, so that they tend to focus on other facets of the environment, such as the 'moral satisfaction' associated with the preservation of particular species or habitats (Kahneman and Knetsch, 1992) when deciding on a monetary valuation. Others (such as Smith, 1992) have argued that embedding is more an artefact of poor survey design. It has also been suggested that, in order to make valuation and financial decisions easier, people tend to think in terms of a system of expenditure budgets, or 'mental accounts', to which they allocate their income (Thaler, 1984). If the amount allocated to the 'environment account' is quite small, this might result in an inability to adjust valuations substantially in response to changes in the size and scope of an environmental good. Therefore, embedding may occur through this imposition in decision-making of an income constraint, which is inflexible and strict (relative to an individual’s total income), and which determines valuations. The debate over embedding has not been resolved. Whether the effect is robust or not, it does appear that careful survey design can reduce its severity, in particular through the provision of precise, contextual descriptions of the good itself, and of the expenditure implications of a particular willingness to pay bid.

There are numerous issues that arise in contingent valuation work in developing countries that demand careful attention in order to increase the likelihood of obtaining high-quality results. Interviewers need to receive a clear explanation of what the study is about and especially the concepts of economic value and maximum willingness to accept or minimum willingness to pay. Attention also needs to focus the presumed difficulty of understanding and interpreting respondents’ answers to sensitive or hypothetical questions.

Focus groups are often used as an auxiliary to contingent valuation studies in order to explore people’s knowledge, perceptions and understanding of the subject of interest. This aids the design of the contingent valuation survey. It indicates the amount of information that needs to be presented, the manner in which to present it; and the way in which questions used in the survey can be refined (Desvousges *et al.*, 1984; Hoehn, 1992). Focus groups can be employed following a contingent valuation survey (Burgess, Clark and Harrison, 1998) to provide insights into the processes that underlie the responses. They can also be used to discuss survey results with the stakeholders involved and relate these to the decision or decisions to be made.

The National Oceanic and Atmospheric Administration (NOAA) panel has offered a set of guidelines that it believes should be followed if contingent valuation is to provide information on non-use values of sufficient quality for it to be usable as the legal basis for compensation claims for environmental damage (Arrow *et al.*, 1993). The use of these guidelines within the profession is now being extended to cover all contingent valuation studies. Contingent valuation is likely to be most reliable for valuing environmental gains, particularly where familiar goods are considered, such as local recreational amenities.

The use of contingent valuation to determine value has stimulated an extensive debate. It has been criticized for its theoretical background, the isolation from contextual issues, and for imposing a market construct and context on respondents. Contingent valuation studies are costly and entail an inevitable comprise between expense and quality.

Environmental economists are accused of blind adherence to an outmoded neo-classical economic theory that lacks empirical verification and political consensus. For some critics, the supposed biases and practical inconsistencies found in contingent valuation surveys further undermine the validity and modern relevance of neo-classical economic value theory. A further criticism is that contingent valuation provides a snapshot of people’s attitudes, preferences and values at a certain point in time. Little attention is given to the background or context against which the values have arisen.

Burgess, Clark and Harrison (1998) question the use of contingent valuation in environmental decision-making. They argue that people provide a monetary value for the environment because they are in a coercive interview situation or because of their trust in the expertise held by those asking the questions. They recommend that decisions about the environment should be based on social consensus about appropriate standards and acceptable choices rather than on individual’s willingness to pay elicited through contingent valuation surveys. However, their critique may have been conditioned by problems in the contingent valuation case study that the authors use as an example. The survey was experimental and, therefore, does not conform to established 'best practice' (G. Garrod, personal communication, 1998). Nevertheless, in-depth group discussions (returned to later) do offer a different perspective on the elicitation of environmental values and are relevant to a comprehensive appraisal of the contingent valuation method.

Contingent valuation is an attractive technique as it generates its own data. However, good-quality contingent valuation studies are costly in terms of time and resources. A good study will cost US$10 000–250 000; an expense that few agencies will agree to. Costs can be reduced by hiring low-cost interviewers, though this entails compromise in the quality of the study. Whenever possible, high-cost studies are to be preferred as they are more likely to produce information that is useful and valuable, and can lead to policy changes that more than cover their costs. Ultimately, the trade-off between expense and reliability is at the judgement of the analyst.

Contingent ranking and conjoint analysis

Contingent ranking is implemented in the same vein as contingent valuation except that the respondent has to rank order a large number of alternatives that comprise various combinations of environmental goods and prices. A random utility framework is used to analyse the data on complete ranking of all the alternatives. The statistical estimation is often performed using essentially a multinomial logit model of the rank order of the random utility level associated with each alternative. Implicit attribute prices or welfare change measures are then calculated from the parameter estimates of the logit model.

Applications of contingent ranking usually involve the ranking of large numbers of alternatives, which often appear similar to the respondent. The cognitive task of arriving at a complete ranking is very difficult. Furthermore, the estimated statistical models used are often poor representations and result in imprecise environmental values. Therefore, the contingent ranking method has met with a mixed response (Smith and Desvousges, 1986; Lareau and Rae, 1989).

Conjoint analysis is related closely to contingent ranking. Individuals participate in a conjoint analysis experiment to undertake a large number of ranking tasks. Each ranking task involves a small number of alternative options. Based on the collected data, a type of utility index model is estimated for each individual. Therefore, it differs from contingent valuation and ranking. Conjoint analysis has strong foundations in psychology and statistics, but has a rather less sound theoretical foundation in terms of individual choice theory. However, there is a trend for valuation studies to move away from reliance on purely statistical methods towards more behaviour-based models.

Environmental value transfer

Environmental value transfer here refers to transfer of values for environmental costs as well as benefits (the latter is otherwise known as 'benefits transfer').

The costs of valuing impacts on the environment can be considerable. However, it is not always necessary to undertake a new valuation study. Where valuation has been undertaken for a similar case elsewhere, it may be possible to transfer the estimates and employ them as indicators of the economic welfare impacts in a new study. The original valuation may have utilized any of the valuation techniques outlined above. Environmental value transfer is undertaken largely for reasons of cost-effectiveness and scope to rapidly inform decision-making. It is a very attractive alternative to resource-intensive and time-consuming valuations based on original data. However, it is fraught with difficulties and subject to a number of caveats.

Boyle and Bergstrom (1992) suggest the following criteria be employed to determine which studies are suitable for use in value transfer:

- the goods or services that are being valued should be the same;
- the relevant populations should be very similar;
- the assignment of property rights for the resources under consideration should be the same.

Desvousges *et al.* (1992) suggest that consideration should also be given to the sites in which the goods or services are located, and quality of the study.

Three broad approaches can be used for environmental value transfer (Pearce, Whittington and Georgiou, 1994).

One approach uses average value estimates. This approach assumes that the change in utility experienced by the individuals considered in the new study is equivalent to that experienced on average by individuals in the previous studies. For example, in the case of a change in resource management that affects recreation benefits, the change in recreation services would be valued in terms of individuals' average willingness to pay per day. This could be estimated using values presented in suitable previous studies. Multiplying the resultant figure by the predicted change in the number of person days of recreation in the new study would yield the total aggregate value of the anticipated impact on recreation. A drawback is that the situations examined by the two studies are unlikely to be identical. Consequently, studies that are suitable for value transfer (according to the criteria listed above) are unlikely to be available.

A second approach uses adjusted average values. This entails the adjustment of mean values from previous studies for any biases in the data to better reflect conditions examined in the new study. For example, adjustments might be made to reflect the socio-economic characteristics of households, the environmental change in question, the policy setting, or the availability of substitute or complementary goods and services. Such adjustments can increase the suitability of values for transfer.

A third approach uses value functions. This entails transfer of the entire demand function for the good or service in question to the new study. It enables transfer of a greater amount of information than through use of average values alone. It is likely to result in better approximations of values, but is more involved than the other two approaches.

Several limitations are common to all of the above approaches for value transfer: a requirement for good-quality studies of similar situations; the potential for characteristics to change between different time periods; and an inapplicability to the valuation of novel impacts. The quality of studies carried out using transferred values can be no better than the quality of the data in its original context (Green *et al.*, 1994). Garrod and Willis (1994) found that for applications in the United Kingdom, even careful modification of available benefits estimates did not yield transfer estimates 'which were reliable and robust enough to be used with confidence in policy applications.' There is little published evidence that tests the validity of environmental value transfer. In the few studies conducted, transfer errors have been found to be substantial (Brouwer 1998). It may be possible to make value transfer more robust if, as well as socio-economic variables, essential physical variables, e.g. ecosystem characteristics and processes, are considered at the different sites. As more information about factors that influence environmental values becomes available, e.g. through meta-analysis, the transfer of values across populations and sites will become more practicable, using either only existing data or supplementing this with new original data.

Environmental value transfer is still in its infancy, partly because only a limited number of high-quality valuation studies have been completed for many environmental impacts. However, it does offer a potentially important and useful means for valuation, and could feasibly provide accurate and robust benefit estimates at a fraction of the cost of original valuation studies.

Meta-analysis

Meta-analysis has played an increasingly important role in environmental economics research since the beginning of the 1990s (van den Bergh *et al.* 1997). Originally used in medical and psychological research, meta-analysis uses statistical techniques to provide a quantitative comprehensive evaluation of what can be large volumes of data presented in multiple empirical studies. It enables researchers to explain variations in the outcomes of single studies based on any differences in underlying assumptions, standards of design and measurement.

In the absence of meta-analysis, data presented in existing studies is usually assessed qualitatively. Meta-analysis offers important advantages. The analysis is objective, so does not prejudge studies or weight their findings subjectively on the basis of study quality (Glass, McGaw and Smith, 1981). However, results of meta-analysis can be biased through the inclusion of only significant study results; studies with insignificant findings are less likely to be published and, therefore, are not available for analysis. In addition, correlation can occur in the data if multiple results from a single study are assumed to be independent without application of the necessary statistical tests (Wolf, 1986).

Meta-analyses have been carried out on the valuation of various functions of water resources, focusing either on the use of single or multiple valuation techniques. An increase in the use of meta-analysis has occurred, triggered by: (i) increases in the number of environmental valuation studies that are available; (ii) seemingly large differences in valuation outcomes caused by differences in research designs (Carson *et al*., 1996); and (iii) the high costs of original valuation studies, which has increased policy-makers' demand for transferable valuation results.

Meta-analysis can be used to identify criteria for valid environmental transfer. They are identified in the meta-analysis as factors that significantly explain variances in valuation outcomes. Meta-analysis can also be used to assess the convergent validity of value estimates. Convergent validity can be tested by splitting a data set in two. Half of the data set is used to identify significant factors. The other half is used to test whether value estimates based on the significant factors fall within the confidence interval of the estimates in the other half of the data set.

Income multiplier method

Income multipliers measure the circulation of expenditures through an isolated economy, tracing the flow of money through individual sectors of the economy. The effect of expenditures in one sector on the whole economy is measured by multiplying the income multipliers by the expenditures. Although these changes in expenditures provide a measure of economic impact, they do not indicate net economic value or willingness to pay (Sorg and Loomis, 1984). They represent the redistribution of economic activity: transfers of surplus between regions, between people, and between industries. These sum to zero in economies with full employment. Therefore, changes in expenditures provide some evidence that an activity or amenity for which expenditures are made is of value but they do not provide guidance on the magnitude of this worth.

Other non-economic approaches to valuation

Energy analysis

Energy analysis has been used to estimate the value of ecosystems based on their biological productivity (Farber and Costanza, 1987). The total energy captured by ecosystems is used as an estimate of the total potential of ecosystems to perform useful work for the economy. The approach is considered to provide an upper bound on the economic value of the products of an ecosystem because not all of the products are used in the economy. The TEV of an ecosystem in providing biological products for an economy is determined by multiplying a money-to-energy conversion factor (measured in a monetary value per unit of energy) by the energy potential of the ecosystem. The resulting measure of welfare represents the total consumptive value of the ecosystem. However, non-consumptive benefits (such as some recreation values) are not accounted for in energy analysis-derived values. A further difficulty with this method is that there is no reason to expect the conversion factor between energy and the monetary value to be approximately constant.

Discussion groups

Some critics consider environmental valuation to be a social process that relies on social agreements (Sagoff, 1988; Jacobs, 1997) and tied only loosely, if at all, to technical valuation methods and techniques. They advocate the use of group discussions (such as citizen's juries and focus groups) as an alternative to the survey-based contingent valuation approach. This offers more of a process-oriented approach to environmental valuation that places emphasis on the processes that underlie and lead to the environmental values that people hold or express. The contingent valuation approach monitors only the end result at a certain point in time and pays little attention to the background or context in which the values occur. The use of group discussions is more in line with a social constructivist approach (Potter, 1996), which understands knowledge and preferences to be dependent upon social processes and cultural factors, and these are simulated in group discussions. It provides an opportunity to open up the process by which respondents perceive the environmental problem presented to them: the processes by which they relate it to their personal experiences, beliefs, norms and values and shape it into a new or existing preference structures. Group discussions provide the researcher with the opportunity to go into more detail about the meaning of respondents' answers in terms of their motivations and the effects of the broader social context

Deliberative group approaches are rooted in a distinct view of how decision-making procedures are, or should be, organized. Different cultural views on social relations are assumed to give rise to different preferences towards decision-making procedures for different kinds of issues, including environmental issues, e.g. Rayner (1984) in the context of risk management. These cultural foundations can be found to underpin the various approaches used for environmental valuation.

The data produced by group discussions is qualitative. Consequently, special attention is required in order to make replicable and valid inferences from these data. This is necessary for the following three interrelated reasons. First, data communicated during qualitative social research may not have a single meaning, especially where the message conveyed is symbolic in nature (Krippendorff, 1980). Meanings are not necessarily shared. A message may convey a multitude of contents even to a single receiver and may convey different meanings to different people. Therefore, claims to have analysed the content of the information communicated during group discussions can be difficult to defend. Second, data and values are embedded in culturally defined worldviews; they cannot be considered to be independent. Consequently, 'facts' can be perceived differently across the various cohorts of society. Third, the qualitative data produced by group discussions are given meaning within at least two distinct contexts: (i) the group context in terms of the various cultural and social-economic backgrounds of the group members; and (ii) the context as constructed by the researcher. These two contexts need to be stated explicitly in order to identify the boundaries beyond which the analysis cannot be extended legitimately (Krippendorff, 1980). The results can only be validated if the purpose of the analysis is stated unambiguously and the context in which the data were produced is defined clearly.

The use of discussion groups is also open to criticism. From a 'critical realism' point of view (Bhaskar, 1989), it can be argued that group discussions may not be mere consultations or mechanisms to reproduce underlying social relationships. Instead, they can constitute scientific and political 'transformational interventions' that are open to manipulation and steering. However, participatory and deliberative approaches to environmental valuation gain in transparency and meaningfulness where the balance between the self-interest and community-based interests of individuals acting as both consumers and citizens is made more explicit.

ECONOMIC VALUATION OF FUNCTIONS AND SERVICES: PRACTICE

This section examines how the valuation techniques discussed above are applied in practice to the economic valuation of water resource functions. The approach taken here employs the concept of functions to link water resource catchment structures and processes to their various uses that give rise to goods and services. The structures and processes determine a variety of functions that can be categorized according to whether they are hydrological, biogeochemical or ecological functions. This section considers the economic valuation of a selection of some of the more important and less well-understood. The application of the valuation techniques to many of the functions has already been considered extensively elsewhere (Gibbons, 1986; Young, 1996; National Research Council, 1997; Renzetti, 2002), and hence discussion of these is limited here. Table 7 shows a summary of many of these functions and the techniques applied to them. In addition, Table 8 summarizes this information according to the main sectoral uses of water.

In addition to the discussion provided in this section, the Appendix provides a number of more detailed case study examples of the techniques in practice.

The adoption of an extended catchment-scale perspective has the advantage that it is easier to identify and take into account the interdependence that exists between the socio-economic impacts of water resource functions. An example of this interdependence arises in the case of the hydrological functions of groundwater recharge and groundwater discharge. The groundwater recharge function may in itself have no impact on human welfare, but it has value in that it provides storage of water in aquifers for later discharge as surface water. Moreover, the processes involved can remove pollutants, thereby enhancing water quality. Care is required to ensure that such interdependence between functions does not result in double counting of benefits (which can occur if one function is integral to another, but they are valued separately and aggregated).

In what follows, a selection of functions is listed, along with some brief discussion of the application of possible techniques for their valuation.

Hydrological functions

Floodwater control

This is the short- or long-term detention and storage of water from over bank flooding and/or slope runoff.

Under the hedonic pricing approach, hedonic pricing can be used to analyse the price differential for properties at risk from flooding. It entails analysis of all variables that could affect price, such as location, size, aspect, and age of property. Use of hedonic pricing requires existence of a property market and existence of known and distinct risks of flooding. It is a complicated procedure that is subject to various complications. Defensive expenditures to reduce flood damage can counter impacts of flooding on property prices (Holway and Burby, 1990). A further complication is that perceived risk of flooding and the resultant impact on house prices can diminish as memories of previous flooding episodes fade (Tunstall, Tapsell and Fordham, 1994). Moreover, house prices may reflect flood hazards only where flooding has occurred relatively recently, regardless of the expected frequency of flooding (Tobin and Newton, 1986).

Under the contingent valuation approach, floodwater control can be valued by asking the affected population what they would hypothetically be willing to pay to either avoid flooding

TABLE 7
Impacts of water resource functions on human welfare, and valuation techniques used

Good or service provided	Impact on human welfare	Valuation techniques used
Potable water for residential use	Change in welfare from change in availability of potable water. Change in human health or health risks.	MP/DF; SCF; C/PCS; CV/CR; AB; HP/W; BT
Water for agricultural crop irrigation	Change in value of crops produced or production costs. Change in human health or health risks.	MP/DF; SCF; C/PCS; CV/CR; AB; HP/W; BT
Water for landscape and turf irrigation	Change in cost of maintaining public or private property.	MP/DF; SCF; C/PCS; CV/CR; BT
Water for livestock	Change in value of livestock products or production costs. Change in human health or health risks.	MP/DF; SCF; C/PCS; CV/CR; AB; HP/W; BT
Water for food product processing	Change in value of food products or production costs. Change in human health or health risks.	MP/DF; SCF; C/PCS; CV/CR; AB; HP/W; BT
Water for other manufacturing processes	Change in value of manufactured goods or production costs.	MP/DF; SCF; C/PCS; CV/CR; BT
Water for hydroelectric power generation	Change in cost of electricity generation.	MP/DF; SCF; C/PCS; CV/CR; BT
Prevention of land subsidence	Change in cost of maintaining public or private property.	MP/DF; SCF; C/PCS; CV/CR; BT
Erosion, flood and storm protection	Change in cost of maintaining public or private property.	MP/DF; SCF; C/PCS; CV/CR; BT
Transport, treatment of and medium for wastes and other by-products of human economic activity	Change in human health or health risks. Change in animal health or health risks. Change in economic output.	MP/DF; SCF; C/PCS; CV/CR; AB; HP/W; BT
Improved water quality through support of living organisms	Change in human health or health risks. Change in animal health or health risks. Change in economic output or production costs.	MP/DF; SCF; C/PCS; CV/CR; AB; HP/W; BT
Improved air quality through support of living organisms	Change in human health or health risks. Change in animal health or health risks.	MP/DF; SCF; C/PCS; CV/CR; AB; HP/W; BT
Recreational swimming, boating, fishing, hunting, trapping, and plant gathering	Change in quantity or quality of recreational activities. Change in human health or health risks.	MP/DF; SCF; C/PCS; CV/CR; TC; AB; HP/W; BT
Commercial fishing, hunting, trapping, and plant gathering.	Change in value of commercial harvest or costs. Change in human health or health risks.	MP/DF; SCF; C/PCS; CV/CR; BT
On- and off-site observation and study for leisure, educational and scientific purposes	Change in quantity or quality of on/off-site observation or study activities.	MP/DF; SCF; C/PCS; CV/CR; TC; BT
Regulation of climate through support of plants	Change in human health or health risks. Change in animal health or health risks. Change in economic output or production costs.	MP/DF; SCF; C/PCS; CV/CR; AB; HP/W; BT
Non-use services	Change in personal utility or well-being.	CV/CR; BT

Note: MP/DF = market price/demand function; SCF = supply or cost function; C/PCS = consumer/producer cost savings; CV/CR = contingent valuation/contingent ranking; TC = travel cost; AB = averting behaviour; HP/W = hedonic price/wage; BT = benefits transfer.
Source: Modified from National Research Council (1997) and Bergstrom *et al.* (1996).

TABLE 8
Water resource uses (sectoral), and valuation techniques used

Function/use category	Habitat/ ecosystem	Wetland/ floodplain	Agriculture	Aquaculture	Water quality	Recreation	Industrial	Commercial	Groundwater	Municipal	Navigation	Power
Averting behaviour									X	X		
Contingent valuation	X	X		X	X	X		X	X	X		
Conjoint analysis												
Dose–response function	X	X	X		X	X	X			X	X	
Hedonic	X		X		X				X			
Markets analysis	X	X	X	X	X	X	X	X	X	X	X	X
Residual imputation	X	X	X	X	X	X	X	X	X	X		X
Replacement cost	X	X	X		X	X	X				X	X
Travel cost	X	X		X	X	X		X				
Other methods	X	X	X			X	X		X	X	X	X

Note: X denotes that the valuation method has been applied in valuation of the specified sectoral use of water resources
Source: Adapted from Lew *et al.* (2001).Hydrological functions

(of some area of interest) or to avoid an increase in the frequency of flood episodes. Given the analytical and resource demands of contingent valuation survey, this is best limited to valuation of the impacts of flooding that are not non-marketed, such as impacts on unique ecosystems.

The damage costs avoided approach considers the costs that would be incurred if flood control provision (e.g. the flood protection provided by a wetland) were not present are given by the damage costs. These consist of direct costs, indirect costs and intangible costs.

The direct costs of flooding are incurred by physical contact with the floodwaters. Costs of damage to the built environment are determined by the type of building (e.g. residential, commercial and industrial) and factors such as the design, function, density and age of the buildings. Cost estimates can be obtained from relevant publications, e.g. the 'FLAIR blue book' in the United Kingdom (N'Jai *et al.*, 1990), government agencies, and site-specific surveys conducted by government agencies or insurers. In determining the costs of damage to movable assets, account needs to be taken of avertive action. For example, in a study of flooding in Maidenhead, United Kingdom, Tunstall, Tapsell and Fordham (1994) found that the reduction in damages by avertive action was "substantial". Higgs (1992) allows for a reduction of 5–10 percent in damage costs resulting from items being moved away in advance from flood-prone areas.

Flooding also imposes costs on productive activities in the non-built environment. Damage to natural ecosystems (wetlands, woodlands and meadows) may be minor and temporary. However, the costs can be substantial for intensive agriculture. Losses in returns to agricultural production are determined by: the depth, extent and duration of flooding; the effluent and silt content of the floodwaters; types of crop, expected yields and price. Silt exacerbates the volume of flooding and is itself a cause of damage. Clark (1985) estimated that silt accounted for 20 and 7 percent of urban and rural flood damage respectively for a study in the United States of America. Turner, Dent and Hey (1983) have calculated returns from agriculture, as the opportunity cost of wetland preservation, based on detailed analysis of output, fixed and variable costs and transfer payments (agricultural subsidies). Estimates of standard losses in agricultural gross margins due to flooding may also be available from official publications (e.g. the Farm Management Pocketbook for the United Kingdom). Long-term impacts on agricultural production through continued exposure to inundation are reflected in the value of the land. Flooding affects the land use categorization of land and this is reflected in the market price (Boddington, 1993); average price data for land use categories is often available from official publications.

Flooding also results in indirect and intangible costs. Disruption to physical and economic linkages in the economy causes indirect costs. They include: costs of implementing immediate emergency measures; reduced production, and the knock-on effects of this on production elsewhere; impacts on transport; and increases in living expenses. By definition, intangible costs are not readily quantifiable. Examples include psychological effects (stress caused by flooding and worry about future events) and poor health caused by flooding. Some costs formerly described as intangibles are now being quantified, such as the effects of disruption and evacuation (Green and Penning-Rowsell, 1986; 1989). Intangible costs could be more significant that the direct damages of a flood episode (Green and Penning-Rowsell, 1989). It is best to acknowledge that such costs are expected but cannot be valued, and that the total cost of damage (and hence the value of the wetland flood protection function) is underestimated as a result.

Defensive expenditures provide only a minimum estimate of the benefits of floodwater control as they may omit costs of flooding against which defensive actions are not taken.

Furthermore, defensive expenditures tend to be low relative to potential damages as individuals underestimate the likelihood of flooding and overestimate their ability to cope with its effects (Tunstall, Tapsell and Fordham, 1994). Defensive expenditures include relocation of assets, such as buildings, nature reserves and livestock (Boddington, 1993), rewiring of electrical points above expected flood levels, and raising of houses on stilts or piles (Tunstall, Tapsell and Fordham, 1994). Relocation may not be to a site that is a direct substitute. Therefore, relocation costs need to be attributed accordingly between the various benefits, and any disadvantages also need to be taken into account.

The replacement cost of flood control can be determined, for example, through the use of shadow projects. In the case of the floodwater control function of a wetland, a shadow project could entail creation or restoration of another wetland that would perform the same function within a given catchment. This would also replace other functions of the wetland and would, therefore, be particularly appropriate in a situation where total loss of a wetland is threatened. Locally relevant costings for wetland creation or restoration are likely to be sparse (although mitigation banking has led to considerable creation and restoration of wetlands in the United States of America). There is uncertainty associated with 'engineered' ecosystems and the functions they can perform. This is more pronounced where the location of the shadow project is distant from the original site and the benefits are consequently derived by a different population. For shadow projects that entail a change in land use for a site (e.g. taking land out of agricultural production), the analysis must also include the opportunity costs of this.

Groundwater recharge

This is the recharge of groundwater by infiltration and percolation of detained floodwater into a significant aquifer.

The groundwater recharge function is only of value where the recharged groundwater is of some benefit to society. The benefits may be direct, such as abstraction of the water for irrigation or domestic use, or indirect, such as the maintenance of water table levels. In addition to these use values of recharging groundwater, there may also be non-use values of maintaining groundwater supplies. Non-use values can be attributed to the maintenance of groundwater supplies for subsequent generations, but only if use of the reserves is anticipated.

Table 1 shows the potential extractive and *in-situ* uses of groundwater acting as a water reserve (stock). As far as the extractive uses are concerned, the techniques involved in assessing the economic value of groundwater recharge are much the same as those outlined below for the 'groundwater discharge/surface water generation' function. Studies that have considered values for groundwater supply are outlined in that section as they illustrate techniques that may also be useful for assessing the value of surface water. They include: hedonic pricing based on variations in availability of groundwater irrigation supplies; costs of establishing substitute well sites; and contingent valuation of willingness to pay for alternative piped water supplies. A number of studies have assessed values associated with maintaining the quality of groundwater (which may be relevant to the *in-situ* uses of the recharge function) and these are considered under the “nutrient retention” function. Two other *in-situ* use values arising from groundwater recharge include prevention of land subsidence and saltwater intrusion.

Concerning the prevention of land subsidence, hedonic pricing is used to analyse a price differential in property that is attributable solely to the risk of subsidence. Where identical sets of housing exhibit variation in prices, and the only non-constant attribute is the risk of subsidence, then price differences can be related to the buyers’ willingness to pay to avoid subsidence. However, it is necessary to assess all relevant variables that could affect price (e.g. location, size, aspect and age), and to isolate the effect of subsidence from these.

Regarding damage costs avoided, predominant land uses are identified and the various costs of a potential subsidence assessed. Estimation of the damage costs avoided owing to groundwater recharge provides an upper bound estimate of the value of this function as it does not technically value society's willingness to pay to avoid the subsidence. Instead, it values the full extent of costs expected to result from subsidence, which could exceed the cost of alternative measures to negate the economic impacts. However, it may not be feasible to estimate all the costs involved, particularly the intangible costs.

Residual imputation and variants can be applied to the case of saltwater intrusion. Intrusion of saltwater can occur as a consequence of falling groundwater in levels in areas in proximity to the coast. Saltwater intrusion can render groundwater unusable for irrigation, thereby impinging directly on agricultural production. The change in net returns that this would cause can be used to assess the value of maintaining groundwater levels to prevent the intrusion of saltwater.

Groundwater discharge/surface water generation

Groundwater discharge and surface water generation can be considered as identical functions for valuation purposes. Whether water originates from direct precipitation, groundwater discharge or another source does not influence the value attributable to surface water generation. The surface water generated contributes to the stocks and flows of surface water, which support a variety of *in-situ* and extractive uses as well as non-use values.

Table 1 shows the potential extractive and *in-situ* uses of surface water, and its interrelationship with groundwater. Extractive uses of surface water include use of water for irrigation and domestic purposes. *In-situ* uses of surface water are more varied and can include maintenance of habitats and provision of aesthetic and recreational value. Several of the *in-situ* uses of surface water are also considered within other functions. For example, the reliance of characteristic wetland ecology on surface water and anaerobic conditions resulting from inundation (and the subsequent capacity to retain excess nutrients) are considered under the 'ecological' and 'nutrient retention' functions, respectively. Downstream habitat and biodiversity maintenance are considered below only in so far as they might contribute to recreational and amenity value. Other benefits associated with maintaining biodiversity could be significant (e.g. non-use values) and valuation methods for these are outlined in the section on 'ecological' functions.

As mentioned above, the techniques outlined below for valuing extractive and *in-situ* uses of surface water are also applicable to the extractive uses listed under the groundwater recharge function. The main extractive and *in-situ* uses and techniques to value them have already been considered comprehensively in, for example, Gibbons (1986); Young (1996); National Research Council (1997), Renzetti (2002). Hence, only a few illustrative application examples are presented here.

One example concerns the use of market-based transactions. Surface water abstraction for use in irrigation can be valued using market prices observed in rentals and sales of water rights. In order for traded water rights (for a specified period or for a permanent right) to reflect the economic value of water use, allocation and enforcement of property rights is required. If necessary, prices should be adjusted to reflect long-term considerations (i.e. social values). In practice, rental rates may be affected by factors other than the marginal value of water. Although observations of prices on markets for perpetual water rights are more appropriate for long-run planning contexts, some degree of care is required in converting this capitalized asset value into the annual values used conventionally in planning and policy analysis (Young, 1996). Furthermore, in circumstances where agricultural subsidies supported crop prices, the use of water right prices will lead to overestimation of the social value of irrigation water.

Another example concerns the use of residual imputation and variants. This is one of the most widely used techniques for valuing irrigation water. Ruttan (1965) employed it in an early study that demonstrated the difference between the value of irrigated and non-irrigated agricultural production. Some degree of care has to be taken with its use in order to ensure that statistical problems, such as multicollinearity between variables, do not bias the analysis. Linear programming models have been applied to farm budget data to derive shadow values on irrigation water (Colby, 1989). Here, crop type is the most important determinant of the marginal value of irrigation water. The presence of uncertainty makes valuation of agricultural water use difficult owing to uncertainty in the need for irrigation (e.g. arising from climatic variation) and in water supplies. Therefore, farmers' attitudes towards risk must be considered when undertaking studies. Furthermore, market distortions and externalities also need to be taken into account. The Appendix contains a case study example for a multiple use irrigation system in Sri Lanka.

Another technique is that of derived demand functions. This technique has been used to estimate households' valuation of domestic water supplies employing relatively easily acquired price and quantity data, e.g. in Young and Gray (1972) and Gibbons (1986). Although these studies addressed households' valuations of a given quantity of water, they did not address complications created by variations in water quality or service reliability. These issues have been considered in studies using contingent valuation and avoided cost approaches.

In principle, hedonic pricing can be used to derive the value of maintenance of river flows by surface water generation (Loomis, 1987). Individuals or businesses (including farms) might pay a premium for property located close to a river. It may be difficult to distinguish use of water in the river from other locational factors, such as benefits associated with aesthetics, recreation or transportation that result from proximity to the river. It is also difficult to determine the contribution made by the discharge of groundwater to maintenance of water levels in the river. Few studies have used hedonic pricing to value surface water generation, presumably because of these complications and demands of the technique. One of the few examples decomposes the value of agricultural land as a function of its attributes including the use of irrigation water (Faux and Perry, 1999). The Appendix provides an example of a detailed case study of water supply in the Philippines.

Concerning the use of the replacement cost/avoided cost technique, avoided cost has been used to value hydroelectric power generation (see Gibbons, 1986). The cost that would be incurred if an alternative source provided the capacity to generate power is used to impute the value of the hydroelectric power generated. However, the method is problematic as it ignores the price elasticity of demand for electric energy. The approach can also be applied to valuation of surface water generation where water is abstracted to provide drinking-water. However, the expense of finding an alternative water supply is likely to be exceeded by benefits of continued use of the existing source. The technique may be particularly suited to this application where there is difficulty in valuing the health implications of restrictions in water supply.

Biogeochemical functions

Nutrient retention and export

This concerns the storage and removal of excess nutrients (nitrogen and/or phosphorus) from water, via biological, biochemical, geochemical, physical and land management processes.

The main impact of storage of nitrogen and phosphorus is improved water quality. Thus, this function is discussed here with respect to water quality. Improvements in water quality have a number of benefits, as discussed in Chapter 1. A few illustrative examples of valuation of the benefits of improved water quality are outlined below. Impacts on recreation can be valued using the travel cost method. The benefits for drinking-water supplies can be considered, for example, via defensive expenditures. Indeed, nutrient retention benefits can be considered generally in terms of the costs of providing substitute treatment facilities. Potential increases in the costs of industrial production processes are not considered here. The residual imputation methodology (discussed above) could also be employed to value the benefits of improved water quality as an input to production processes.

Research based on contingent valuation has been used widely to consider water quality. Jordan and Elnagheeb (1993) used the approach to assess households' valuations of improvements in drinking-water supplies (following reductions in nitrate levels). One of the most challenging aspects of this approach is the manner in which water quality information is conveyed to survey respondents, and specifically whether objective or subjective measures of water quality are used. Poe (1998) argues that objective measures are preferable because people do not have reliable and well-informed reference points regarding water quality. Conjoint analysis and contingent ranking has also been used to value water quality improvements. For example, Georgiou *et al.* (2000) used contingent ranking to value urban river water quality improvements. The Appendix contains a case study on water quality in the Philippines

The travel cost method has been used to assess the value of improved water quality at recreational sites. A complex form of travel cost analysis, which includes measures of water quality as independent variables, is applied to sites that vary in water quality (but are similar in other attributes) or to one site for which water quality changes over time. This is an extremely involved procedure, which measures only the recreational benefits associated with improved water quality downstream. There are a number of difficulties with such analysis. In particular, for a multisite study, the influence of water quality between sites needs to be isolated from other varying attributes that might affect recreation demand. In the case of a single-site temporal study, changes in water quality need to be isolated from other attributes that might change over time. Smith and Kaoru (1990) undertook a meta-analysis of travel cost studies relating to water-based recreational values. They found that five features consistently had an influence on results: type of recreational site; the definition of the usage and quality of a site; measurement of the opportunity cost of time; the description of substitutes; and specification of the demand model.

Regarding the hedonic price method, the price of properties in close proximity to waterbodies can be affected by the quality of the water and, therefore, by nutrient retention. The value of the nutrient retention function is derived from: (i) property values that are attributable to water quality; and (ii) the role of the function in maintaining the water quality. This entails analysis of prices for otherwise similar properties that are located close to polluted and unpolluted waterbodies. However, the data demands are considerable. A rough approximation of value can be derived directly from a summation of adjustments in property prices, which could be based on assessments of experts, such as estate agents, rather than actual observed price differentials in the property market.

Regarding the defensive expenditures/avoided cost approach, the value of improved water quality can be estimated based on the expenditures undertaken by people to avoid consumption of poor-quality water. The sum of defensive expenditures on marketed goods, such as water purification equipment, represents the lower boundary on society's willingness to pay for improved water quality. This accounts only for changes in behaviour made by consumers in response to poor water quality. It does not take into account consumers who do not undertake defensive actions but would nonetheless prefer improved water quality. Such individuals may be inhibited from acting by inconvenience associated with the defensive activities, or lack of information about pollutant levels and possible adverse effects. Abdalla, Roach and Epp (1992) used this valuation approach to determine the time and money that households expend to avoid risk arising from groundwater contamination. Their approach assumes that households undertake a two-step decision-making process in which they first decide whether to undertake any avertive action, and then decide on the intensity of those actions. Abdalla (1994) also provides a survey of the literature on averting cost methods.

The retention of nutrients can be valued using the replacement cost in terms of the cost of substitutes. Substitute activities include reduction of nitrate and phosphate pollution at source by limiting applications of agricultural fertilizers or by the installation of water treatment facilities. The replacement cost is particularly useful where the benefits of reduced nutrient loading are difficult to estimate. Examples include estimation of the benefits of avoiding deleterious health effects or the benefits of maintaining water quality and ecosystems for future generations.

Sediment retention

This concerns the net retention of sediment carried in suspension by surface water, including runoff from the contributory area and overbank flooding.

Retention of sediment reduces the sediment load in water downstream and thereby improves water quality. The value of this may be most readily estimated in terms of the additional costs that industrial and municipal users of water would incur through the necessity for water treatment in the absence of sediment retention. Higher water quality may also lead to increased opportunities downstream, e.g. for recreation and commercial fisheries, and may have biological impacts on survival of habitats and species. Habitats and biodiversity are considered here only in so far as they might contribute to recreational and amenity value. Techniques for valuing the benefits of improved water quality (or the costs of poor water quality) are covered under the 'nutrient retention' function (above).

Additional benefits of reduced sediment loads include mitigation of damages to water conveyance facilities. Such damages can occur through deposition of sediment in rivers, drainage ditches and irrigation canals, which can lead to adverse effects on navigation and water storage capacity, and can increase flooding. Some of the techniques for valuing those benefits that have not already been considered under other functions are discussed below.

Regarding the techniques of avoided cost/damage costs, the benefits of maintaining navigation can be estimated in terms of the avoided costs of alternative transport. This approach does not usually account for the differences in speed between alternative modes of transport. Alternatively, the benefits of maintaining navigation can be valued as the damage costs avoided in terms of reduced accidents and groundings. However, values are likely to be low, especially where the costs of infrastructure have already been accounted for. The benefits of mitigating damages to water conveyance facilities, such as deposition in drainage ditches and irrigation canals, is peculiar to the sediment retention function. Estimating the damage costs avoided in terms of the costs of reversing possible adverse impacts is the most appropriate valuation technique to use.

Considering the application of residual imputation and variants, the presence of fine silt particles in water used for irrigation can lead to a loss in productivity, as they can seal the surface of the soil, making it impermeable. However, the addition of sediment can increase soil fertility and thereby improve productivity. As sediment impinges directly on agricultural production, for which market prices exist, then changes in marketed outputs can be used to assess the value of sediment retention.

Ecological functions

Ecosystem maintenance

This concerns the provision of habitat for animals and plants through the interaction of physical, chemical and biological processes.

The economic value of ecological functions is generally only derived through contact with or concern for species or habitats that are components of an ecosystem. Thus, it focuses on aspects of biodiversity (both quantity and variety of organisms). With respect to biodiversity maintenance, the valuation techniques of relevance include: contingent valuation, hedonic pricing and replacement cost.

Contingent valuation can be particularly useful for assessing the value of biodiversity maintenance, indicating willingness to pay for conservation of biodiversity. It is the only technique currently regarded as suitable for estimating non-use values associated with the maintenance of species diversity and population sizes. By definition, these values are not reliant on individuals visiting the site (so are not associated with measurable changes in behaviour). Brouwer *et al.* (1997) provide a meta-analysis that attributes values to various ecological functions estimated from a large number of contingent valuation studies.

With hedonic pricing, differences in property prices that can be attributed to aesthetic and amenity benefits of proximity to a wetland can provide a value for maintenance of biodiversity on the wetland site. This requires analysis of prices for otherwise similar properties that are located close to and distant from wetlands with a diversity of species.

The replacement cost of the biodiversity maintenance function is based on the costs of creation or renovation of an alternative. To provide a replacement, the alternative is required to provide similar habitats to the original site. Indeed, a possible management option would entail relocation of species to an alternative site. To have corresponding value, the alternative site is required to provide the same benefits. These are influenced by the location of the alternative site: its proximity to population centres, ease of access and availability of substitute sites. There is also the question of 'authenticity'. The original, naturally occurring site may be preferred to an exact replica, thereby affecting amenity and non-use values. Valuation using the replacement cost is most straightforward for sites that predominantly provide the single function of biodiversity maintenance. For sites that provide multiple functions, the costs of replacement are attributed between the respective functions. Opportunity costs of the conversion of the alternative site and any externalities are also taken into account.

In addition to biodiversity maintenance, anthropogenic export of this biodiversity is also an important ecological function. This has consumptive use value associated with commercial exploitation, subsistence provision, and recreational use. The value of commercial exploitation of fish, shrimp or timber harvesting can generally be assessed through analysis of market prices. Subsistence value can be more difficult to estimate because the products are not marketed. However, market prices may exist for the products, alternative products or inputs to production that can be used as surrogates for prices. Consumptive recreation activities most often involve fishing and hunting. These can be assessed using the travel cost method or the contingent valuation method.

REVIEW OF VALUATION STUDIES

There have been a number of reviews of water resources in the past three decades. Early surveys were undertaken by Young and Gray (1972) and Gibbons (1986), while more recent work includes Moore and Willey (1991), Young (1996), Frederick, VandenBerg and Hanson (1997). Renzetti (2002) provides an up-to-date survey of the water demand literature. There have also been a number of specific surveys of the value of water in specific uses. For example, Bogess, Lacewell and Zilberman (1993) consider the economics of water use in agriculture. These reviews are based on sectoral views of water resources, which despite the approach advocated here, are useful in highlighting important themes that have implications for policy.

In their review of water valuation studies, Frederick, VandenBerg and Hanson (1997) found wide variation in estimated values across water use sectors (summarized in Table 9). While not the lowest, values in the irrigation water sector tended to be much lower than domestic and industrial uses. However, these figures are based on an unevenly distributed sample of studies across the different sectors. While there are a relatively large number of studies in irrigation and recreational uses, few studies have been undertaken for industrial and domestic applications. A similar picture emerges from an analysis undertaken by Briscoe (1996) using data from developed and developing country studies (summarized in Figure 11).

Based on the data in Figure 11, and other studies that show consistent results, Briscoe (1996) makes the following conclusions:

- The value of irrigation water in industrialized countries: irrigated agriculture accounts for a large proportion of water use, especially in many water-scarce areas, and the value of water for many low-value crops, such as food grains and fodder, is universally very low. Nevertheless, the value of water can be high (of the same order of magnitude as values in M&I end uses) where reliable supplies are used on high-value crops.

- The value of irrigation water in developing countries*:* a similar picture to that for industrialized countries is found in developing countries. Where water is used on high-value crops, including fruits, vegetables and flowers, then the value of water, as reflected in active and sophisticated water markets, can be high (typically around US$0.05/m^3). However in many public (mostly surface) irrigation systems, the quality of the irrigation supply is poor, food grains are the major crop produced, and the value of water is typically only about US$0.005/m^3, orders of magnitude lower than for private irrigation schemes that use groundwater.

- The value of water for hydropower: the short-run values for use of water in hydroelectric power generation in industrialized countries are typically quite low, often no higher than the value in irrigated agriculture. Long-run values are even lower. The economic viability of hydropower depends on factors in the economy, the power sector and the water sector. Hydropower is most likely to be worthwhile where water is abundant and there are few competing uses. In developing countries, high environmental costs of alternative sources of power and a growing demand for power may make hydropower an attractive option. It is sometimes argued that hydropower is a non-consumptive use and as such does not impose externalities on others. However, in reality, it can modify flow regimes with the result that major costs are imposed. The key issue is not consumptive or non-consumptive use, but the costs imposed on others by a particular use of the resource.

- The value of water for household purposes is usually much higher than the value for most irrigated crops. Within household usages, the value for 'basic human needs' is much higher than the value for discretionary uses (such as garden watering). Reliability of supply is an important factor in how the resource is valued.

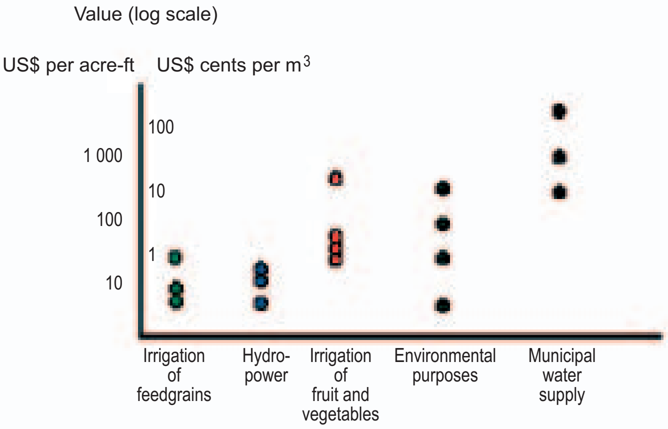
- The value of water for industrial purposes is typically of a similar order of magnitude to that of supplies for household purposes;

TABLE 9
Values of water use in the United States of America, by sector

	Value of water use in 1994 US$/acre-foot of water				No. observations
	Average	Median	Minimum	Maximum	
In situ					
Waste disposal	3	1	0	12	23
Recreational/ habitat	48	5	0	2 642	211
Navigation	146	10	0	483	7
Hydropower	25	21	1	113	57
Withdrawal					
Irrigation	75	40	0	1 228	177
Industrial	282	132	28	802	7
Thermal power	34	29	9	63	6
Domestic	194	97	37	573	6

Source: Frederick, VandenBerg and Hanson (1997).

FIGURE 11
Typical market and non-market values for water use in the western United States of America



Source: Briscoe (1996).

- The value of environmental and ecological purposes varies widely but typically falls between the agricultural and municipal values (as shown in Figure 11).

Given the focus on the functional perspective in this report, the Appendix provides a review of a large selection of water resource valuation studies relating mainly to the uses provided by the hydrological, biogeochemical and ecological functions under the functional perspective. The review is not comprehensive but it does indicate that valuation techniques have been applied extensively in both developed and developing countries to a large range of water resource functions. It further indicates that significant economic values have been attached to these various functions. Such a review could form the basis of a meta-analysis, although this is beyond the scope of the present study.

Chapter 5
Conclusions

This last chapter revisits briefly some of the key issues examined in previous chapters. It examines their practical implications and consequences for water policy and management in agriculture. The key issues are highlighted in the context of the new integrated catchmentwide approach to water policy and management in place in North America and evolving in Europe. Although the socio-cultural, institutional and economic setting of water policy and management is very different in developing countries, the essentials of the more integrated management approach will eventually also need to be incorporated in their water policy and management as water (and especially water of good quality) becomes scarcer and its value increases. The core concern is that demand for water is increasing both in agriculture and in other areas, such as the municipal sector. Scarcity of future freshwater generation capacity and escalating costs of exploitation are formidable challenges. The problem is exacerbated by worries over the environmental impact of agricultural water use, in particular water quality degradation effects. Thus, the fundamental policy and management question is quite simple: how can the available water resources be managed more sustainably to enhance the efficiency of food production and to safeguard environmental systems and their provision of goods and services?

VALUES AND SERVICES

The values of the extractive and *in-situ* services provided by water resources in their naturally occurring settings have proved difficult to capture. The thrust of economic valuation of “water” has concentrated on the 'pricing' and 'efficiency' of water supply services with a view to full cost recovery for the service provided. Such analyses rarely consider the extractive and *in-situ* values of the resource base itself and the complications contingent upon its common pool/property character, e.g. lack of clear boundaries linking the physical flow domain and socio-economic/public domain.

However, the competition for raw water is intensifying and agriculture is often cited as the principal 'user' of raw water. The fact that agricultural use involves returns of significant (although often degraded) volumes of water is sometimes ignored. Nevertheless, national agriculture policies in developing countries continue to promote irrigated agriculture to minimize perceived risks in food supply and distribution. In addition, the promotion of agricultural activity is considered strategic in fixing and developing rural economies. In many cases the existing systems of water use rights have reinforced the seniority of agriculture user rights. Nevertheless, relative to water use in industry and municipal sectors, agricultural water supplies are very sensitive to supply shocks (Rosegrant *et al.* 2000).

These circumstances are being questioned continually as intersectoral competition for raw water between agriculture, domestic, municipal and industrial uses intensifies at national level and at international level where economic asymmetry between riparian countries drives competition over shared water resources. In addition, public interest in the maintenance of *in-situ* environmental services (for amenity, recreation, biodiversity, conservation and ecology) is pressuring the large sectoral users of water into accommodations and trade-offs. Therefore, the agriculture sector needs a transparent system of resource evaluation with which to negotiate and regulate allocation of the resource, both at the national level and at the international level in the case of shared river basins, aquifers and catchments.

Integrated approaches to water policy and water management has recently been institutionalized in Europe through the adopted Water Framework Directive (2000/60/EC). The Water Framework Directive is one of the first European Directives to recognize explicitly the role of economics in reaching environmental and ecological objectives. The Water Framework Directive calls for the application of economic principles (e.g. polluter pays), economic methods (e.g. cost–effectiveness analysis) and economic instruments (e.g. water pricing methods) for achieving good water status for all waters in the most effective manner. Furthermore, the Water Framework Directive has specific characteristics that have their roots in a systems approach to environmental management in general. It is the striking of a balance between the complementarity and the trade-off that exists between economic growth and water resource degradation and depletion that defines the context underlying the question of how to decide on economic and environmental policies and investments for water resources.

Thus, it is possible to summarize the sustainable water resource use problem as comprising the following features (Turner and Dubourg, 1993):

- Water is generally non-substitutable (although at the limit there is an almost infinite supply of seawater, which can be converted into freshwater at a cost of energy and some pollution).
- Water faces rising overall demand and use intensification.
- Water has limits to use. There are physical limits, e.g. the rate of groundwater recharge. However, at the aggregate level, the notion of an absolute physical limit is less valid because adjustment mechanisms (recycling, etc.) should mean that water will be available for the foreseeable future at reasonably practicable prices. There are relative cost limits in the sense that, as usage of existing supplies intensifies and new supplies are sought, the cost of extraction and usage will escalate. Finally, there are social limits set by the social acceptability of the effects of certain uses, e.g. water quality and flow conditions for recreational activities.

Notions of efficiency

In the face of the growing scarcity of water resources and the need for better management, much of the discussion has focused on increasing current water use efficiency and the promotion of efficient allocation of water resources among different users.

Traditionally, economic efficiency of irrigation water use has been measured in terms of crop output per unit of water applied or the overall financial returns in terms of net benefits from the project. This concept has been used widely in investment decision-making, where the desire is to maximize returns from irrigation over the life of a project. However, there is a need to recognize fully that the aim of water resource management is not simply to provide water of sufficient quality and quantity. Water resources have additional value, e.g. in terms of their recreational and ecological services. As such, the concept of economic efficiency can be defined more generally in terms of the Pareto optimality condition, where it is not only private costs and benefits that are considered, but also the non-financial social costs and benefits. Economic efficiency also refers to the maximization of the overall socio-economic net benefits from the different water sectors, with the aim of minimizing the intersectoral and intrasectoral socio-economic opportunity costs.

In addition, considering economic efficiency from a sustainability point of view as 'critical natural capital' implies that water must be managed in such a way as not to reduce the opportunities for potential use by future generations. In this respect, water withdrawal and use for irrigation purposes can have negative impacts on wetlands, aquatic ecosystems and corresponding ecological functions, which the usual view of water use efficiency does not take into consideration. Negative impacts also include external costs, such as those from waterlogging, salinization and soil erosion, which are also not usually incorporated into the economic price of irrigation water. There may also be ecological limits to water use such that even though water is being used more efficiently, the total amount being withdrawn still exceeds the sustainable supply.

Valuations and pricing

Because water resources and effects are often non-marketed, it is extremely important to ensure that the 'true' economic value of such resources are accounted for where possible when making decisions on capital investment and linked water and environmental policy. As such, there is a fundamental connection between the issue of economic valuation of water resources and the pricing of water resources. Efficient allocation and sustainable use of water require the setting of the "correct" price for water, namely that corresponding to its marginal economic value. Nevertheless, how to arrive at this "correct" price remains open to debate.

Many countries and water management agencies are turning increasingly to water pricing mechanisms in order to regulate irrigation water consumption. 'Pricing' can mean that actual prices are introduced (amended), where goods were previously free (underpriced). It can also mean that actual prices are not introduced (amended), but that the marginal economic value of the resource is entered into an appraisal and accounting procedure, such as cost–benefit analysis. Both forms of 'pricing' result in the internalization of environmental damage costs. Unless water resources are priced correctly, and those prices are internalized in actual decisions, there will be distortions in the economy. These distortions can have the effect of biasing investment and policy decisions against water resource degradation concerns, such that there is a misallocation of resources and social welfare is not maximized. Methods of water pricing and their performance will be dependent on the physical, social, institutional and political context. Several water pricing methods have developed in practice, depending on the nature of the economic and natural conditions in existence. In particular, these include, volumetric pricing, non-volumetric pricing and market-based methods. It has long been recognized that markets are a mechanism to allocate water according to its real value, thus leading to efficiency gains. While markets are considered to be more flexible than administrative means for allocating water, their use has often been questioned, especially because there are certain characteristics associated with water production and delivery that give rise to market failure. Such failures include externalities, recharge constraint, imprecise information, large fixed investment costs, and declining average costs of delivery.

This report has extended its focus to a wider concept of efficiency and water resource management than that considered by the traditional water pricing literature. It has incorporated environmental, ecological and other social spheres of concern, which need to be reflected in any pricing system. This is especially important where water allocation is being considered within a region or river catchment, or irrigation projects are to be considered at this appropriate scale. Focusing on the local-level scale is not sufficient to ensure efficiency gains in terms of a wider efficiency concept. The report has also taken a wider perspective in terms of the scope/scale of water resource allocation being considered, with the catchment as its minimum basis. A more integrated approach to water management is required to deal with the policy challenges at this broader scale.

AN INTEGRATED FRAMEWORK TO WATER RESOURCE VALUATION, APPRAISAL AND MANAGEMENT

Given the generic goal of sustainable water resource management, this report has taken an approach based on an integrated framework in which water is an integral component of a catchmentwide ecosystem, a natural resource, and a social and economic good, whose quantity and quality determines the nature of its use. At this scale, coupled hydrological economic models and information must underpin water management (Rosegrant *et al.* 2000). While still rudimentary, this form of analysis is evolving quickly.

At the heart of this approach are a number of generic principles that together form a powerful and comprehensive case for the wider adoption of a decision-support system based around economic analysis:

- the principle of cost–benefit analysis;
- the principle of functional diversity maintenance;
- the principle of integrated planning and management at the catchment level;
- the principle of long-term planning and precaution;
- the principle of stakeholder inclusion in decision-making;

Such a management strategy requires efforts to combine three related dimensions:

- systems ecology – thereby enabling improved understanding of how each component of the water system (across a catchment scale) influences other components;
- hydrological, biogeochemical and physical – so as to focus on how water interacts with other natural systems;
- socio-economic, socio-cultural and political – so as to recognize and plan for the accommodation of links to relevant policy networks and economic and social systems with attendant culture and history, so maximizing chances of achieving a cooperative solution/mitigation strategy.

The evaluation framework and decision-support system proposed in this document are in line with the sustainable water resource management approach advocated by the World Bank (1993), which has at its core the adoption of a comprehensive policy framework and the treatment of water as an economic good, combined with decentralized management and delivery structures, greater reliance on pricing, environmental protection and fuller participation by stakeholders. It is recognized that the adoption of such a comprehensive framework facilitates the consideration of relationships between the ecosystem and socio-economic activities in river basins. Such a management approach requires analysis to: take into account social, environmental and economic objectives; evaluate the status of water resources within each basin; assess the level and composition of projected demand; and take into consideration the views of all stakeholders.

In order to deliver the sustainable utilization and management of water resources, it is necessary to underpin management actions by a scientifically credible and pragmatic environmental decision-support system, which, while having the objective of economic efficiency at its heart, nevertheless recognizes other dimensions of water resource value and decision-making criteria. The decision-support system incorporates a toolbox of evaluation methods and techniques, complemented by a set of environmental change indicators and an enabling analytical framework, thus allowing managers to identify operational decision steps. Individual projects or schemes can be appraised in their own right and clearly cost-ineffective options can be discarded. However, individual schemes and more extensive programmes must be further placed in a wider analytical context encompassing spatial scales up to the level of the catchment and temporal scales beyond the short run. Only in this way is it possible to gain a full appreciation of their effect on overall economic allocative efficiency and parallel sustainability objectives.

In summary, the 'proper' appraisal of water-related projects, programmes or courses of action require a comprehensive assessment of water resources and supporting ecosystems. The DPSIR auditing framework is recommended as the basis for any such assessment in its full or 'reduced' form. This framework provides a conceptual connection between ecosystem change and the driving forces of such change, together with the effects of change (impacts and their distribution) on human welfare. Policy-response feedback effects can also be incorporated into the framework. The formulation of such a framework is a useful scoping procedure even where data sets are deficient.

A combination of quantitative and qualitative research methods has been advocated in order to generate a blend of different types of policy relevant information. This applies to both the biophysical assessment of management options and the evaluation of the welfare gains and losses people perceive to be associated with the environmental changes and management responses. The main generic approaches that can form the methodological basis for appraising strategic options are:

- stakeholder analysis;
- cost–effectiveness analysis;
- extended cost–benefit analysis and risk–benefit analysis;
- social discourse analysis;
- multicriteria analysis.

It is recognized that the complete adoption of such a procedure requires an institutional, financial and scientific capacity that may not be feasible in all countries. Therefore, the aim should be to move iteratively from a 'reduced form' procedure towards a comprehensive assessment over time. However, certain elements are fundamental: the adoption, as a minimum, of the catchment scale for analysis; the recognition of the importance of the functional approach to water uses and resources; the need for a scoping exercise (DPSIR) that encompasses distributional impacts; and the acceptance of economic principles for water valuation albeit constrained by cultural, political and other factors.

The implications for sustainability of productivity

The more sustainable future water allocation and management approach advocated here will probably be implemented incrementally over time. For some, this will be too little, too slowly (Postel, 2003). This polar ecocentric position would hold that the human water economy is a subset of nature's water economy and intimately dependent on it. From this perspective, water allocation priorities need reversing so that basic human needs and ecosystem health requirements are met first and only then should water flow to uses such as irrigation, hydropower, etc. There is a growing consensus that the technocentric view of water systems as resources to be exploited fully for human development needs modification and urgent reform in some developing countries. However, the sustainable way forward is not clear-cut. The safeguarding of the life-support and other services provided by water resources needs a scientific knowledge base. However, this knowledge base is currently deficient when it comes to quantifying what ecosystem resilience and integrity needs really are. The use of water for purposes such as irrigation is just as much a component as is the provision of safe drinking-water supplies in any rural poverty alleviation strategy.

However, water productivity will have to be enhanced significantly in the coming decades via efficiency gains enabled through economic measures such as valuation, pricing and trading, as well as through technological innovation and the application of appropriately 'scaled' technical fixes. Community-based watershed restoration and rainwater harvesting projects, low-cost drip irrigation for smallholders and rural credit provision, for example, will be just as much part of the sustainability strategy as will large-scale water resource augmentation projects. In all this striving for sustainable production based on water, the valuation of the resource needs to be the first step in laying out policy and management options.

References

Abdalla, C. 1994. Groundwater values from avoidance cost studies implications for policy and future research. *Am. J. Ag. Econ.*, 76: 1062–1067.

Abdalla, C., Roach, B. & Epp, D. 1992. Valuing environmental quality changes using averting expenditures: an application to groundwater contamination. *Land Econ.*, 68(2): 163–169.

Adger, W.N. 1999. Social vulnerability to climate change and extremes in coastal Vietnam. *World Dev.*, 27(2): 249–269.

Arrow, K., Solow, R., Schuman, H., Ragner, R. & Portney, P. 1993. Report to the NOAA Panel on contingent valuation. *US Fed. Reg.*, 58(10): 4602–4614.

Barbier, E.B. 1994. Valuing environmental functions: tropical wetlands. *Land Econ.,* 70(2): 155–173.

Barbier, E.B., Markandya, A. & Pearce, D.W. 1990. Environmental sustainability and cost benefit analysis. *Env. Plan. A.*, 22: 1259–1266.

Bateman, I.J., Carson, R.T., Day, B., Hanemann, W.M., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S., Ozdemiroglu, E., Pearce, D.W., Sugden, R. & Swanson, J. 2002. *Economic valuation with stated preferences techniques: a manual*. Cheltenham, UK, Edward Elgar.

Bateman, I.J., Willis, K.G., Garrod, G.D., Doktor, P., Langford, I.H., & Turner, R.K. 1992. *Recreation and environmental preservation value of the Norfolk Broads: a contingent valuation study*. Report to the National Rivers Authority. Environmental Appraisal Group, University of East Anglia, UK. pp. 403.

Bergstrom, J.C., Boyle, K.J., Job, C.A. & Kealy, M.J. 1996. Assessing the economic benefits of ground water for environmental policy decisions. *Wat. Res. Bull.*, 32(2): 279–291.

Bhaskar, R. 1989. *Reclaiming reality: a critical introduction to contemporary philosophy*. London, Verso.

Bird, J. & Wallace, P. 2001. Dams and water storage. *In* R.S. Meinzen-Dick & M.W. Rosegrant, eds. *Overcoming water scarcity and quality constraints.* 2020 Focus 9, Brief 7. Washington, DC, International Food Policy Research Institute.

Bishop, R.C. 1978. Endangered species and uncertainty: the economics of a safe minimum standard. *Am. J. Ag. Econ.*, 60: 10–18.

Boadway, R.W. & Bruce, N. 1984. *Welfare economics*. Oxford, UK, Basil Blackwell.

Boddington, M.A.B. 1993. Financial and economic measurement of environmental factors. *J. Inst. Wat. Env. Man.*, 7: 125–133.

Bogess, W., Lacewell, R. & Zilberman, D. 1993. The economics of water use in agriculture. *In* G. Carlson, D. Zilberman, & J. Miranowski, eds. *Agricultural and environmental resource economics*. New York, USA, Oxford University Press.

Bos, E. & Bergkamp, G. 2001. Water and the environment. *In* R.S. Meinzen-Dick & M.W. Rosegrant, eds. *Overcoming water scarcity and quality constraints.* 2020 Focus 9, Brief 6. Washington, DC, International Food Policy Research Institute.

Boyle, K.J. & Bergstrom, J.C. 1992. Benefits transfer studies: myths, pragmatism, and idealism. *Wat. Res. Res.*, 28(3): 657–663.

Braden, J.B. & Kolstad, C.D., eds. 1991. *Measuring the demand for environmental quality.* Amsterdam, Netherlands, North-Holland

Briscoe, J. 1996. *Water as an economic good: the idea and what it means in practice*. Paper presented at the World Congress on Irrigation and Drainage, Cairo, September 1996.

Briscoe, J. 1997. *Managing water as an economic good: rules for reformers*. Paper to the International Committee on Irrigation and Drainage Conference on Water as an Economic Good. Oxford, UK, September 1997.

Brouwer, R. 1998. *Future research priorities for valid and reliable environmental value transfer*. Global Environmental Change Working Paper 98-28. University of East Anglia and University College London, UK, CSERGE.

Brouwer, R., Turner, R.K. & Georgiou, S. 2001. *Water policy decision support tools: towards an integrated assessment method.* CSERGE Working Paper (forthcoming). University of East Anglia and University College London, UK, CSERGE.

Brouwer, R., Langford, I.H., Bateman, I.J., Crowards, T.C. & Turner, R.K. 1997. *A meta-analysis of wetland contingent valuation studies*". CSERGE Working Paper GEC 97-20. University of East Anglia and University College London, UK, CSERGE.

Brouwer, R., Powe, N.A., Turner, R.K., Bateman, I.J. & Langford, I.H. 1999. Public attitudes to contingent valuation and public consultation. *Env. Val.*, 8(3), 325–347.

Brown, L.R. 2001. *Worsening water shortages threaten China's food security*. Eco-Economy Updates. Washington, DC, Earth Policy Institute.

Burbridge, P.R. 1994. Integrated planning and management of freshwater habitats, including wetlands. *Hydrobiologia*, 285: 311–322.

Burgess, J., Clark, J. & Harrison, C.M. 1998. Respondents' evaluation of a CV survey: a case study based on economic valuation of the Wildlife Enhancement Scheme, Pevensey Levels in East Sussex. *Area*, 30(1): 19–27.

Burke, J.J. & Moench, M.H. 2000. *Groundwater and society – resources tensions and opportunities*. New York, USA, United Nations Department of Economic and Social Affairs.

Burke, J.J. 2003. Implementation of national irrigation strategies: fuzzy vision, harsh realities and strange bedfellows. In proceedings of *Irrigation policies: micro and macro economic considerations: Agadir 2003*. http://www.worldbank.org/agadirconference.

Carruthers, I. & Clark, C. 1981. *The economics of irrigation*. Liverpool, UK, Liverpool University Press.

Carson, R.T., Flores, N.E., Martin, K.M., Wright, J.L. 1996. Contingent valuation and revealed preference methodologies: comparing the estimates for quasi-public goods. *Land Econ.*, 72: 80–99.

Chichilnisky, G. & Heal, G. 1998. Economic returns from the biosphere. Nature, 391: 629–630.

Ciriacy-Wantrup, S.V. 1952. *Resource conservation: economics and policies.* Berkeley, USA, University of California Press.

Clark, E.H. 1985. The off-site costs of soil erosion. *J. Soil Wat. Con.*, Jan-Feb: 19–21.

Colby, B. 1989. Estimating the value of water in alternate uses. *Nat. Res. J.*, 29(2): 511–527.

Conrad, J.M. & Clark, C.W. 1987. *Natural resource economics: notes and problems.* Cambridge, UK, Cambridge University Press.

Costanza, R. 1994. Three general policies to achieve sustainability. *In* A.-M. Jansson, M. Hammer, C. Folke & R. Costanza, eds. *Investing in natural capital: the ecological economics approach to sustainability.* Washington, DC, Island Press.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. & van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387: 253–260.

Crowards, T.M. 1996. *Addressing uncertainty in project evaluation: the costs and benefits of safe minimum standards.* Global Environmental Change Working Paper GEC 96-04. University of East Anglia and University College London, UK, CSERGE.

Crowards, T.M. 1997. Combining economics, ecology and philosophy: safe minimum standards of environmental protection. *In* M. O'Connor & C. Spash, C., eds. *Valuation and environment: principles and practices.* Aldershot, UK, Edward Elgar.

Daly, H. 1995. On Wilfred Beckerman's critique of sustainable development. *Env. Val.,* 4(1): 49–55.

De Groot, R.S. 1992. *Functions of nature.* Amsterdam, The Netherlands, Wolters-Noordhoff.

De Moor, A. & Calamai, P. 1997. *Subsidizing unsustainable development – undermining the earth with public funds*. The Earth Council.

Desvousges, W.H., Smith, V.K., Brown, D.J. & Pate, D.K. 1984. *The role of focus groups in designing a contingent valuation survey to measure the benefits of hazardous waste management regulation*. RTI Project No. 2505-13. Research Triangle Park, USA, Research Triangle Institute.

Desvousges, W.H., Johnson, F.R., Dunford, R.W., Boyles, K.J., Hudson, S.P. & Wilson, K.N. 1992. *Measuring nonuse damages using contingent valuation: an experimental evaluation of accuracy*. Research Triangle Institute Monograph 92-1. Research Triangle Park, USA, Research Triangle Institute.

Dinar, A. (ed). 2000. The Political economy of water pricing reforms. Oxford, UK. 405 pp.

Dinar, A., Rosegrant, M.W. & Meinzen-Dick, R. 1997. *Water allocation mechanisms: principles and examples*. World Bank Policy Research Working Paper 1779. Washington, DC, World Bank.

Dublin Statement. 1992. *International conference on water and the environment: development issues for the 21st century*. 26–31 January 1992. Dublin.

Dubourg, W.R. 1992. *The sustainable management of the water cycle: a framework for analysis*. CSERGE Working Paper WM-07. University of East Anglia and University College London, UK, CSERGE.

Dubourg, W.R. 1997. Reflections of the meaning of sustainable development in the water sector. *Nat. Res. For.*, 21(3): 191–200.

Easter, K.W. & Hearne, R. 1995. Water markets and decentralized water resources management: international problems and opportunities. *Wat. Res. Bull.,* 3 (1): 9–20.

European Commission. 1998. *Towards sustainable water resources management: a strategic approach*. Luxembourg.

FAO. 1996. *Control of water pollution from agriculture,* by E.D. Ongley. Irrigation and Drainage Paper No. 55. Rome.

FAO. 2002a. *Crops and drops – making the best use of water for agriculture*. Rome.

FAO. 2002c. *Agricultural drainage water management in arid and semi-arid areas,* by K.K. Tanji & N.C. Kielen. Irrigation and Drainage Paper No. 61. Rome.

FAO. 2003a. *Unlocking the water potential of agriculture*. Rome.

FAO. 2003b. Issue paper for Ministerial meeting on water for food and agriculture, Kyoto, Japan.

FAO. 2003c. *World agriculture: towards 2015/2030. London, Earthscan Publications Ltd.* Lodon.

FAO. 2004. Water charging in irrigated agriculture: an analysis of internal experience. *FAO Water Reports No. 27*. Rome.

FAO. 2004. *AQUASTAT* Web site http://www.fao.org/ag/aquastat.

Farber, S. & Costanza, R. 1987. The economic value of wetlands systems. *J. Env. Man.,* 24: 41–51.

Farnworth, E.G., Tidrick, T.H., Jordan, C.F., & Smathers, W.M. 1981. The value of ecosystems: an economic and ecological framework. *Env. Con.*, 8: 275–282.

Faux, J. & Perry, G. 1999. Estimating irrigation water value using hedonic price analysis. *Land Econ.*, 75(3): 440–453.

Fisher, A.C. & Krutilla, J.V. 1975. Resource conservation, environmental preservation, and the rate of discount. *Quart. J. Econ.,* 89: 358–370.

Frederick, K., VandenBerg, T. & Hanson, J. 1997. **Economic values of freshwater in the United States**. Discussion Paper 97-03. Washington, DC, Resources for the Future.

Freeman, A.M. 1982. *Air and water pollution control.* New York, USA, John Wiley.

Freeman, A.M. 1993. *The measurement of environmental resources values.* Washington, DC, Resources for the Future.

Garrod, G. & Willis, K. 1994. *The transferability of environmental benefits: a review of recent research in water resources management*. Working Paper 12. Centre for Rural Economy.

Georgiou, S., Bateman, I., Cole, M. & Hadley, D. 2000. *Contingent ranking and valuation of river water quality improvements: testing for scope sensitivity, ordering and distance decay effects*. CSERGE Working Paper GEC 2000-18. University of East Anglia, UK, CSERGE.

Georgiou, S., Whittington, D., Pearce, D. & Moran, D. 1997. *Economic values and the environment in the developing world*. Cheltenham, UK, Edward Elgar.

Gibbons, D.C. 1986. *The economic value of water*. Washington, DC, Resources for the Future.

Glass, G.V., McGaw, B. & Smith, M.L. 1981. *Meta-analysis in social research*. Beverly Hills, USA, Sage Publications.

Green, C.H. & Penning-Rowsell, E.C. 1986. Evaluating the intangible benefits and costs of a flood alleviation proposal. *J. Inst. Wat. Eng. Sci.*, 40(3): 229–248.

Green, C.H. & Penning-Rowsell, E.C. 1989. Flooding and the quantification of 'intangibles'. *J. Inst. Wat. Env. Man.*, 38: 27–30.

Green, C., Tunstall, S., Garner, J. & Ketteridge, A.-M. 1994. *Benefit transfer: rivers and coasts*. Paper prepared for the CEGB meeting on benefit transfer. H.M. Treasury. Publication No. 231. Middlesex University, UK, Flood Hazard Research Centre.

Gren, I-M., Folke, C., Turner, R.K. & Bateman, I. 1994. Primary and secondary values of wetland ecosystems. *Env. Res. Econ.,* 4: 55–74.

Hammack, J. & Brown, G.M. 1974. *Water and wetlands: towards bioeconomic analysis*. Washington, DC, Resources for the Future.

Hanley, N.D. 1990. *Valuation of environmental effects: final report - stage one*. Industry Department of Scotland and the Scottish Development Agency.

Hanley, N.D. & Craig, S. 1991. Wilderness development decisions and the Krutilla-Fisher model: the case of Scotland's low country. *Ecol. Econ.*, 4(2): 145–164.

Hanley, N.D. & Spash, C.L. 1993. *Cost-benefit analysis and the environment*. Aldershot, UK, Edward Elgar.

Harremoës, P. & Turner, R.K. 2001. Methods for integrated assessment. *Reg. Env. Change*, forthcoming.

Higgs, A.W. 1992. *Purley on Thames flood alleviation scheme*. Paper to the Economic Appraisal Group, National Rivers Authority.

Hoehn, J.P. 1992. *Natural resource damage assessment and contingent valuation: Issues and research needs*. Staff Paper. USA, Michigan State University.

Holway, J.M. & Burby, R.J. 1990. The effects of floodplain development controls on residential land values. *Land Econ.*, 66(3): 259–271.

House, M.A. & Sangster, E.K. 1991. Public perception of river corridor management. *J. Inst. Wat. Env. Man.*, 3: 336–344.

Howe, C.W., Schurmeier, D.R. & Shaw, W.D. 1986. Innovative approaches to water allocation: the potential for water markets. *Wat. Res. Res.*, 22(4): 439–445.

International Conference on Water and the Environment (ICWE). 1992. *The Dublin Statement on water and sustainable development*. Geneva, Switzerland, Hydrology and Water Resources Department, World Meteorological Organization.

International Fund for Agricultural Development (IFAD). 2001. *Rural poverty report 2001. The challenge of ending rural poverty.* Oxford, UK, Oxford University Press.

Jacobs, M. 1997. Environmental valuation, deliberative democracy and public decision-making institutions. *In* J. Foster, ed. *Valuing nature?* London, Routledge.

Johansson, R.C. 2000. Pricing irrigation water: a literature survey. Washington, DC, World Bank.

Johansson, R.C., Tsur, Y., Roe, T.L., Doukkali, R. & Dinar, A. 2002. Pricing irrigation water: a review of theory and practice. *Wat. Pol.*, 4: 173–199.

Jordan, J.L. & Elnagheeb, A.B. 1993. Willingness to pay for improvements in drinking water quality. *Wat. Res. Res.*, 29(2): 237–245.

Julius, D.S. & Alicbusan, A. 1989. *Public sector pricing policies: a review of bank policy and practice*. PPR Working Paper 49. Washington, DC, World Bank.

Kahneman, D. & Knetsch, J. 1992. Valuing public goods: the purchase of moral satisfaction. *J. Env. Econ. Man.*, 22 (1): 57–70.

King, A.W. 1993. Considerations of scale and hierarchy. *In* S. Woodley, J. Kay & G. Francis. *Ecological integrity and the management of ecosystems*. Ottawa, St Lucie Press.

Kloezan, W.H. 2002. Accounting for water. *Institutions viability and impacts of market-oriented irrigation intervention in Central Mexico.* Wageningen University. The Netherlands.

Krippendorff, K. 1980. *Content analysis: an introduction to its methodology.* Beverly Hills, USA, Sage Publications.

Krutilla, J.V. & Fisher, A.C. 1985. *The economics of natural environments-studies in the valuation of commodity and amenity resources*. Washington, DC, Resources for the Future.

Lareau, T.J. & Rae, D.A. 1989. Valuing WTP for diesel odor reductions: an application of the contingent ranking technique. *South. Econ. J.*, 55(3): 728–742.

Ledoux, L., Crooks, S., Jordan, A.& Turner, R.K. 2000. Implementing EU biodiversity policy: UK experiences. *Land Use Pol.*, 17: 257–268.

Lew, D.K., Larson, D.M., Suenaga, H. & DeSousa, R. 2001. *The beneficial use values database*. University of California, USA, Department of Agricultural and Resource Economics.

Loomis, J.B. 1987. The economic value of instream flow: methodology and benefit estimates for optimum flows. *J. Env. Man.*, 24: 169–179.

Maass, A. & Anderson, R. 1978. *And the desert shall rejoice.* Cambridge, USA, MIT Press.

Maltby, E., Holdgate, M., Acreman, M. & Weir, A. 1999. *Ecosystem management: questions for science and society.* Virginia Water, UK, Royal Holloway Institute for Environmental Research.

Markandya, A. & Pearce, D.W. 1988. *Environmental considerations and the choice of discount rates in developing countries*. Environment Department Working Paper No. 3. Washington, DC, World Bank.

Marsh, L.L., Porter, D.R. & Salvesen, D.A. 1996. *Mitigation banking: theory and practice*. Washington, DC, Island Press.

McCrain, G.R. 1992. Habitat evaluation procedures (HEP) applied to mitigation banking in North Carolina. *J. Env. Man.*, 35: 153–162.

Mitchell, B. 1990. *Integrated water management: international experiences and perspectives.* London, Belhaven Press.

Moore, D. & Willey, Z. 1991. Water in the American west: institutional ecolution and environmental restoration in the 21st century. *Univ. Col. Law Rev.*, 62 (4): 775–825.

Morey, E.R. 1984. The choice of ski areas: estimation of a generalised CES preference ordering with characteristics. *Rev. Econ. Stat*., 66: 584–590.

Morey, E.R. 1985. Characteristics, consumer surplus, and new activities: a proposed ski area. *J. Pub. Econ*., 26(2): 221–236.

Morgan, M.G. & Henrion, M. 1990. *Uncertainty: a guide to dealing with uncertainty in quantitative risks and policy analysis.* Cambridge, UK, Cambridge University Press.

N'Jai, A., Tapsell, S.M., Taylor, D., Thompson, P.M., Witts, R.C., Parker, D.J. & Penning-Rowsell, E.C. 1990. *Flood loss assessment information report*. Middlesex University, UK, Flood Hazard Research Centre.

Naeser, R.B. & Bennett, L.L. 1998. The cost of noncompliance: the economic value of water in the middle Arkansas river valley. *Nat. Res. J.,* 38(3): 445–463.

National Research Council. 1997. *Valuing ground water. Economic concepts and approaches*. Committee on Valuing Ground Water. Water Science and Technology Board. Commission on Geosciences, Environment and Resources. National Research Council. Washington, DC, National Academy Press.

Northeast-Midwest Institute & National Oceanic and Atmospheric Administration (NMI & NOAA). 2001. *Revealing the economic value of protecting the Great Lakes*. Washington, DC.

Norton, B.G. 1986. *Towards unity among environmentalists*. Oxford, UK, Oxford University Press.

O'Neil, J. 1997. Managing without prices: the monetary valuation of biodiversity. *Ambio*, 26: 546–550.

O'Riordan, T. & Ward, R. 1997. Building trust in shoreline management: creating participatory consultation in shoreline management plans. *Land Use Pol.*, 14(4): 257–276.

OECD. 1994. *Managing the environment: the role of economic instruments*. Paris.

Olsen, D., Richards, J. & Scott, R.D. 1991. Existence and sport values for doubling the size of Columbia river basin salmon and steelhead runs. *Rivers*, 2(1): 44–56.

Pearce, D.W. & Turner, R.K. 1990. *Economics of natural resources and the environment.* London, Harvester Wheatsheaf.

Pearce, D.W., Markandya, A. & Barbier, E.B. 1989. *Blueprint for a green economy*. London, Earthscan.

Pearce, D.W., Whittington, D. & Georgiou, S. 1994. *Project and policy appraisal: integrating economics and environment*. Paris, OECD.

Perry, C. & Kite, G. 2003. Water accounting at basin scale: a critique of the AQUASTAT approach. FAO, Rome. 22pp.

Plusquellec, H. 2002. How design, management and policy affect the performance of irrigation projects. Emerging modernisation procedures and design standards. FAO, Bangkok.

Poe, G. 1998. Valuation of groundwater quality using a contingent valuation-damage functions approach. *Wat. Res. Res.*, 34(12): 3627–3633.

Postel, S.L. 2003. Securing water for people, crops and ecosystems: new mindset and new priorities. *Nat. Res. For.* 27: 89–98.

Potter, J. 1996. Discourse analysis and constructionist approaches: theoretical background. *In* J.T.E. Richardson, ed. *Handbook of qualitative research methods for psychology and the social sciences*. Leicester, UK, British Psychological Society.

Rayner, S. 1984. Disagreeing about risk: the institutional cultures of risk management and planning for future generations. *In* S. Halden, S., ed. *Risk analysis, institutions and public policy*. New York, USA, Associated Faculty Press.

Renault, D. & Montginoul, M. 2003. Positive externalities and water service management in rice-based irrigation systems of the humid tropics. *Ag. Wat. Man.,* 59: 171–89.

Renzetti, S. 2002. *The economics of water demands.* Boston, USA, Kluwer Academic Publishers.

Repetto, R. 1986. *Skimming the water: rent seeking and the performance of public irrigation systems*. Washington, DC, World Resource Institute.

Rogers, P., Bhatia, R. & Huber, A. 1997. *Water as a social and economic good: how to put the principle into practice*. Paper prepared for the meeting of the Technical Advisory Committee of the Global Water Partnership in Namibia. Washington, DC, World Bank.

Rosegrant, M.W. & Svendsen, M. 1993. Asian food production in the 1990s – irrigation investment and management policy. *Food Pol.,* 18(Feb): 13–32.

Rosegrant, M.W., Cai, X. & Cline, S.A. 2002. *World water and food to 2025: dealing with scarcity*. Washington, DC, International Food Policy Research Institute.

Rosegrant, M.W., Ringler, C., McKinney, D.C., Cai, X., Keller, A. & Donoso, G. 2000. Integrated economic-hydrologic water modeling at the basin scale: the Maipo river basin, *Ag. Econ.*, 24: 33–46.

Rotmans, J., van Asselt, M.B.A., de Bruin, A.J., den Elzen, M.G.J., de Greef, J., Hilderink, H., Hoekstra, A.Y., Janssen, M.A., Köster, H.W., Martens, W.J.M., Niessen, L.W. & de Vries, H.J.M. 1996. *Global change and sustainable development: a modelling perspective for the next decade*. RIVM report 461502004. Bilthoven, The Netherlands.

Roy, D. & Shah, T. 2003. Socio-ecology of groundwater irrigation in India. In Llamas, P. and Custodio, E. *Intensive use of groundwater: challenges and opportunities*. A.A. Barkema Publications.

Ruttan, V. 1965. *The economic demand for irrigated acreage: new methodology and some preliminary projections, 1954–1980.* Baltimore, USA, Resources for the Future.

Sagoff, M. 1988. *The economy of the earth*. Cambridge, UK, Cambridge University Press.

Saliba, B.C. & Bush, D.B. 1987. *Water markets in theory and practice: market transfers and public policy.* Boulder, USA, Westview Press.

Sather, J.H. & Smith, R.D. 1984. *An overview of major wetland functions and values*. FWS/OBS-84/18. USA, Fish and Wildlife Service, US Dept of the Interior.

Seckler, D., Molder, D. & Sakthivadivel. 2003. The concept of efficiency in water resources management and policy. In Kinja, J.W., Barker, R. and Molder, D. *Improving water management in agriculture.* CABI Publishers.

Sherman. R. 1989. *The regulation of monopoly*. Cambridge, UK, Cambridge University Press.

Smith, V.K. 1992. Arbitrary values, good causes, and premature verdicts. *J. Env. Res. Econ.*, 22(1): 71–89.

Smith, V.K. & Desvousges, W.H. 1986. *Measuring water quality benefits*. Boston, USA, Kluwer-Nijhoff Publishing.

Smith, V.K. & Kaoru, Y. 1990. Signals or noise? Explaining the variation in recreation benefit estimates. *Am. J. Ag. Econ.*, May 1990, pp. 419–433.

Sorg, C.F. & Loomis, J.B. 1984. *Empirical estimates of amenity forest values: a comparative review*. General Technical Report, RM-107. Fort Collins, USA, Rocky Mountain Forest and Range Experiment Station, Forest Service, USDA.

Steele, J.H. 1991. Marine functional diversity. *Bioscience*, 41: 470–474.

Thaler, R. 1984. Toward a positive theory of consumer choice. *J. Econ. Behav. Org.*, 1: 29–60.

Tietenberg, T.H. 1992. *Innovation in environmental policy: economic and legal aspects of recent developments in liability and enforcement*. Cheltenham, UK, Edward Elgar.

Tobin, G.A. & Newton, T.G. 1986. A theoretical framework of flood induced changes in urban land values. *Wat. Res. Bull.,* 22(1): 67–71.

Tsur, Y. & Dinar, A. 1997. On the relative efficiency of alternative methods for pricing irrigation water and their implementation. *World Bank Econ. Rev.*, 11: 243–262.

Tunstall, S.M., Tapsell, S.M. & Fordham, M. 1994. *Public perception of rivers and flood defence: final report.* R&D Note 444. Bristol, UK, National Rivers Authority.

Turner, R.K. 1993. Sustainable environmental economics and management: principles and practice. London, Belhaven Press.

Turner, R.K. 2000. Integrating natural and socioeconomic science in coastal management. *J. Mar. Sci.*, 25: 447–460.

Turner, R.K. & Dubourg, W.R. 1993. Water resource scarcity: an economic perspective. CSERGE Working Paper PA 93-06. University of East Anglia and University College London, UK, CSERGE.

Turner, R.K. & Jones, T., eds. 1991. *Wetlands, market and intervention failures*. London, Earthscan.

Turner, R.K. & Pearce, D.W. 1993. Sustainable economic development: economic and ethical principles. *In* E.B. Barbier, ed. *Economics and ecology: new frontiers and sustainable development*. London, UK, Chapman and Hall.

Turner, R.K. & Postle, M. 1994. *Valuing water: an economic perspective*. CSERGE working paper WM 94-08. University of East Anglia and University College London, UK, CSERGE.

Turner, R.K., Bateman, I. & Adger, W.N. 2001. *Economics of coastal and water resources: valuing environmental functions.* Dordrecht, The Netherlands, Kluwer.

Turner, R.K., Brouwer, R. & Georgiou, S. 2001. *Ecosystem functions and the implications for economic valuation*. English Nature Research Report No. 441. Peterborough, UK, English Nature.

Turner, R.K., Dent, D. & Hey, R.D. 1983. Valuation of the environmental impact of wetland flood protection and drainage schemes. *Env. Plan. A.*, 15:871–888.

Turner, R.K., van den Bergh, J.C.J.M., Barendregt, A. & Maltby, E. 1997. Ecological-economic analysis of wetlands: science and social science integration. *In* T. Söderquist, ed. *Wetlands: landscape and institutional perspectives*. Proceedings of the 4th workshop of the Global Wetlands Economics Network (GWEN), 16–17 November 1997, Beijer, International Institute of Ecological Economics. Stockholm, The Royal Swedish Academy of Sciences.

Turner, R.K., van den Bergh, J.C.J.M., Söderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E. & van Ierland, E.C. 2000. Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecol. Econ.,* 35(1): 7–23.

UN. 1992. *Report of the United Nations Conference on Environment and Development*. Geneva.

UN. 2002. The Johannesburg Declaration on Sustainable Development. World Summit on Sustainable Development, Johannesburg, 2002.

Van den Bergh, J.C.J.M., Button, K.J., Nijkamp, P. & Pepping, G.C. 1997. *Meta analysis in environmental economics*. Dordrecht, The Netherlands, Kluwer.

Van Kooten, G.C. & Bulte, E.H. 2000. *The economics of nature: managing biological assets*. Malden, USA, Blackwell Publishers.

Van Kooten, G.C. & Schmidtz, A. 1992. Preserving waterfowl habitat on the Canadian prairies: economic incentives versus moral suasion. *Am. J. Ag. Econ.*, 74: 79–89.

Westman, R.E. 1985. *Ecology, impact assessment and environmental planning*. Chichester, UK, Wiley.

Winpenny, J. 1994. *Managing water as an economic resource*. London, Routledge.

Wolf, F.M. 1986. *Meta-analysis*. Beverly Hills, USA; Sage Publications.

World Bank. 1993. *Water resources management.* A World Bank Policy Paper. Washington, DC.

World Bank. 2003. *Water resources sector strategy: strategic directions for World Bank engagement.* Washington, DC.

World Water Assessment Programme. 2001. *Water security: a preliminary assessment of policy progress since Rio*. World Water Assessment Programme.

Young, R.A. 1996. *Measuring economic benefits for water investments and policies*. World Bank Technical Paper No. 338.

Young, R.A. & Gray, S.L. 1972. *Economic value of water: concepts and empirical estimates*. Technical Report to the National Water Commission.

Young, R.A. & Haveman, R.H. 1985. Economics of water resources: a survey. *In* A.V. Kneese & J.L. Sweeney, eds. *Handbook of natural resources and energy economics II*. Amsterdam, The Netherlands, Elsevier Science Publishers.

Annex
Case studies

HEDONIC PRICING: WILLINGNESS TO PAY FOR WATER IN THE PHILIPPINES

Introduction

This study illustrates that it is feasible to use an indirect, non-market valuation technique to estimate the economic benefits that result from improved water supply projects. The hedonic property valuation method is used to determine how imputed household rental values in a large rural area of the Philippines reflect households' WTP for different types of water supply service (private connection in the house, or a tap in the yard). The economic benefits of improved water supplies are likely to be especially large in peri-urban communities where households already purchase the majority of their water from vendors. The economic benefits in rural areas of developing countries where water vending is not present are typically much lower.

Fieldwork and data collection

Data used for the analysis came from a 1978 random survey of 1 903 households in a 14 000 square kilometre area of the Bicol region, one of the poorest parts of the Philippines. The sample was designed to be representative of the region in terms of population and income distribution. The authors used a human capital formation model to estimate the permanent income of each household in the sample, based on all possible sources of cash or 'in-kind' income. These estimates were used to place households into three income categories used for the analysis. Monthly rent was imputed as one percent of the reported value of the dwelling.

Information from the survey was used to describe characteristics of the dwelling, including water source, number of bedrooms, quality of construction materials, and location. Two variables were used to characterise the type of water supply:

1. Households with piped water in the house;
2. Households with a deep-well and water pumped into the house or yard.

The authors hypothesised that these two types of water supply would add to the perceived value of the dwelling relative to a public tap or use of a traditional source of water.

Results of the analysis

The authors estimated households' WTP in terms of the capitalised value of improvements to water supply. A bid-rent function was formulated between the pertinent characteristics of the dwellings (which included the water source, construction materials, number of rooms and lot size) and community, and the payment of more rent. The parameter estimates that this produced are presented in Table A.1, where the coefficients can be interpreted as the marginal WTP for each housing characteristic, assuming that tastes are similar within each of the three income groups. The results of the model (in Table A.1) show that the coefficients of non-water characteristics generally behave as hypothesised.

Households in all income ranges are willing to pay about half of their monthly imputed rent to have piped water in the house supplied by a public system, with a WTP in 1978 for the

TABLE A.1
Results of bid–rent estimations[a]

	Mean hedonic price or discrete bid–rent (in 1978 US$)		
Household income category	**Low income**	**Middle income**	**High income**
Intercept	–25.924 (5.52)	–46.243 (10.87)	–47.321 (11.02)
Piped water in the house	10.427* (1.70)	18.130* (3.85)	15.486* (3.31)
Deep well water into the house or yard, or a yard tap	–2.147 (0.57)	6.948* (2.42)	6.459* (2.25)
Number of bedrooms	2.194 (1.38)	7.967* (6.21)	11.290* (9.77)
Distance to central town	–0.834* (5.81)	0.011 (0.51)	0.396* (2.04)
House materials	9.863* (4.18)	2.734* (5.98)	10.321* (4.97)
Scale parameter		0.044 (123.96)	

[a] Where the dependent variable is imputed monthly rent and *t* statistics are given in parentheses.
* Indicates significance at or above the 10 percent level for a two-tailed test. The model as a whole is significant at better than the one percent level using a likelihood ratio test.

higher income households of US$1.95 per month, US$2.25 for middle-income households, and US$1.41 for low-income households. These amounts are additional to the monthly costs of using these services (including any existing water tariffs). The poorest households are not willing to pay more for water in the yard or house if it is supplied by the household's own well. Middle-income households would pay about US$0.94 per month for the capitalised cost of this option and high-income households would pay about US$0.88 per month.

Discussion

The analysis shows that, in this poor rural area of the Philippines, value is placed on the type of water supply in the housing market and that this is capitalised in the price (imputed rental value) of the house. The authors found high WTP for piped, in-house water supplies for all income groups and somewhat lower WTP for water supplies in the yard.

A project that provided individual house connections would significantly increase wellbeing. However when the authors compared their estimates of households' WTP for water supply improvements with cost estimates for water supply systems in the Philippines, they concluded that WTP was probably not adequate to cover the capital cost of piped water supply either in the house or yard.

North, J. H. and Griffin, C.G. (1993).
Water source as a housing characteristic:
hedonic property valuation and willingness-to-pay for water.
Water Resources Research 29 (7) 1923–1929.

RESIDUAL VALUE: THE VALUE OF NON-IRRIGATION USES OF WATER IN A MULTIPLE-USE IRRIGATION SCHEME IN SRI LANKA

Introduction

This study assesses the relative economic contributions of irrigated agriculture and non-irrigation uses of water in the Kirindi Oya irrigation and settlement project (KOISP) in south eastern Sri Lanka. The residual value approach is used to indicate the importance of the multiple uses of irrigation water to local economies. The study focuses on irrigated paddy production and the non-irrigation use of water in reservoir fisheries.

Agriculture plays a substantial role in the local economy of the Kirindi Oya area, accounting for 55 percent of household income and 75 percent of all employment. Within the agricultural sector, paddy cultivation is the largest single source of income. The study estimated the value of water for paddy cultivation under current and targeted cropping intensities. Though expansion of irrigated paddy production was a primary justification of the KOISP and though inland fisheries make a significant contribution to the local economy, no economic values had previously been determined.

Fieldwork and data collection

The residual valuation methodology requires special care to ensure that all cash and non-cash costs of production are adequately captured. In the production of paddy, particular care was taken to ensure all input costs were included, including non-cash costs such as land, family labour, returns to management (taken to be 5 percent of value of gross output) and depreciation of machinery and equipment. Data were obtained from detailed farm-level cost of production surveys, conducted in the KOISP area. A total of 84 agricultural producers were selected from a stratified random sample of the ten subsystems within the irrigated area.

To value the inland fisheries, data collection was focused on commercial fisheries in three reservoirs within the KOISP area, which account for about 81 percent of the total reservoir surface area of the project. In-depth interviews were conducted with 12 percent of the 157 fisher boats that operated in the three reservoirs, to determine, the type of boat and nets in use, monthly catch data, amount of catch sold or consumed at home, prices received in wholesale and retail markets and detailed cost information.

Results of the analysis

The study obtained values for the use of irrigation water by employing a producer-level profit maximisation model to calculate the value of irrigation water in irrigated paddy production and inland fisheries. The economic return to water was assessed for both of the identified uses of irrigation water, by valuing water in its current use. This was determined as the total value of marketed and non-marketed production less all cash and non-cash.

Irrigated paddy production

The average adjusted yield for the area was 4 728 kg per hectare, and the average farm gate price for paddy was Rs 14 (US$0.2) per kg. The value of output, costs of production and economic returns to water on a per-hectare basis are shown in Table A.1. The total economic return to water for paddy production in the KOISP area in 1999 was estimated at Rs 215 707 (US$3 083).

TABLE A.1
Economic returns to water from irrigated paddy production in KOISP area

	1999 Rs ('000s) /ha
Value of production (consumed in the home and marketed)	65.5
Inputs:	
Land	10.3
Materials	11.4
Labour	15.7
Machinery	7.2
Operating interest	0.8
Economic returns to water	16.7

TABLE A.2
Economic returns from inland fisheries in three reservoirs in the KOISP area

	1999 Rs ('000s)
Value of produce (consumed in the home and marketed)	24.2
Costs of production (boats, nets and other)	7.9
Economic return per trip	0.6
Economic return per boat	16.3
Economic return to inland fisheries in the three reservoirs	38.1 – 39.6

Inland fisheries production

The productivity of the fisheries was measured as the catch per boat trip, known as catch per unit effort. (CPUE). The average annual yield for each reservoir was estimated according to the CPUE for each surveyed boat, the number of trips per month for each boat and the estimated number of boats on each reservoir. From the survey data, an average CPUE of 35 kg was determined, with four percent of the catch kept for home consumption. Table A.2 shows the average monthly value of production, costs and economic returns for fishing in the three reservoirs in KOISP area.

This study estimated that the economic value of returns to fisheries in the three reservoirs in the KOISP area was Rs 38 087 – 39 604 (US$544 000 – 566 000) in 1999.

Discussion

An improved understanding of the relative economic contributions of multiple uses of irrigation water is crucial to the design and implementation of effective water management strategies. The economic importance of fisheries was demonstrated in the study: total economic returns to fisheries were about 18 percent of the total economic returns to water from irrigated paddy production.

Renwick, M.E. (2001)
Valuing water in irrigated agricultural and reservoir fisheries:
a multiple-use irrigation system in Sri Lanka
Research Report 51. Colombo, Sri Lanka
International Water Management Institute

CONTINGENT VALUATION: WATER QUALITY IN THE PHILIPPINES

Introduction

This study examines the magnitude of household demand for environmental quality improvement in the context of a specific proposal: the clean up of the river and sea near Davao City, in the Philippines. A contingent valuation survey was carried out in 1992 to determine how much households in Davao City were willing to pay for improved water quality in nearby rivers and the sea. These improvements would result in increased recreational opportunities and possible public health improvements for residents of Davao City.

In 1992, the City Health Department found very high levels of faecal coliforms and pathogens in water off Times Beach, a popular beach near Davao city. Prior to the health warnings that were issued, thousands of residents of Davao City used the local beaches for picnicking and swimming at weekends.

Fieldwork and data collection

A total of 581 in-person interviews were completed with respondents throughout Davao City about a city-wide plan to improve water quality. The overall response rate was 65 percent; 32 percent of the households in the sample could not be located by enumerators and only three percent of the total number of households in the sample refused to be interviewed. Extensive pre-testing of the household questionnaire was undertaken with focus groups (to discuss water pollution problems) and a pilot survey of about 200 households before the questionnaire was finalised.

All of the versions of the survey instrument covered five basic areas:

1. the household's existing water and sanitation situation;
2. the household's level of satisfaction with these services;
3. the household's priorities regarding environmental improvements, use of beaches near Davao City, knowledge and level of concern about water pollution problems;
4. WTP for improvements in water pollution problems;
5. the household's socioeconomic characteristics and housing conditions.

The contingent valuation survey used a referendum format to measure household demand for water quality improvements. Respondents were asked to vote on whether they would support a hypothetical city-wide plan to clean up the rivers and sea and make Times Beach safe again for swimming. Each household would be required to pay a monthly fee and industries would also do their fair share to reduce waste water discharges to the river: different monthly fees were randomly assigned to individual households.

Results of the analysis

The authors estimated WTP for improved water quality through the statistical analysis of responses to the randomly assigned monthly fees. The results show that household WTP for water quality improvements was low, both in absolute terms and as a percentage of income, and 15 percent of the respondents refused to pay anything at all.

Further analysis of the data showed that respondents considered their personal circumstances and budget constraints when answering the WTP questions: responses to the WTP question were dependent on the price offered. The mean monthly household income in Davao City was about 5 100 pesos (US$204) in 1992, and no respondent voted for the plan at 200 pesos per month. Households with higher incomes were willing to pay more for environmental improvements than households with lower incomes and households that used Times Beach were willing to pay about 30 pesos per month (about 0.6 percent of mean household income); while non-users were willing to pay almost nothing.

Low estimated of household WTP was consistent with information collected in the household survey about households' social and environmental attitudes and priorities,

- less than ten percent of households viewed water pollution as a priority for government action,
- 80 percent of households had not gone swimming at Times Beach since the public health alert,
- ten percent of households did not eat seaweed or shellfish collected from the sea near Davao City because of concerns about contamination.

Discussion

The analyses of the data collected in this contingent valuation survey in Davao City showed that household demand for water pollution control was not a high priority of residents of Davao City. Households were willing to pay very little of their income for water quality improvements and beach clean up, both in absolute terms and as a percent of their income.

As households' WTP for water quality improvements in Davao City is much lower than the costs of providing such improvements, and because most households feel that other environmental problems such as deforestation and poor solid waste collection and disposal deserve higher priority, the appropriate strategy appeared to be to wait until incomes are higher and WTP has risen before embarking on a large water pollution control investment program.

Choe, K. Whittington, D. and Lauria, D.T. (1995)
Household demand for surface water quality improvements in the Philippines:
a case study of Davao City
The Environment Department
World Bank
Washington DC

PRODUCTION FUNCTION APPROACH: THE VALUE OF THE GROUNDWATER RECHARGE FUNCTION IN NIGERIAN WETLANDS

Introduction

This study applies the production function approach to estimate the value of the groundwater recharge function in the Hadejia-Nguru wetlands of northern Nigeria. In an area which receives 80 percent of its annual rainfall in two months, the wetland areas (known as '*fadamas*'), play an important role in the recharge of underlying shallow aquifers which are used for domestic and irrigation water supplies in the dry season.

The production function approach valued groundwater used in dry-season agriculture as an environmental input. Consequently, it provides only a partial valuation of the recharge function. The study focuses on dry season irrigation that is dependent on the use of pump irrigation to abstract water from shallow aquifers, ensuring a more secure and year round water supply for the crops. A drop in groundwater levels of 1 m, from 7m to 6m in depth from the surface, is hypothesised resulting from reduced recharge due to planned water diversion schemes upstream of the wetlands.

Fieldwork and data collection

Production data on the crops grown in the Madachi *fadama* was based on field surveys of 37 farms from four villages in 1995–1996. In the area, 309 operational tubewells were used to tap into the shallow aquifers to provide water for irrigation. The total area of the Madachi *fadama* and its' influence area was estimated to be around 6 600 ha. The villages that were surveyed were believed to be representative of the area, comprising a mixture of large, medium and small farmers. The main cash crops grown were wheat, tomatoes and pepper, and okra and eggplants were grown for home consumption.

Financial prices for the outputs were estimated from market surveys conducted in 1995–1996, and farm surveys of farmgate prices received by farmers. The per hectare value of irrigated agriculture in the Madachi area was calculated to be 36 308 Naira per hectare (US$412.5), with an total estimated economic value of 239 million Naira (US$2.7 million).

Results of the analysis

Production functions were estimated separately for the production of wheat and vegetables, due to the different nature of irrigation, fertiliser applications and other farming decisions. The functions were defined such that output was dependent on the following inputs: land, labour, seeds, fertiliser and water. The authors used a log-linear functional form for the estimation as it enabled variation in the water input variable whilst all other inputs were held constant. The parameter estimates of these production functions (shown in Table A.1) were used to calculate the associated change in productivity in response to the fall in recharge levels.

The average and total change in welfare was measured for a drop in groundwater levels to 7m, as shown in Table A.2. It can be seen that the welfare changes associated with groundwater loss on wheat production are very high.

This study shows that a drop in ground water levels of one metre would cause a decrease in the welfare of 2 863 Naira (US$32.5) for each vegetable farmer and 29 110 Naira (US$331) for each wheat farmer. Based on an average household income of 3 155 Naira per month, the estimated welfare loss would account for approximately 8 percent of annual income for vegetable farmers and 77 percent for wheat farmers. The total loss associated with a one

TABLE A.1
Log-linear production functions for wheat and vegetables[a]

	Wheat production	Vegetable production
Variable:		
Log Land	0.38 (1.442)	0.231 (0.823)
Log labour	-0.024 (0.156)	0.585[c] (2.206)
Log seeds	0.026 (0.33)	-
Log fertiliser	0.47[b] (2.71)	0.593[b] (2.827)
Log water	0.6885[d] (1.881)	0.4268[c] (2.437)
Constant	3.4[c] (2.39)	3.13[b] (11.439)
Adjusted R^2	0.9	0.66
F Statistic	37.49	18.88
Breusch-Pagan χ^2	18.27 (d. f. 5)	4.24 (d.f. 4)
Observations	21	37

[a] t-statistics in parenthesis. [b] 2% significance level. [c] 5% significance level. [d] 10% significance level.

TABLE A.2
Impact on welfare for farmers in Madachi of a fall in groundwater levels of one metre

Crop	Total change in welfare (Naira)	Average change in welfare per ha (Naira)	Average change in welfare per farmer (Naira)	Total loss for Madachi farmers (Naira)
Wheat	550 320	54 372	2 863	383 642
Vegetables	130 659	4 399	29 110	5 094 296

metre change in the naturally recharged groundwater levels is estimates as 5 477 938 Naira (US$ 62 249) for the influence area of the Madachi *fadama*.

Discussion

The analysis within this study shows that groundwater recharge is of considerable importance to wetland agriculture in Madachi. Reduced recharge would lower levels of groundwater, resulting in high welfare losses for the population of the floodplains. The Madachi *fadama* is regularly inundated and has good groundwater stocks; it is likely that effects would be more devastating in areas with less reliable flooding. In the face of this uncertainty, the value of shallow aquifers in irrigated agriculture and consequently the value of the recharge function of wetlands must be recognised by policies that affect hydrological conditions within the floodplain.

Acharya, G. and Barbier, E.B. (2000)
Valuing groundwater recharge through agricultural production
in the Hadejia-Nguru wetlands in northern Nigeria
Agricultural Economics 22 247-259

OVERVIEW OF STUDIES

The overview of studies presented here, like previous reviews, mainly considers examples from developed countries though a number of developing country studies are included. The review classifies the studies in terms of the goods and services provided by the water resource wherever possible. Due to the multipurpose nature of many studies, in many cases it is not possible to specify this precisely, if at all. Hence many of the studies are listed in terms of the more general socio-economic uses and benefits that they consider.

The overview uses the following categories of beneficial use and valuation techniques:

Beneficial use

Agricultural supply
Aquaculture
Habitat
Commercial fishing
Flooding
Freshwater replenishment
Groundwater recharge
Hydropower generation
Industrial supply
Migration of aquatic organisms
Municipal and domestic water supply
Navigation
Recreation
Rare or endangered species
Shellfish harvesting
Spawning and/or early development
Water quality
Non-use value
TEV
Amenity value

Valuation techniques

SM= Simulation Models (Residual imputation or variant)
OM= Optimisation Models (Residual imputation or variant)
DF= Damage cost Approach
MV= Market based
RC= Replacement Cost Method
AB= Averting Behaviour Approach
DR= Dose Response
RUM= Random Utility Model
TC = Travel Cost
CV= Contingent Valuation
HP= Hedonic Pricing

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Abdalla , C.W., B.A. Roach and D.J. Epp.	''Valuing Environmental Quality Changes Using Averting Expenditures: An Application to Groundwater Contamination,''	*Land Economics,* 68(2), 163-169.	1992	Groundwater quality. Function-Use: groundwater recharge.	AB	1989	Dollars per household per week.	Value is the average weekly increase in averting expenditures per household in response to TCE contamination: 0.4.	groundwater	local	USA
Adamowicz, W., G. D. Garrod and K.G. Willis.	''Estimating the Passive Use Benefits of Britain's Inland Waterways,''	Centre for Rural Economy Research Report, University of Newcastle upon Tyne.	1995	WTP to preserve canal network in a state fit to support boating activities and maintaining towpath facilities. Function-Use: Recreation.	CV		Pounds per British household per year.	8	canal	national	United Kingdom
Amundsen, B.-T.	''Recreational and non-use value of the fish population in Oslomarka,''	M.Sc. thesis, Agricultural University of Norway, 89 pp.	1987	Non-use value of freshwater fish stocks. Function-Use: Non-use value.	CV		NOK per household per year.	WTP to avoid an unspecified ''reduction'' of the current trout stocks in Oslomarka lakes: 375 (both use and non-use values).	lakes	local	Norway
Anderson, R. W.	''Estimating the Recreation Benefit from Large Inland Reservoirs,''	In Recreational Economics and Analysis (ed. G. Searle), Longman, Harlow.	1975	Total annual recreation benefits. Function-Use: Recreation.	TC		Million pounds.	2.3-2.6	reservoir	regional	United Kingdom
Baan, P.J.A.	''Benefits of environmental water policy,''	Ministry of Public Housing, Physical Planning and Environmental Management: Leidschendam.	1983	Overview of potential benefits of a maximum improvement in water quality of Dutch surface waters, related to the type of pollution. Function-Use: Water Quality.	DR		Dflm per year.	Total annual benefits of maximum surface water improvement: 198-556.	Surface water	national	The Netherlands
Barnard, J.R.	"Externalities from Urban Growth: The Case of Increased Storm Runoff and Flooding,''	*Land Economics*, 54 (3), 298-315.	1978	Increased frequency and magnitude of flooding due to urban growth, and its impact on urban residential property values Function-Use: Flooding.	HP	1973	Dollars, per property for properties subject to flood hazard.	727	streams	local	USA

Bibliographic study characteristics	**Study characteristics**										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Barrett, C.J.	"A Comparison of the CVM and Conjoint Analysis: a Groundwater Case Study,"	Thesis, Department of Resource Economics, University of Massachusetts, USA.	1997	Comparing CVM and conjoint analysis estimates of groundwater protection benefits. Function-Use: Municipal and Domestic Water Supply.	CV	1995	In dollars, per year and per household.	(1): ordered logistic procedure/Tobit WTP (a. aquifer protection district): \$349.88/\$323.58; WTP (b. water treatment plant): \$195.10/ \$174.56; WTP (c. private filter on tap): \$306.44/\$300.48; WTP (d. bottled water): \$65.62/\$58.45.	Groundwater	local	USA
Bateman, I., *et al*.	"A Contingent Valuation Study of the Norfolk Broads,"	Report to the National Rivers Authority.	1992	Average WTP to preserve present landscape. Function-Use: Habitat, Non-use value.	CV		English pounds per person per year	Use values: 78-105 Non-use values of local population: 14.7 Non-use values of the rest of GB: 4.8	broads	regional	United Kingdom
Bateman, I.J., I.H. Langford, R.K. Turner, K.G. Willis, and G.D. Garrod.	"Elicitation and Truncation Effects in Contingent Valuation Studies,"	*Ecological Economics,*12, 161-179.	1995	Analysis of methods of eliciting WTP in a CV study of flood protection of a UK wetland. Function-Use: Flooding, Recreation, Habitat.	CV	1991, August, September.	English pounds/ year	67.19	wetland	local	United Kingdom
Bergland, O., K. Magnussen, and S. Navrud.	"Benefit Transfer: Testing for Accuracy and Reliability,"	Discussion Paper No. D-03/1995, Department of Economics and Social Sciences, The Agricultural University of Norway, As, Norway.	1995	A direct test of benefit transfer approach by conducting two similar contingent valuation studies of water quality improvements in two different Norwegian water courses. Function-Use: Recreation, Water quality.	CV	1995	Norwegian Kroner	2983.96; 3144.77.	streams	local	Norway
Bergstrom, J.C. and J.H. Dorfman.	"Commodity Information and Willingness-to-Pay for Groundwater Quality Protection,"	*Review of Agricultural Economics*, 16, 413-425.	1994	Information provision effects on the economic value of groundwater quality. Function-Use: Agricultural Supply, Municipal and Domestic Water Supply.	CV	m.d.	Dollars, per year and per person.	320	groundwater	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Bergstrom, J.C., J.R. Stoll, J.P. Titre, and V.L. Wright.	"Economic Value of Wetlands-Based Recreation,"	*Ecological Economics,* 2, 129-147.	1990	Wetlands loss and recreational value. Function-Use: Recreation.	CV	1986-1987.	Dollars, per user.	360	wetland	regional	USA
Bergstrom, J.C., J.R. Stoll, J.P. Titre, and V.L. Wright.	"Economic Value of Wetlands-Based Recreation,"	*Ecological Economics,* 2, 129-147.	1990	Wetlands loss and recreational value. Function-Use: Recreation.	CV	1986-1987.	Dollars, per user.	360	wetland	regional	USA
Berrens, R.P., P. Ganderton, and C.L. Silva.	"Valuing the Protection of Minimum Instream Flows in New Mexico,"	*Journal of Agricultural and Resource Economics*, 21 (2), 294-309.	1996	Non-market benefits associated with protecting minimum instream flows. Function-Use: Recreation, Municipal and Domestic Water Supply.	CV	1995	Dollars, per household and per year.	28.73 ; and 89.68 .	river	regional	USA
Bishop, R.C., K.J. Boyle, and M.P. Welsh.	"Toward Total Economic Evaluation of Great Lakes Fishery Resources,"	*Transactions of the American Fisheries Society*, 116, 339-345.	1987	Indirect and intrinsic (i.e. other than sport and commercial exploitation) values associated with Great Lakes fishery resources. Function-Use: Recreation, Habitat.	CV	1984	Dollars, per year.	5.66; and 4.16.	lake	regional	USA
Bjonback, R.D.	"The Value of Water-Based Recreation Losses Associated With Drought: The Case of Lake Diefenbaker 1984,"	paper presented at the Canadian Hydrology Symposium (CHS: 86), Associate Committee on Hydrology, National Research Council of Canada, June 3-6, 1986, Regina, Saskatchewan, Canada.	1986	Water-based recreational losses associated with extremely low lake levels experienced during the 1984 summer drought. Function-Use: Agricultural Supply, Municipal and Domestic Water Supply, Recreation, Hydopower Generation.	CV	1984	US$ Per day, and per season	1.97	lake	regional	Canada
Blomquist, G.	"Valuing Urban Lakeview Amenities Using Implicit and Contingent Markets,"	*Urban Studies*, 25 (4), 333-340.	1988	Comparison of hedonic price and contingent valuation approaches for two view-related amenities, based on a single group of people. Function-Use: Recreation.	CV	1981	US$ per month.	147.06.	lake	regional	USA

Bibliographic study characteristics	Study Characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Blomquist, G.	"Valuing Urban Lakeview Amenities Using Implicit and Contingent Markets,"	*Urban Studies*, 25 (4), 333-340.	1988	Comparison of hedonic price and contingent valuation approaches for two view-related amenities, based on a single group of people. Function-Use: Recreation.	HP	1981	US$ per month.	31.85.	lake	regional	USA
Boadu, F.O.	"Contingent Valuation for Household Water in Rural Ghana,"	*Journal of Agricultural Economics*, 43, 458-465.	1992	This study uses an iterative bidding approach to examine the relationship between selected socioeconomic characteristics of households and their willingness to pay for water. Function-Use: Municipal and Domestic Water Supply.	CV	1992 ?	US$ per month, per person.	They described the WTP as: Household Bid for Public Standpipe (A), and Household Bid For Private Connection (B). A1) 1,064; A2) 0,986; A3) 1,183; A4) 1,594; A5) 1,775; A6) 0,675; A7) 1,211; B2) 4,735; B3) 11,727; B4) 9,725; B5) 8,096; B6) 5,718.	NO RIVER, JUST groundwater	regional	Ghana
Bockstael, N.E., W.M. Hanemann, and C.L. Kling.	"Estimating the Value of Water Quality Improvements in a Recreational Demand Framework,"	Water Resources Research, 23 (5), 951-960.	1987	To discuss some issues which arise in the application of recreation demand models to the valuation of environmental quality changes such as water quality improvements. Function-Use: Recreation.	TC	1975	In dollars, per visit, per choice occasion and per season.	DCM: average compensating variation estimates of 10% reduction in pollutants at all sites: oil: per choice/per season (in $): 0.05/0.96; Chemical Oxygen Demand (COD): 0.12/2.65; fecal coliform: 0.02/0.19. 30% Reduction: oil: 0.20/4.66; COD: 0.29/7.15; fecal coliform: 0.12/2.85; all together: 050/12.04, this compared to 30% reduction at downtown Boston beaches: 0.27/6.13. HTCM: CS for a 10% change in COD of $450/visit.	Beaches and lake	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Bonnieux, F., J.P. Boude, C. Guerrier and A. Richard.	''La pêche sportive du saumon et de la truite de mer en Basse-Normandie - Analyse économique" (Angling for salmon and sea trout in Normandie - An economic analysis). In French.	Working paper CSP, INRA-ENSA - Rennes.	1991	The value of sports fishing in Western France. Function-Use: Recreation.	CV	1990	FF per person. FF per person annually.	(a. Salmon angling; angling without catch limitation after June 1st: 103; (b. Sea-trout angling; WTP to participate in a fund to buy 5 km, where anglers would be entitled to fish freely for three years: 578.	rivers	regional	France
Booker, J.F. and R.A. Young.	'' Modeling Intrastate and Interstate Markets for Colorado River Water Resources,"	*Journal of Environmental Economics and Management*, 26(1), 66-87.	1994	Agricultural, recreational, and municipal water uses. Function-Use: Agricultural Supply.	OM		Dollars millions per year. Dollars per acre foot.	(a. Value represents annual consumption benefits for water under intra- and inter state transfers based on consumption value and salinity reduction: 1151; (b. Estimate reflects the value of water from Upper Colorado River used for consumptive purposes in a scenario where allocations are based on maximizing consumptive and nonconsumptive use benefits: 96.	river	regional	USA
Bowker, J.M., D.B.K. English, and J.A. Donovan.	"Toward a Value for Guided Rafting on Southern Rivers,"	*Journal of Agricultural and Applied Economics*, 28 (2), 423-432.	1996	To estimate the per trip consumer surplus for guided whitewater rafting on two rivers in Carolina. Function-Use: Recreation.	TC	1993	In dollars, per trip and per person.	Mean CS CR: reported costs: 0% wage/25%/50% (in $): 139.56/192.66/ 286.22; imputed costs: 119.16/ 181.00/270.94. Mean CS NR: reported costs: 133.73/ 136.91/ 191.29; imputed costs: 89.03/124.70/182.50. Mean TCOST CR: reported costs: 103.34/157.45/213.30; imputed costs: 117.00/ 171.40/227.25. Mean TCOST NR: reported costs: 43.62/ 73.75/103.85; imputed costs: 51.31/81.29/111.39.	river	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Boxall, P.C., D.O. Watson, and J. Englin.	"Backcountry Recreationists' Valuation of Forest and Park Management Features in Wilderness Parks of the Western Canadian Shield,"	*Canadian Journal of Forest Research*, 26 (6), 982-990.	1996	To report on the influence of forest characteristics, levels of development and recreation management features on recreation site choice and valuation. Function-Use: Recreation.	TC	1993	In dollars, per visit and per year.	Mean per trip welfare measures ($/ha): Mature jack pine: Tulabi Lake/ Seagrim Lake/Rabbit River/ Beresford Lake/Manigotagan River: 0.241/0.048/ 0.049/<0.001/0.006; Mature black spruce: -0.020/-0.009/-0.008/-0.002/ -0.008; White spruce: -/-/0.025/0.006/ -; Aspen: -0.021/-/-/-0.001/-0.001; Cottage developments: -4.752/-1.745/-2.059/0.557/ 0.733; Additional portages: -0.423/-0.197/-0.168/-0.015/-0.020. Mean trip welfare impacts of severe fires in 1993: Maskwa Lake burn: change to base/ to mature forest (in $/ha): 3.435/5.878; Long Lake burn: 2.905/21.761.	lake, river	regional	Canada
Boyle, K.J. and R.C. Bishop.	"Welfare Measurements Using Contingent Valuation: A Comparison of Techniques,"	*American Journal of Agricultural Economics*, 70, 20-28.	1988	To compare three commonly used techniques of asking the CV-question. Function-Use: Recreation, Habitat.	CV	1982	In dollars, per year and per household.	Iterative bidding: $29.82; payment card: $29.36; dichotomous choice: $18.88.	river	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Boyle, K.J., M.P. Welsh, and R.C. Bishop.	"The Role of Question Order and Respondent Experience in Contingent-Valuation Studies,"	*Journal of Environmental Economics and Management*, 25, 80-99.	1993	The objective was to estimate a statistical relationship between Hicksian surplus for white-water trips and average daily Colorado River flows between 5,000 and 40,000 cfs. Function-Use: Recreation.	CV	1986	In dollars per trip.	Commercial passengers' actual-trip Hicksian surplus rises from $127 per trip at 5000 cfs to a maximum of $888 per trip (at 33000 cfs) and declines to $842 per trip (40000 cfs). Private boaters' actual-trip Hicksian surplus estimates rise from $111 (5000) to a maximum of $637 per trip (28000) and decline to $455 per trip (40000). Scenario estimates for commercial passengers rise from $205 per trip (5000) to a maximum of $760 per trip (26000) and decline to $479 per trip (40000). Private boater scenario estimates rise from $315 per trip (5000) to a maximum of $623 per trip (25000) and decline to $461 per trip (40000).	River	regional	USA
Breaux, A. S. Faber and J. Day.	"Using Natural Coastal Wetlands Systems for Wastewater Treatment: An Economic Benefit Analysis,"	*Journal of Environmental Management*, 44, 285-291.	1995	Wetland value for waste treatment use. Function-Use: Industrial Supply.	RC		Dollars per year per firm. Dollars per acre per 25 years.	(a. Value represents annualized cost savings to the firm from using a more extensive discharge dispersion system on a 6.2 acre wetlands site: 26700; (b. Estimate is wetland's treatment value per acre, including all plants' capitalized cost savings and based on treatment systems with a 25-year lifetime (low estimate): 6231.	wetlands	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Broadhead, C., J.P. Amigues, B. Desaigues, and J. Keith.	"Riparian Zone Protection: The Use of the Willingness to Accept Format (WTA) in a Contingent Valuation Study,"	paper presented at the World Congress of Environmental and Resource Economists in Venice, Italy.	1998	In 1997, a study was financed by the French Ministry of Environment to evaluate the costs of preserving riparian habitat on the banks of the Garonne River. The CVM was used to study households that currently own land on the banks of the river. More precisely, a WTA was used to estimate the loss to owners for no longer being able to farm riverbank areas activity. Results of this study are reported and analyzed in this paper. Function-Use: Agricultural Supply.	CV	1997	FF/ha/year	Mean WTA for program 1373FF/ha.	River	regional	France
Brouwer, R., I.H. Langford, I.J. Bateman, T.C. Crowards and R.K. Turner.	"A meta-analysis of wetland contingent valuation studies,"	CSERGE Working Paper GEC 97-20.	1997	30 studies from USA, UK and the rest of Europe / meta analysis. Mean WTP including indirect use and non-use values. Function-Use: Non-use Value, Habitat, Recreation, Flooding.	CV		Pounds per household per year.	(a. average for USA: 47; (b. average for the UK: 17; (c. average for the rest of Europe: 15.	Surface water	national	USA, Europe
Brouwer, R. and L.H.G. Slangen.	"Contingent Valuation of the Public Benefits of Agricultural Wildlife Management: The Case of Dutch Peat Meadow Land,"	*European Review of Agricultural Economics*, 25, 53-72.	1998	To provide a conservative estimate of the public benefits of agricultural wildlife management on Dutch peat meadow land and to provide a monetary estimate of the public benefits of management agreements. Function-Use: Habitat, Rare or Endangered Species.	CV	1994	Dutch guilders and years.	WTP: South Holland/ Friesland/Limburg/ total: 131.4/113.6/64.5/ 124.5;	ditch	regional	Netherlands

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Brown, T.C. and J.W. Duffield.	"Testing Part-Whole Valuation Effects in Contingent Valuation of Instream Flow Protection,"	*Water Resources Research*, 31 (9), 2341-2351.	1995	This study examines the implications of consumtion theory for part-whole valuation experiments. Function-Use: Recreation.	CV	1989	Dollars, years and per river.	Sample means: number of rivers protected by trust: 2.350; distance of respondent home from river(s) to be protected: 159.342; gender dummy (1= male): 0.695; dummy with value 1 if visited this (any of these) river(s) in last three years: 0.518.	river	regional	USA
Brown, T.C., B.L. Harding and E.A. Payton.	''Marginal Economic Value of Streamflow: A Case Study for the Colorado River Basin,"	*Water Resources Research*, 6(12), 2845-2859.	1990	River instream flows. Function-Use: Agricultural Supply.	MV	1985	Dollars per acre foot.	(a. Reported value is per acre foot benefits of stream increase for consumptive uses. Value is based on the consumptive use level of 1990 with lower target storage levels: 14.25; (b. Reported value is per acre foot benefits of stream increase for consumptive uses. Value is based on the consumptive use level of 1990: 6.96.	river	regional	USA
Butcher, W.R., N.K. Whittlesey and J.F. Osborn.	''Economic Values of Water in a Systems Context,"	Report prepared for National Water Commission. Report #NWC-SBS-72-048.	1972	Agricultural use for water. Function-Use: Agricultural Supply.	OM		Dollars per acre foot.	(a. Average value of water per acre foot for 7,682 acres of irrigated water for sweet corn production is reported: 35.76; (b. Marginal value of water per acre foot on 15,640 acres of irrigated land for hops production is reported: 3.24.	river	regional	USA
Carlos, C.	"What is Town Water Worth?,"	*Australian Journal of Soil and Water Conservation*, 4 (3), 32-36.	1991	To answer the question: What is town water worth? Function-Use: Municipal and Domestic Water Supply.	CV	1991	In dollars, per year and per household.	First bid: $24.33; second bid: $42.21. The average value respondents were WTP was $39 after being informed about the state of the catchment.	River	catchment	Australia
Carlsen, A.J.	''Economic valuation of hydroelectric power production and salmon fishing,"	In Carlsen, A.J. (ed.) 1987: Proceedings. UNESCO Symposium on Decision Making in Water Resources Planning, May 5-7 1986, Oslo; 173-82.	1985	Non-use values of freshwater fish stocks. Function-Use: Hydropower Generation, Recreation, Non-use Value.	CV		NOK per household per year.	WTP to avoid ''some" and ''considerable" reductions in the salmon stock in River Numedalslågen: 43-88.	river	local	Norway

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Carson, R.T. and R.C. Mitchell.	"Valuing Drinking Water Risk Reductions Using the Contingent Valuation Method : A Methodological Study of Risks from THM and Giardia,"	Working paper, prepared for the U.S. Environmental Protection Agency under Cooperative Agreement, Washington D.C., USA	1986	To measure the benefits of mortality and morbidity drinking water risk reductions. Function-Use: Municipal and Domestic Water Supply.	CV	1985	In dollars, per year and per household.	Version A: risk improvement: 0.04 (mortality risk per 100,000): mean/ 5% trimmed mean/ adjusted mean (in $): 3.78/1.13/ 2.86; 0.43: 11.37/8.30/ 9.19; 1.33: 23.73/18.99/ 20.49.	lake	regional	USA
Carson, R.T. and R.C. Mitchell.	"The Value of Clean Water: The Public's Willingness to Pay for Boatable, Fishable, and Swimmable Quality Water,"	*Water Resources Research*, 29 (7), 2445-2454.	1993	national benefits freshwater pollution control (Clean Water Act) Function-Use: Recreation.	CV	1983	US$ per year, per household.	242	catchment	national	USA
Carson, R.T., L. Wilks and D. Imber.	"Valuing the Preservation of Australia's Kakadu Conservation Zone,"	*Oxford Economic Papers*, 46(5),727-749.	1994	Preservation value of a conservation zone. Function-Use: Habitat.	CV	1990	Australian dollar million per year. Australian dollar million per year per person.	(a. Value represents a conservative estimate of the aggregate annual WTP for preserving the KCZ: 435; (b. Value represents the sample median annual WTP per person to avoid the major impact scenario (for total national sample). The major impact scenario is designed to describe a realistic worst case from mining operations in the KCZ: 143.26.	wetland	local	Australia
Caudill, J.D. and J.P. Hoehn.	"The Economic Valuation of Groundwater Pollution Policies: The Role of Subjective Risk Perceptions,"	Working Paper No. 92-11, Department of Agricultural Economics, Michigan State University, USA.	1992	To estimate the statewide benefits of clean groundwater and well water for Michigan. Function-Use: Municipal and Domestic Water Supply.	CV	1990	In dollars, per year and per household.	Open-ended means: rural: $43 to $465/HH/ year; urban: $34 to $69/ HH/year.	Groundwater	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Chatterjee, B., R.E. Howitt and R.J. Sexton.	"The Optimal Joint Provision of Water for Irrigation and Hydropower,"	*Journal of Environmental Economics and Management*, 36, 295-313.	1998	Water in agriculture and power production. Function-Use: Agricultural Supply.	OM	1988	Dollars thousands Dollars per megawatt of electricity.	(a. Reported value is the change in revenues from agriculture and power from base levels during high flow year assuming optimal groundwater pumping: 586; (b. Value is the average value per megawatt generated from hydropower in a high-flow year assuming optimal groundwater pumping: 53.22.	ground and surface water	local	USA
Cho, Y. and K.W. Easter.	"How Much Would Minnesotans Pay To Improve Their Drinking Water?,"	*Minnesota Agricultural Economist*, 685, 3-7.	1996	assessment consumers willingness to pay for improving quality drinking water. Function-Use: Municipal and Domestic Water Supply.	CV	1995	US$ annual, Per household	4.82	groundwater	regional	USA
Choe, K., D. Whittington, and D.T. Lauria.	"The Economic Benefits of Surface Water Quality Improvements in Developing Countries: A Case Study of Davao, Phillippines,"	*Land Economics*, 72 (4), 519-537.	1996	value of improving water quality of nearby rivers and sea Function-Use: Recreation.	CV	1992	pesos/dollar per month per household and per improvement	37	river, sea	regional	Philippines
Clayton, C. and R. Mendelsohn.	"The Value of Watchable Wildlife: A Case Study of McNeil River,"	*Journal of Environmental Management*, 39, 101-106.	1993	User value of a bear-watching game sanctuary. Function-Use: Recreation.	CV	1990	Dollars per person.	Value is mean WTP calculated from adjusted sample; sample was asked for their willingness to pay for a permit to the McNeil River when transportation costs were $100 to $300 higher than what had been paid: 277.	River	local	USA
Clemons, R. and A.R. Collins.	"Contingent Valuation of Protecting Groundwater Quality by a Wellhead Protection Program,"	Paper Submitted to the AAEA Annual Meeting, Indianopolis, USA.	1995	Estimate the benefits of a Wellhead Protection Program against contamination of water sources. Function-Use: Municipal and Domestic Water Supply.	CV	1995	dollars per quarter per protection program	5.25	groundwater	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Cocker, A. *et al*.	''An evaluation of the recreational and amenity benefits of a flood alleviation scheme for Maidenhead,"	Flood Hazard Research Centre, Enfield.	1989	Recreation value of environmental improvements to a river corridor. Function-Use: Recreation.	CV		Pounds per annum per household.	WTP: 13.9	river	local	United Kingdom
Coelli, T., J. Lloyd-Smith, D. Morrison, and J. Thomas.	"Hedonic Pricing for a Cost Benefit Analysis of a Public Water Supply Scheme,"	*The Austrialian Journal of Agricultural Economics*, 35 (1), 1-20.	1991	Benefits of Comprehensive Water Supply Scheme (a network of pipelines, build during the 1950s and 60s to provide water to many farms in the central wheatbelt of Western Australia). Function-Use: Agricultural Supply, Municipal and Domestic Water Supply.	HP	1989	Australian Dollars. Per hectare	18.44 per hectare (North East), 77.39 (Lakes Districts)	pipeline system in region in South Western Australia	regional	Australia
Connelly, N.A. and T.L. Brown.	"Net Economic Value of the Freshwater Recreational Fisheries of New York,"	*Transactions of the American Fisheries Society*, 120, 770-775.	1991	Recreational value of freshwater fisheries. Function-Use: Recreation.	CV	1988	US$ per person, per day	15.87	lake, river	regional	USA
Cooper, J. and J.B. Loomis.	"Testing whether Waterfowl Hunting Benefits Increase with Greater Water Deliveries to Wetlands,"	*Environmental and Resource Economics*, 3(6), 545-561.	1993	Impact on recreational waterfowl hunting benefits of an increase in refuge water supplies to levels necessary for biologically optimal refuge management Function-Use: Recreation.	TC	1990	US$ per acre-foot of additional water supply	0.93 -- 20.40 (OLS), 0.64 -- 14.05 (Poisson)	wetlands	regional	USA
Cooper, J.C.	"Using the Travel Cost Method to Link Waterfowl Hunting to Agricultural Activities,"	*Cahiers d'Economie et Sociologie Rurales*, 36, 5-26.	1995	Impact of contaminated irrigation run-off on waterfowl hunting benefits. Function-Use: Recreation, Agricultural Supply.	TC	1988	US$ per hunter day and total for Kesterson	55.41	wetlands	regional	USA
Cooper, J.C.	"Combining Actual and Contingent Behavior Data to Model Farmer Adoption of Water Quality Protection Practices,"	*Journal of Agricultural and Resource Economics,* 22 (1), 30-43.	1997	Estimates the minimum incentive payments a farmer would accept in order to adopt more environmentally friendly 'best management practices' (BMPs). Function-Use: Agricultural Supply.	CV	1992	US$ per acre	m.d.	surface- and groundwater	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Cordell, H.K. and J.C. Bergstrom.	"Comparison of Recreation Use Values Among Alternative Reservoir Water Level Management Scenarios,"	*Water Resources Research*, 29 (2), 247-258.	1993	Recreational benefits of three water level management alternatives in comparison to other use values (hydropower, flood control, etc.) Function-Use: Flooding, Recreation, Hydro power Generation.	CV	1988/1989	US$, per individual (>=12 years old) for access to TVA reservoirs per year	41.70 -- 75.05	lake (reservoir)	regional	USA
Costanzo, R., S.C. Farber and J. Maxwell.	"Valuation and Management of Wetland Ecosystems,"	*Ecological Economics*, 1, 335-361.	1989	Coastal wetlands in Louisiana. Function-Use: Commercial Fishing.	MV	1983	Dollars per acre. Dollars per acre per year.	(a. Present value of the marginal product of an acre of wetland through production of five commercial fishery products (brown and white shrimp, menhaden, oyster, and blue crab) is reported. 3% was used for discounting: 845; (b. Estimated value of annual average product of an acre of marsh and open water area is reported. This estimate may overvalue the wetland since average product is generally lower than marginal product, the more appropriate measure: 5.8.	wetlands	regional	USA
Crandall, K.B., B.G. Colby, and K.A. Rait.	"Valuing Riparian Areas: A Southwestern Case Study,"	*Rivers*, 3 (2), 88-98.	1992	economic value of river preserve, in particular riparian areas Function-Use: Recreation.	CV	1990	US$ per visitor, per year	65	river	regional	USA
Creel, M. and J.B. Loomis.	Recreation Value of Water to Wetlands in the San Joaquin Valley: Linked Multinomial Logit and Count Data Trip Frequency Models,	*Water Resources Research*, 28 (10), 2597-2606.	1992	recreation benefits from an increase in water quantity or quality. Function-Use: Recreation.	TC	1988/1989	US$ Per visitor, per year	126 -- 655	wetlands	regional	USA
Croke, K., R. Fabian, and G. Brenniman.	"Estimating the Value of Improved Water Quality in an Urban River System,"	*Journal of Environmental Systems*, 16 (1), 13-24.	1986	benefits of improved water quality in the metropolitan Chicago area river system. Function-Use: Recreation.	CV	1985	US$ per houshold, per year	32.48 -- 49.63	river	regional	USA

Bibliographic study characteristics	**Study characteristics**										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Crutchfield, S.R., J.C. Cooper, and D. Hellerstein.	"Benefits of Safer Drinking Water: The Value of Nitrate Reduction,"	Agricultural Economic Report No. 752, Economic Research Service, U.S. Department of Agriculture, Washington DC, USA.	1997	potential benfits of reducing nitrates in the drinking water supply. Function-Use: Municipal and Domestic Water Supply.	CV	1994	US$ per respondent, per month	45.42 -- 65.11	groundwater	regional	USA
Cummings, R.G., P.T. Ganderton, and T. McGuckin.	"Substitution Effects in CVM Values,"	*American Journal of Agricultural Economics*, 76, 205-214.	1994	To design and implement a CVM survey that estimates the impact of substitution effects on the WTP for an environmental program. The objective is to extend the HRL (Hoehn, Randall and Loomis) approach. Function-Use: Recreation, Agricultural Supply.	CV	???	In dollars, per year and per person.	#1: program 1/1,2/1,2,3 (in $): 9.72/13.00/17.91; #2: program 2/2,3/1,2,3: 17.18/21.30/25.72; #3: program 3/1,3/1,2,3: 11.28/ 11.86/14.86; #4: program 1: 8.49.	river	regional	USA
Dalecki, MG., J.C. Whitehead and G.C. Blomquist.	"Sample Non-Response Bias and Aggregate Benefits in Contingent Valuation: an Examination of Early, Late, and Non-respondents,"	*Journal of Environmental Management*, 38: 133-143.	1993	Wetland preservation. Function-Use: Wetland Habitat.	CV	1990	$/person/year.	(a. Individual median WTP estimate for wetland preservation of the first wave (response rate = 24%): 24.4; (b. Individual median WTP estimate for wetland preservation of the fourth wave (response rate = 67%): 6.54.	wetlands	regional	USA
Dalgard, M.	"Willingness to pay for regulatory actions towards water pollutionin the Drammen Fjord,"	M.Sc. thesis, Department of Economics, University of Oslo. Centre for Industrial Research, Report no. 881108-2, August 1989, 95 pp.	1989	Valuation of improved water quality in the Drammen Fjord. Function-Use: Water Quality.	CV		NOK per household per year.	585	fjord	local	Norway
Daubert, J.T. and R.A. Young.	"Recreational Demand for Maintaining Instream Flows: A Contingent Valuation Approach,"	*American Journal of Agricultural Economics*, 63(4), 666-676.	1981	Recreational value of streams, in competition with other uses Function-Use: Recreation, Agricultural Supply.	CV	1978	US$ per day, per cubic feet second per day	4.85 -- 30.35	stream	regional	USA
Davis, J. and C. O'Neill.	"Discrete-choice valuation of recreational angling in Northern-Ireland,"	*Journal of Agricultural Economics*, 43(3), 452-457.	1992	WTP for angling licences. Function-Use: Recreation.	CV	1992	Pounds per annual permit.	40.54	Surface water	regional	Ireland

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Delavan, W.A.	''Valuing the benefits of protecting ground water from nitrate contamination in Southeast Pennsylvania,''	Master of Science Thesis, Department of Agricultural Economics and Rural Sociology, Pennsylvania State University, University Park.	1997	Ground water protection. Function-Use: Water Quality.	CV	1996	US Dollars	WTP for an improvement in water quality so that in 10 years 75% of the private wells will meet the standard: 59	groundwater	regional	USA
Desaigues, B. and V. Lesgards.	''La valorisation des actifs naturels - un exemple d'application de la méthode d'évaluation contingente" (Valuation of natural resources - an application of the Contingent Valuation Method). In French.	Working paper. Université de Bordeaux.	1991	Evaluation of the ecological and recreational benefits of an alternative management of the water level of a reservoir. Function-Use: Recreation, Habitat.	CV	1990	FF per person.	(a. Tobit model: 94.3; (b. Linear model: 91.8 (c. Loglinear model: 60.4 (d. Box-Cox model: 44.8	lake	local	France
Desvousges, W.H., V.K. Smith, and M.P. McGivney.	''A comparison of alternative approaches for estimation of recreational and related benefits of water quality improvement,"	*Report to the USEnvironmental Protection Agency*, Washington D.C.	1983	WTP to prevent the loss of a river for recreation. Function-Use: Recreation.	CV		Pounds per household per year	(a. use values: 19-49; (b. non-use values:42.	river	local	USA
Desvousges, W.H., V.K. Smith, and A. Fisher.	"Option Price Estimates for Water Quality Improvements: A Contingent Valuation Study for the Monongahela River,"	*Journal of Environmental Economics and Management*, 14, 248-267.	1987	option price bids for improved recreation resulting from enhanced water quality Function-Use: Recreation.	CV	1981	US$ Price per discrete change per person	7.2 --117.9	river	regional	USA
Dolan, K., A. Gilbert, L. Frymier, and C. Mitchell.	"The Value of River Protection in Vermont,"	Watershed 96 Proceedings, Environmental Protection Agency, Washington DC, USA.	1996	water level management. Function-Use: Recreation.	CV	m.d. (1995?)	US$ per household, per scenario	22 -- 70	catchment	regional	USA
Donnelly, W.A.	"Hedonic Price Analysis of the Effects of a Floodplain on Property Values,"	*Water Resources Bulletin*, 25 (3), 581-586.	1989	flood hazard potential reflected in land values Function-Use: Flooding.	HP	1984/1985	per $ of property tax liability	5.53 per $ property tax liability	river	regional	USA
Donnelly, D.M., J.B. Loomis, C.F. Sorg, and L.J. Nelson.	"Net Economic Value of Recreational Steelhead Fishing in Idaho,"	Resource Bulletin RM-9, 1985, Fort Collins: U.S. Department of Agriculture, Forest Service, USA.	1985	willingness to pay for steelhead (Salmo, gairdneri) fishing	CV	1983	US$ per trip, per person (note: also increase catch, and increase size)	10.96 -- 69.50	lake	regional	USA
				Function-Use: Recreation.	TC		US$ per trip, per person.	18.89 -- 35.58			

Bibliographic study characteristics	Study characteristics									
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Dornbusch, D.M. and S.M. Barrager.	"Benefit of Water Pollution Control on Property Values,"	Prepared for the Office of Research and Monitoring, U.S. EPA. Report # EPA-600/5-73-005.	1973	Effect of water pollution abatement on property values. Function-Use: Water Quality.	HM		$/ residence.	Value represents increase in property value attributable to pollution abatement since 1960 for residential land 1000 yds from water in Clackamas County, Oregon: 1455.	river	regional	USA
Driscoll, P., B. Dietz, and J. Alwang.	"Welfare Analysis When Budget Constrains are Nonlinear: The Case of Flood Hazard Reduction,"	*Journal of Environmental Economics and Management*, 26, 181-199.	1994	methodology (direct utility model) illustrated by case study Function-Use: Recreation.	HP	1980-1990	US$ per chance of flooding	204.29 -- 6,105.20	river	local	USA
Duffield, J.W., C.J. Neher, and T.C. Brown.	"Recreation Benefits of Instream Flow: Application to Montana's Big Hole and Bitterroot Rivers,"	*Water Resources Research*, 28 (9), 2169-2181.	1992	Allocation of water among competing uses (such as recreation and irrigation). Function-Use: Recreation.	CV	1988	US$ per trip, per acre.	199 -- 3377	River	regional	USA
Eckstein, O.	"Water-Resource Development: The Economics of Project Evaluation,"	Harvard University Press, Cambridge, Mass.	1958	The economic benefits of water used in navigation. Function-Use: Navigation.	Other		Dollars.	Reported value is the transportation savings for shipments on Columbia Slough. Value is based on the shipments of 10 commodity groups with 413,100 tons: 72300.	rivers	regional	USA
ECOTEC	"A Cost Benefit Analysis of Reduced Acid Deposition: UK Natural and Semi-Natural Ecosystems,"	Working Papers 4 and 5, Birmingham.	1993	Creation of a new trout fishery. Function-Use: Recreation.	CV		Pounds per angler per visit.	(a. economic rent: 4.4-12.2; (b. consumer surplus: 2.2-6.7.	river	national	United Kingdom
Edwards, S.F.	"Option Price for Groundwater Protection,"	*Journal of Environmental Economics and Management*, 15, 475-487.	1988	The "primitive knowledge" of the benefits of potable water in order to carry out efficiency analyses on public water qualties policies. This study reports on direct estimates of the total economic value of potable water. An extra goal of this study is to increase the knowledge of the public's total WTP to prevent uncertain, future contamination of potable supply of groundwater. Function-Use: Municipal and Domestic Water Supply.	CV	1986 (?)	In dollars, per year and per household.	Income (M): 55,413; scale for cost effective supply (L): 3.7; probability of future demand (p_2): 0.7; bequest scale (B): 4.6; ln(1-OP/M): -0.009; p_2*L*(r_2-q_2): 2.09; B*(r_2-q_2): 3.85. Derived from Figure 2 in article: $0 to $1,623/HH/year.	The aquifer (coastal areas).	Regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Environmental Resources Limited (ERM).	"Economic Appraisal of the Environmental Costs and Benefits of Potential Solutions to Alleviate Low Flows in Rivers: Phase 2 Study,"	London, Environment Agency.	1997	WTP for alleviation of low flow in six rivers. Function-Use: Freshwater Replenishment.	CV		Pounds per household per year.	(a. Malmesbury Avon: 5.7; (b. Tavy: 6.81.	rivers	national	United Kingdom, South East region of the EA
Epp, D.J. and K.S. Al-Ani.	"The Effect of Water Quality on Rural Non-farm Residential Property Values,"	*American Journal of Agricultural Economics*, 61(3), 529-534.	1979	Water quality in Pennsylvania rivers and streams. Function-Use: Water Quality.	HP	1972	$ / property.	Value measures the estimated increase in the average sales value of a typical residential property with a one point increase in pH (water quality measure): 653.96.	rivers	regional	USA
Ewers, H.J. and W. Schulz.	"The monetary benefits of water quality improving measures - Demonstrated by the example of the Lake Tegeler in Berlin,"	Duncker and Humblot, Berlin, 358p.	1981	Quantification of the recreational benefits resulting form a potential water quality improvement of the Lake Tegel in the city of Berlin. Function-Use: Recreation.	TC		Million DM	Total benefit - as an aggregate of all recreation categoriesand of all users: 51.	lake	local	Germany
Foster, V., I.J. Bateman and D. Harley.	"Real and Hypothetical Willingness to Pay for Environmental Preservation: A Non-Experimental Comparison,"	In Environmental Valuation, Economic Policy and Sustainability: Recent Advances in Environmental Economics. Melinda Acutt and Pamela Mason (eds.). Northampton, MA: Edward Elgar, 35-49.	1998	Land purchases, species preservation, and habitat conservation. Function-Use: Habitat, Rare or Endangered Species.	MV	1995	Pounds sterling per mailing Pounds Sterling	(a. Reported value is the mean donation per mailing to the RSPB fund raiser. The fund raising appeal was for the land purchase of maritime health habitat in Ramsey Island in 1992. This is the average donation (includes returned & not returned): £1.73/mailing; (b. Reported value is the total value of donations for the RSPB fund raiser. The fund raising appeal was for the protection of reedbed habitat for bittern in 1993: £268430.	Wetlands	national	United Kingdom
Garrod, G.D. and K.G. Willis.	"Estimating the Benefits of Environmental Enhancement: A Case Study of the River Darent,"	*Journal of Environmental Planning and Management*, 39 (2), 189-203.	1996	This paper outlines the use of contingent valuation methods in an ex ante appraisal of the costs and benefits of enhancing river flow for recreational purposes in a low flow river. Function-Use: Recreation.	CV	1993	In UK pounds 1993, per year, per household.	**I:** 1a) 15,06; 1b) 9,76; 2a) 18,45; 2b) 12,32; 3a) 17,18; 3b) 12,92. **II:** 1a) 7,16; 1b) 4,85; 2a) 10,19; 2b) 6,25: 3a) 3,85; 3b) 3,00.	River	regional	United Kingdom

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Garrod, G.D. and K.G. Willis.	''The hedonic price method and the valuation of countryside characteristics	*Countryside Change Working Paper*, 14, University of Newcastle, Newcastle.	1991	Amenity value of waterways. Function-Use: Amenity Value.	HP		%	Existence of local river/ canal amenity increased house price by 4.9%.	River, canal	national	United Kingdom
Gayatri, A.	''Valuing the Environment as an Input: The Production Function Approach,''	In Environmental Valuation, Economic Policy and Sustainability: Recent Advances in Environmental Economics. Melinda Acutt and Pamela Mason (eds.). Northampton, MA: Edward Elgar, 63-78.	1998	Groundwater recharge functions of wetlands. Function-Use: Agricultural Supply.	MV		Dollars	(a. Value expressed as the welfare loss for the wetlands area due to decrease in groundwater levels to approximately 7 meters in depth within a single year for the entire wetland: $1182737; (b. Values expressed by welfare loss resulting from a 1 meter decrease in naturally recharged groundwater level for farmers in the Madachi area: $62249.	Ground and surface water	regional	Nigeria
Gibbons, D.	''Hydropower,''	Ch. 7 in The Economic Value of Water. Resources for the Future, Washington D. C.	1986	Water used in hydropower generation. Function-Use: Hydropower Generation.	Other	1980	$/ acre foot.	Reported estimate is the long run value of water used for hydropower generation on the Columbia River from Grand Coulee to sea level: 5.	river	regional	USA
Gibbons, D.	''Navigation,''	Ch. 6 in The Economic Value of Water. Resources for the Future, Washington D. C. 74-85.	1986	Water used for navigation. Function-Use: Navigation.	Other	1980	$/acre ft.	Estimate reflects short run average value of water for navigation on Illinois waterway: 239.	river	regional	USA
Gisser, M., R.R. Lansford, W.D. Gorman, B.J. Creel and B. Evans.	''Water Trade-Off Between Electric Energy and Agriculture In the Four Corners Area,''	*Water Resources Research*, 15(3), 529-538.	1979	The marginal value of water for the agricultural sector. Function-Use: Agricultural Supply.	OM		Dollars per acre foot per year.	Reported value is the shadow value (decline in the net revenue in agriculture) of the water per acre foot per year when irrigation water to farms in the Four Corner area at elevations lower than 5000 feet declined by 30%: 731.	Ground and surface water	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Gonzalez-Caban, A. and J.B. Loomis.	"Economic benefits of maintaining ecological integrity of Rio Mameyes, in Puerto Rico,"	*Ecological Economics*, 21, 63-75.	1997	In this paper we report the findings of the application of a CVM to quantify the total economic value to households in Puerto Rico for preserving the ecological integrety and riparian zone viability in the Rio Mameyes via alternative flow levels in the river (one measure of ecological integrity). In addition we also report the results of applaying the CVM to quantify the total economic value to households in Puerto Rico for preserving flows and avoiding a dam on the Rio Fajardo. Function-Use: Recreation, Municipal and Domestic Water Supply.	CV	1995	$ per household , per year for the next 5 years	1) 27,28; 2) 26,75; 3) 28,12; 4) 30,91;	river	regional	Puerto Rico
Gookowski, J.J. and L.H. Keller.	"An Economic Analysis of Trout,"	University of Tennessee, Agricultural Experiment Station Research Report 88-02.	1988	Trout production. Function-Use: Aquaculture.	MV	1985	Dollars	Value is net return above variable expenses in 1985 $ for a market trout enterprise with production of 1679 pounds per gallon/ minute and 1300 gallons/ minute discharge: $16018.	Springs	regional	USA
Green, C.H. and S.M. Tunstall.	"The Amenity and Environmental Value of River Corridors in Britain,"	in P.J. Boon, P.Calow, and G.E. Petts (eds.), *River Conservation and Management*, Chichester: John Wiley, 425-441.	1992	To evaluate three different potential benefits from water quality improvements: 1) the additional enjoyment to existing users; 2) the increase in amenity enjoyment to residents living near the river corridor; 3) the overall non-use value. Function-Use: Recreation.	CV	< 1990.	In UK pounds, per visit or per lump sum.	Residents: arithmetic mean (lump-sum payment in UK pounds) for water quality good enough for 1. Water birds/ 2. To support many fish, dragonflies and to allow many different types of plant to grow both in the water and on the edges/ 3. To be safe for children to paddle or swim: 546/562/ 582; log mean: 2.72/2.67/ 2.90. Visitors (in pence per visit): 1.: for town centre/local park/honeypot: 37/42/ 41; 2: 42/48/41; 3: 36/38/45. Remote sites survey: WTP for non-user/ users: 13.59/ 19.56 per year.	River	national	United Kingdom

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Green, C.H. and S.M. Tunstall.	"The Evaluation of River Water Quality Improvements by the Contingent Valuation Method,"	*Applied Economics*, 23, 1135-1146.	1991	To estimate the recreational benefits which would result from improvements in river water quality. Function-Use: Recreation.	CV	1987	UK Pounds per year and per month.	Value of increased enjoyment (valid cases for those who would get more enjoyment, in pences): standard A: log mean/mean: 1.78/51 (n=388); standard B: 1.82/60 (n=464); stan-dard C: 1.85/52 (n=311). WTP of each sample who were WTP increased water rates, the mean WTP of those that were so willing, the log mean, the mean and n: WTP/year: 53%, 2.96, 1203, 173; WTP/month (starting point 50p per month): 59%, 135, 153; WTP/month (starting point 1 pound per month): 56%, 2.08, 166, 132.	River	regional	United Kingdom
Green, C.H. *et al*.	''The economic evaluation of environmental goods,"	*Project Appraisal* 5, pp. 70-82.	1990	River water quality improvement. Function-Use: Water quality.	CV		Pounds per annum per capita.	(a. WTP (non visitors): 13.6; (b. WTP (visitors): 15.6.	river	regional	United Kingdom
Green, C. H. and K. G. Willis.	''New Non-Use and Angling Economic Data,"	Report to Foundation for Water Research, Marlow, Bucks.	1996	WTP of anglers for improvements in water quality Function-Use: Recreation.	CV		Pounds per angler per visit Pounds per household per km per year	(a. new relatively poor coarse fishery: 4; (b. new good coarse fishery: 6.4; (c. new good trout fishery: 16.8; Non use value for improvements in quality: (d. from poor to medium: 0.0056; (e. from medium to good: 0.0021.	river	local	United Kingdom
Greenley, D.A., R.G. Walsh, and R.A. Young.	"Option Value: Empirical Evidence from a Case Study of Recreation and Water Quality,"	*The Quarterly Journal of Economics*, 96, 673.	1981	To develop and apply a procedure for measuring option value and other preservation values of water quality, compared to benefits from water-based recreation activities. Function-Use: Recreation, Non-use.	CV	1976	Dollars, per month and the option, bequest, existence, recreation and total preservation and recreation values.	Mean population-weighted value of the WTP additional sales taxes for the 80% of sample households who expect to continue to use waterways in the River Basin for recreation activities in the future: $23. The total recreation-derived benefit of improved water quality to 80% of the households who expect to continue to use waterways for recreation is $79. It was equivalent to appr. $5 per household recreation activity day in 1976. The WTP for the existence value of the 20% of the households who do not use the River Basin for recreation: $25 annually, $17 annually for bequest value; total non-user value of $42 annually. For present users: WTP for existence value: $34, bequest value: $33, total: $67 annually (60% more).	River	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Gren, I.M.	''Alternative Nitrogen Reduction Policies in the Malar Region, Sweden,''	*Ecological Economics*, 7(2), 159-172.	1993	Denitrification functions of wetlands. Function-Use: Habitat.	RC	1991	SEK millions (1US$= SEK 5.8). SEK/ Kg N.	(a. Value is the total cost of restoring wetlands that reduce the load of nitrogen by 1,194 tons. Significant cost reduction for nitrogen abatement can be attained through restoring wetlands: 49; (b. Value is the high-end estimate for the marginal cost of abating 1 Kg of nitrogen through restoring wetlands. Significant cost reduction for nitrogen abatement can be attained through restoring wetlands.	Wetland	regional	Sweden
Gren, I.M., C. Folke, R.K. Turner, and I.J. Bateman.	"Primary and Secondary Values of Wetland Ecosystems,"	*Environmental and Resource Economics*, 4(1), 55-74.	1994	The purpose of this paper is to compare diferent approaches aimed at measuring the performance of wetlands, in particular with respect to their ability to capture the primary and secondary values of wetlands. Two categories of methods are considered; biophisical methods, and methods based on behavioural models. Due to the fact that only one case study dealt entirely with this last type of model, only that case study will be investigated here. (Bateman et al. 1993) Function-Use: Recreation.	CV	1993	British Pound per year	1a) 67; 1b) 75; 1c) 140; 2a) 12,45; 2b) 4,08.	Wetland	local	United Kingdom
Gupta, T.R. and J.H. Foster.	''Economic Criteria for Freshwater Wetland Policy in Massachusetts,''	*American Journal of Agricultural Economics*, 57(1), 40-45.	1975	Multiple uses/benefits associated with wetlands (value of wildlife, visual-cultural benefits, water supply, and flood control benefits of wetlands). Function-Use: Flooding.	DF	1972	Dollars per acre per year.	(a. Value represents average benefits from flood control for low quality acres: 10; (b. Value represents average benefits from flood control for high quality acres: 80.	Wetlands	regional	USA
Hammad, M., R. Aburas and B. Abuzahra.	''The Potential of Hydropower Generation in Jordan: Micro-Hydropower Analysis,''	*Energy Policy*, 22(6), 523-530.	1994	Hydropower in Jordan. Function-Use: Hydropower Generation.	Other		$ thousands/ year.	(a. Value represents the cost of fuel saved from hydropower versus alternative power generation (US$1,000/year) for sites at Samra. Capital requirement and operating costs for hydropower facility were also reported: 31.6; (b. Value represents the cost of fuel saved from hydropower versus alternative power generation (US$1,000/year) for sites at Adasia. Capital requirement and operating costs for hydropower facility were also reported: 146.8.	river	local	Jordan

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Hanemann, W.M.	"Water Quality and the Demand for Recreation,"	California Agricultural Experiment Station, University of California-Berkeley, Working Paper No. 164	1981	Beach recreation and water quality at selected beaches in the Boston area. Function-Use: Recreation.	TC	1974	cents/ household	(a. Average benefit per household from a 50% reduction in TURB at Malibu Beach/Savin Hill, Boston is reported: 3; (b. Average benefit per household from a 50% reduction in TURB at Sandy Beach/Upper Mystic Lake, Winchester is reported: 0.3.	Beaches, lake	regional	USA
Hanemann, M., B. Loomis, and B. Kanninen.	"Statistical Efficiency of Double-Bounded Dichotomous Choice Contingent Valuation,"	*American Journal of Agricultural Economics*, 73(4), 1255-1263.	1991	The aim of the study is to show how the statistical efficiency of dichotomous choice CVM can be improved by asking the respondent to engage in two rounds of bidding. Function-Use: Habitat, Agricultural Supply.	CV	1989	In dollars, per year and per household.	Truncated mean (Hanemann, 1989): wetland maintenance: single/double-bounded model ($/yr): 257/152; wetland improvement: 269/251; contamination maintenance: 214/187; contamination improvement: 300/308; salmon improvement: 336/181.	River	regional	USA
Hanley, N.D.	"Problems in valuing environmental improvement resulting from agricultural policy changes,"	In : A. Dubgaard and A. Nielson (eds.) Economic aspects of environmental regulation in agriculture, Wissenschaftsverlag, Vauk Kiel, Kiel.	1989	Drinking water quality improvements (reduced nitrate). Function-Use: Water quality.	CV		Pounds per household per year.	WTP to guarantee water supplies with nitrate levels not exceeding 50mg/l: 17.14	Ground and surface water	national	United Kingdom
Hardner, J.J.	"Measuring the Value of Potable Water in Partially Monetized Rural Economies,"	*Water Resources Bulletin*, 32 (6), 1361-1366.	1996	This pilot study was conducted to test the potential of the CVM to reveal the value of non-market goods in a partially monetized subsistence economy. CVM was used to estimate the WTP in the form of labour for potable drinking water in a rural local community. Function-Use: Municipal and Domestic Water Supply, Water quality.	CV	1996	WTP in days (NB here a non-monatary measure of WTP was used)	1.4 days a week for a period of one year, or 23 percent of real income	river of catchment	regional	Ecuador
Harpman, D.A., E.W. Sparling and T.J. Waddle.	"A methodology for quantifying and valuing the impacts of flow changes on a fishery,"	*Water Resources Research*, 29(3), 575-582.	1993	Mean WTP of anglers for their average catch of brown trout, and hypothetical additions to this number of fish caught. Function-Use: Recreation.	CV		Pounds per day.	16 - 21.5.	river	local	USA

Bibliographic study characteristics	Study characteristics									
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Harrington, W., A.J. Krupnick, and W.A. Spofford.	"The Economic Losses of a Waterborne Disease Outbreak,"	*Journal of Urban Economics*, 25, 116-137.	1989	This paper considers the valuation of consequences of a water contamination episode that arises in the household sector of the economy, that is those directly related to individual illness or households related to a contaminated water supply. Function-Use: Municipal and Domestic Water Supply.	CV	1984	In dollars, per year and per household.	$1540.4 for employed individuals (implicit after-tax wage rate of $6.39 per hour); $517.6 for individuals living on minimum wages (implicit after-tax minimum wage of $2.65 per hour); $484.8 for unemployed individuals (implicit after-tax wage rate of $0 per hour).	The whole system.	Local	USA
Hassan, A.A.	"Economic Consequences of Water Quality Change on Industrial Uses in the Chino-Riverside Area,"	Report to Department of Water Resources, State of California. Southern District, Planning Branch. No. 1335-3-C-6.	1969	Industrial water use. Function-Use: Industrial Supply.	Other		Dollars per acre foot. Dollars per ppm per acre foot.	(a. Value represents cooling water treatment cost for water used in large cooling towers for Feather River Project Water with hardness 110 ppm.: 9; (b. Value represents processing water treatment costs/ ppm of hardness/ acre foot of water for industries that demineralize water: 1.	river	regional	USA
Hayes, D.F., J.W. Labadie, T.G. Sanders and J.K. Brown.	"Enhancing Water Quality in Hydropower System Operations,"	*Water Resources Research*, 34(3), 471-483.	1998	Hydropower. Function-Use: Hydropower Generation.	SM	1985	$ millions.	Value of power, in millions of dollars, was derived from a model with operations modified to reduce dissolved oxygen content of downstream water to the extent possible, using 1985 data: 11.	river	local	USA
Heiberg, A. and K.-G. Hem	"Use of formal methods in evaluating countermeasures to coastal water pollution,"	In H.M. Seip and A. Heiberg (eds.) 1989: Risks management of chemicals in the environment, Plenum Press, London.	1987	Valuation of changes in water quality in the Kristiansand Fjord. Function-Use: Water Quality.	CV		NOK per household per year.	450	fjord	local	Norway
Heiberg, A. and K.-G. Hem.	Regulatory impact analysis of the inner Oslo Fjord. A comparison of three different methods.	Centre for Industrial Research, report no. 880105-1, September 1988, 67 pp.	1988	Valuation of improved water quality in the Inner Oslo Fjord. Function-Use: Water Quality.	CV		NOK per household per year.	700-900	fjord	local	Norway
Heimlich, R.E.	"Costs of an Agricultural Wetland Reserve,"	*Land Economics*, 70(2), 234-46.	1994	Wetlands converted from cropland. Function-Use: Agricultural Supply.	RC	1982	Dollars per acre.	(a. Value is the high estimate of the marginal costs of a 5 million acres of wetland reserve: 1184; (b. Value is the high estimate of the total average cost (in $/ acre) that minimizes reserve costs for wetland reserve of 1 million acres: 286.	Wetlands	national	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Herriges, J.A. and F. Shogren.	"Starting point Bias in Dichotomous Choice Valuation with Follow-Up Questioning,"	*Journal of Environmental Economics and Management*, 30, 112-131.	1996	This paper investigates starting point bias as one explanation for the significant difference between the WTP distributions implied by initial and follow-up question responses. Function-Use: Recreation.	CV	Local residents: 1992; visitors: 1993.	In dollars, on a one time basis (payable in installments of $… over the next five years) and per program.	Both of the one-way street formats yield biased estimates of the mean. In the one-way street up format the mean WTP is drawn further down toward the initial bid (=BL=100) as the anchoring effect increases, with the mean WTP estimated to be roughly 200 (rather than its true value of 250) when achoring effect is 0.5. A similar pattern emerges from the one-way street down format. In case of the double-bounded approach, no bias arises.	Lake	regional	USA
Hervik, A., M. Risnes and J. Strand.	''Implicit costs and willingness to pay for development of water resources,"	In Carlsen, A.J. (ed.) 1987: Proceedings. UNESCO Symposium on Decision Making in Water Resources Planning, May 5-7 1986, Oslo: 195-202.	1987	Estimation of the implicit WTP of the policy makers for river preservation embedded in the MP. Function-Use: Habitat.	CV		NOK per household per year.	850-1550	river	national	Norway
Hjalte, K., K. Lidgren, A.-L. Thelander and C. Wells.	''Economic Consequences of Water Quality Changes in Lakes,"	Report March 1982, TEM University of Lund.	1982	Recreational value affected by future water quality (given 3 water quality scenarios). Function-Use: Water Quality.	TC		SEK per visitor per year.	Recreational value: 4 (on average for all recreational activities over the time period considered).	lake	local	Sweden
Holm-Müller, K., H. Hansen, M. Klockman and P. Luther.	''The demand for environmental quality in the Federal Republic of Germany,"	Berichte des Umweltbundesamtes 4/91, Erich Schmidt Verlag, Berlin, 346 p.	1991	The study seeks to determine the demand for environmental quality. Function-Use: Water Quality.	CV		DM per months.	(a. Marginal WTP for surface water quality improvement: 35-110; (b. Mean WTP for an improvement of the drinking water quality: 4.3.	Surface water	local	Germany
Hoevenagel, R. and J.W. van der Linden.	"Effects of Different Descriptions of the Ecological Good on Willingness to Pay Values,"	*Ecological Economics*, 7, 223-238.	1993	To study the effects of three descriptions of the good: a clean environment around the year 2015 on the respondents' WTP. Function-Use: TEV	CV	1989	Dutch Guilders, per household and per year.	Mean WTP: CE-0: ƒ30.22; CE-4: ƒ49.62; CE-7: ƒ52.77.	The whole system.	Regional	Netherlands

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Holway, J.M. and R.J. Burby	"The Effects of Floodplain Development Controls on Residential Land Values,"	*Land Economics*, 66 (3), 259-271.	1990	Considering the effects of the National Flood Insurance Program (NFIP). The purpose of this study is to determine the extent to which floodplain management programs are indeed reducing the value of vacant land in the floodplain. Function-Use: Flooding.	HP	1975-1977	US$ per thousand square feet.	Arvada: mean land value/mean parcels size (acre)/mean flood hazard (fifths in floodplain): 1,009/3.1/4.4; Cape Girar-deau: 200/1.8/3.5; Fargo: 706/1.9/4.6; Omaha: 499/ 9.6/3.0; Palatine: 1,248/ 0.4/3.5; Savannah: 348/ 9.7/4.3; Toledo: 387/ 4.5/2.3; Tulsa: 259/3.5/ 3.8; Wayne: 1,131/4.5/ 4.4; average: 782/3.7/3.7.	river	regional	USA
Houston, J.E. and N.K. Whittlesey.	'' Modeling Agricultural Water Markets for Hydropower Production in the Pacific Northwest,"	*Western Journal of Agricultural Economics*, 11(2), 221-231.	1986	Agricultural and electric uses for water. Function-Use: Agricultural Supply.	OM	1985	Dollars Millions.	(a. Value represents estimated regional consumer surplus under optimal allocation when hydropower water was valued at 40 mills (1 mill = $.001) per kilowatt hour: 2648; (b. Value represents estimated regional consumer surplus under optimal allocation when hydropower water was valued at 20 mills (1 mill = $.001) per kilowatt hour: 2686.	River	regional	USA
Howe, C.W. and M.G. Smith.	"The Value of Water Supply Reliability in Urban Water Systems,"	*Journal of Environmental Economics and Management*, 26(1), 19-30.	1994	To determine an optimum level of urban water supply reliability and to measure what water users would be WTP for different levels of reliability. Function-Use: Municipal and Domestic Water Supply.	CV	Year of publications: 1994.	Dollars and the probability of the SASE.	Average WTA for: Scenario 1: B: $4.53; A: $6.65; L: flat: $10.05, metered: $11.44, all: $11.08. Scenario 2: B:$5.44; A: $8.73; L: flat: $13.99, metered: $17.53, all: $16.06. Scenario 3: B: $4.67; A: $5.82; L: flat: $5.62, metered: $6.27, all: $5.99; WTP (no): B: $1.07; A: $1.86; L: $0.96 (all). Scenario 4: B: $5.32; A: $6.51; L: flat: $6.25, metered: $9.18, all: $7.97; WTP (no): B: $1.01; A: $1.95; L: $1.42 (all).	Groundwater	regional	USA
Huppert, D.D.	Measuring the Value of Fish to Anglers: Application to Central California Anadromous Species.	*Marine Resource Economics*, 6(2), 89-107.	1989	Recreational fishing for anadromous species (chinook salmon and striped bass). Function-Use: Recreation.	CV		$ / person.	(a. Value represents the maximum amount respondents would be willing to pay to avoid a loss in fishing quality of 50% (mean across full sample): 31.1. (b. Value represents the maximum amount that respondents who reported catching some fish would be willing to pay for an increase in fishing quality by 100% (mean across sample of anglers who reported positive catch rates): 40.8.	river, bay	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Hushak, L.J., J.M. Winslow, and N. Dutta.	"Economic Value of Great Lakes Sportfishing: The Case of Private-Boat Fishing in Ohio's Lake Erie,"	*Transactions of the American Fisheries Society*, 117, 363-373.	1988	The purpose of this paper is to present the results and implications of three surveys conducted in 1981 and 1982. Function-Use: Recreation.	TC	1981 and 1982.	In dollars per person per trip and per person per day.	Per person per trip: W: 0%: 15.28/ 69.60/4.63/89.51; 25%: 21.62/117.33/ 6.88/ 145.83; 50%: 34.88/165.06 /9.67/ 209.61. YP: 0%: 15.70/55.49/3.97/ 75.16; 25%: 23.07/96.60/5.16/ 125.13; 50%: 31.01/138.32 /6.7/176.05. CB: 0%: 3.40/ 15.06/0.26/18.72; 25%: 6.04/43.14/0.45/49.63; 50%: 8.72/ 71.21/0.66/ 80.59.	lake	regional	USA
Jay, J.M.	"The Net Benefits of Backcountry Canoeing in Ontario Wilderness Parks: The Application of Random Utility Methods to Travel Cost Analysis,"	unpublished Master Thesis, University of Guelph, USA.	1996	The primary purpose of this study is to estimate non-market recreational welfare measures associated with policy decisions affecting the quality and quantity of wilderness canoeing in three parks. Function-Use: Recreation.	TC	Canoeing season of 1993.	In dollars per trip.	Estimated mean compensating variation (CV) for the elimination of each trip and park alternative: A: 1/2/3 or > trips (in $): 119.46/62.50/ 1.67; K: 39.76/4.32/0.00; Q: 9.03/ 19.33/12.43. Per day: A: 36.45/17.55/ 0.56; K: 9.43/ 1.14/0.00; Q: 1.43/2.49/ 2.06. Mean estimates CV for a 50% reduction in expected encounters while paddling and portaging: A: 33.52/ 48.39/43.07; K: 1.97/ 3.58/4.48; Q: 1.508/2.23/ 1.47.	river	regional	Canada
Johnson, N.S. and R.M. Adams.	On the Marginal Value of a Fish: Some Evidence from a Steelhead Fishery.	*Marine Resource Economics*, 6(1), 43-55.	1989	Steelhead Fishing. Function-Use: Recreation.	CV		$/additional steelhead.	Estimate represents the value of catching one more steelhead trout: 6.65.	river	regional	USA
Johnson, N.S. and R.M. Adams.	"Benefits of Increased Streamflow: The Case of the John Day River Steelhead Fishery,"	*Water Resources Research*, 24 (11), 1839-1846.	1988	To evaluate the recreational fishing benefits of incremental streamflow changes using biologic and economic assessment methods. Function-Use: Recreation.	CV	1986/ 1987 steelhead fishing season.	Catch rate in hours per steelhead and dollars.	Mean bids: WTP (A): $8.58 (mean expected catch rate (hrs/steelhead): 7.1). WTP (B): $11.11 (5.0); WTP (C): $13.59 (2.9).	catchment	regional	USA
Johnson, N.S., Adams R.M. and G.M. Perry.	"The On-Farm Costs of Reducing Groundwater Pollution,"	*American Journal of Agricultural Economics,* 73, 1063-1073.	1991	Agricultural benefits from reducing groundwater pollution Function-Use: Agricultural Supply.	SM		Dollars, per hectares, per year.	(a. Value measures annual increase in profits from corn production under optimal nitrogen use in Shano Silt soil: 90; (b. Value measures annual increase in profits from wheat production with a 25% reduction in soil nitrates: - 79; (c. Value measures annual increase in profits from potato production under 25% reduction in soil nitrates: - 819.	Groundwater	local	USA

Bibliographic study characteristics	Study characteristics									
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Johnson, R.L., N.S. Bregenzer and B. Shelby.	Contingent Valuation Question Formats: Dichotomous Choice versus Open-Ended Responses.	Ch. 12 in Economic Valuation of Natural Resources: Issues, Theory, and Applications. Edited by Rebecca L. Johnson & Gary V. Johnson. Westview Press: Boulder, Colorado.	1990	Whitewater rafting in the Rogue River, Oregon. Function-Use: Recreation.	CV	1985	$/ person.	(a. Value is sample mean WTP estimate per visitor for a permit to access the Rogue River. Open-ended CVM question format used: 32.66; (b. Value is median WTP estimate per visitor for a permit to access the Rogue River. Dichotomous Choice CVM question format used: 48.32.	river	regional	USA
Jordan, J.L. and A.H. Elnagheeb.	"Willingness to Pay for Improvements in Drinking Water Quality,"	*Water Resources Research*, 29 (2), 237-245.	1993	The water qualtity of 125,000 private wells throughout Georgia poses a potential hazard to health. The nonpoint source nature of the contamination of groundwater makes the problem difficult to address with normal regulatory procedures. Function-Use: Municipal and Domestic Water Supply, Agricultural Supply.	CV	February 1991.	In dollars, per household and per month.	Before rejecting outliers:city/county users for OLS: 12.31; for ML: 11.13. Private well users for OLS: 21.78; ML: 14.01. After rejecting outliers: city/county users for OLS: 11.28; ML: 10.07. Private well users for OLS: 16.06; ML: 12.38. The conditional mean: before rejecting outliers: city/county users for OLS: 11.59; for ML: 11.49. Private well users for OLS: 18.87; ML: 16.11. After rejecting outliers: city/county users for OLS: 10.19; ML: 10.09. Private well users for OLS: 9.00; ML: 8.89. Averages of midpoints from payment card: $12.17/HH/mo public ($146/HH/yr); $14.09/HH/mo private ($169).	Ground- and surfacewater	regional	USA
Kanazawa, M.	"Pricing Subsidies and Economic Efficiency: The U.S. Bureau of Reclamation,"	*Journal of Law and Economics*, 36(1), 205-234.	1993	The shadow (marginal) value of water sold by Bureau of Reclamation to farmers in California. Function-Use: Agricultural Supply.	MV	1977	Dollars per additional acre foot.	The value reported is the average marginal value of water to farms in the Westland Water District in 1982: 53.05.	Ground and surface water	regional	USA
Kaoru, Y.	"Measuring Marine Recreation Benefits of Water Quality Improvements by the Nested Random Utility Model,"	*Resource and Energy Economics*, 17(2), 119-136.	1995	Recreation fishing benefits from water quality improvement. Function-Use: Habitat.	TC	1982	Dollars per trip.	(a. Value is $/trip benefits for visitors to the Pamlico Sound. When fish catch rate improves by 25%, nitrogen pollution reduced to mid-level and discharged suspended solids reduced to lowest level: 0.25; (b. Value represents the average welfare loss from a site closure if Albemarle was closed: -2.19.	estuary	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics:** **Mean / Total**	**Water system:**	**Spatial scale**	**Country**
Kaoru, Y., V.K. Smith, and J.L. Liu.	"Using Random Utility Models to Estimate the Recreational Value of Estuarine Resources,"	*American Journal of Agricultural Economics*, 77, 141-151.	1995	Using a household production framework to link measures of nonpoint source pollution to fishing quality and a random utility model to describe how that quality influences sport fishing parties' decision. Function-Use: Recreation.	TC	1981 and 1982.	Dollars, years, miles per hour, horsepower and nitrogen loadings.	Range of mean value in the database per study*(min--max)* 11-site Model: 0.1186/ appr. 9.5; 23-site Model: appr. 1.0/11.0; 35-site Model: appr. 2.0/9.0.	Estuarine. BAY	regional	USA
Kask, S.B. and J.F. Shogren.	"Benefit Transfer Protocol for Long-Term Health Risk Valuation: A Case of Surface Water Contamination,"	*Water Resource Research*, 30 (10), 2813-2823.	1994	There are not many studies of the concept of benefit transfer. Up to now these studies have only focused on recreational benefits and the discussion must now be expanded to include the reduction in risk to public health.They want to estimate the ex ante economic value to avoid an increase in dioxin limits and estimate the value of avoiding an increase in the probability of chronic morbidity or cancer mortality, or both. Function-Use: Recreation, Agricultural Supply, Municipal and Domestic Water Supply.	Ben Trans	It differs: 1989, 1991 and 1992 (???).	Dollars and years.	Viscusi et al.: $ per 1/100,000 decrease in risk of chronic bronchitis; mean: 8.83 (WTP). Implicit dollar value per chronic bronchitis case: mean 883,000 (WTP). $- value per 1/ 100,000 decrease in risk of accidential death: mean: 81.84 (WTP). Mean value of statistical life, millions of $: 8.184 (WTP). Smith and Desvousges: example: WTP in $ per 5/50 decrease in exposure with contamination endpoint risk of 1/100; mean: $14.19 (WTP). For endpoint 1/200: mean: $26.20 (WTP).	Surface water.	Regional	USA
Kiel, K.A.	"Measuring the Impact of the Discovery and Cleaning of Identified Hazardous Waste Sites on House Values,"	*Land Economics*, 71 (4), 428-435.	1995	To estimate the effect of the existence of toxic sites on house values from before information on their toxicity was released by the federal government until several years after cleaning strategies were announced. Function-Use: Municipal and Domestic Water Supply.	HP	January 1975 through December 1992.	Dollars, square feet, years and miles.	n.a.	Wells. NO WATER: TOXIC WASTE ON SITE FOR HOUSES	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Kirchhoff, S., B.G. Colby, and J.T. LaFrance.	"Evaluating the Performance of Benefit Transfer: An Empirical Inquiry,"	*Journal of Environmental Economics and Management*, 33, 75-93.	1997	To develop a methodololy to evaluate the performance of direct benefit transfer and benefit function transfer. Function-Use: Recreation, Habitat.	CV	Spring and summer of 1992.	US$	Policy site (= site under consideration)/ study site (= site for which the original estimates were obtained): Taos Box/ Lower Gorge: 26.68; Lower Gorge/Taos Box: 20.22; Ramsey Canyon/ San Pedro, all respondents: 125.74; Ramsey Canyon/ San Pedro, birders: 125.74; San Pedro, all respondents/Ramsey Canyon: 80.41; San Pedro, birders/ Ramsey Canyon: 90.14.	river	regional	USA
Kirshner, D. and D. Moore.	"The Effect of San Francisco Bay Water Quality on Adjacent Property Values,"	*Journal of Environmental Management*, 29(3), 263-274.	1989	This study estimates the value of variations in water quality to the Bay Area residents by using a HP equation to examine the price of residential properties adjacent to the Bay. Function-Use: Municipal and Domestic Water Supply, Recreation, Agricultural Supply.	HP	1985 and 1986.	In dollars and per property.	1. The implicit marginal price of proximity to water is appr.: $65,000 (=20% of property's value), while in 2. The implicit marginal price is appr.: $24,000 (=9%). So the marginal implicit price of this change in water condition is estimated to be appr. $41,000 (11%) per waterfront property.	Estuarine system. WATER FLOWS FROM RIVERS	regional	USA
Klein, R.J.T. and I.J. Bateman.	"The Recreation Value of Cley Marshes Nature Reserve: An Argument against Managed Retreat?,"	*Water and Environmental Management*, 12, 280-285.	1998	The main aim of this study is to provide an estimate of the recreational value of the Cley Reserve. Function-Use: Recreation, Habitat.	CV, TC	1996	A: In UK pounds, per household, per year or per visit. B: In UK pounds, per party per annum.	WTPfee (incl. Zero-bids, in UK pounds): 1.58; WTPfee (excl.): 2.22; WTPtax (incl.): 48.15; WTPtax (excl.): 62.08.	Reserve.	Regional	United Kingdom

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Kosz, M.	"Valuing Riverside Wetlands: The Case of the "Donau-Auen" National Park,"	*Ecological Economics*, 16, 109-127.	1996	The aim of this paper is briefly to review the main results of the cost-benefit analysis concerning all the variables that depend on direct anthropocentric use, including energy production with hydroelectric power stations, shipping, ground water protection, stabilisation of the river bed to stop channel erosion, visitors' benefits, forestry, farming, fishing, hunting, and the costs of establishing a national park. This was done because there was a plan to build one or more hydroelectric power stations in the area under study, the Donau-Auen. This was operationalized by 4 different development projects. (1) Establishing a national park in all easily available areas (not included in the WTP value). (2) Founding a national park in all available areas including private property; concept of hydraulic engeneering including extensive measures artificially changing the waterway to avoid further river bed erosion. (3) Constuction of a hydroelectric power station near Wolfsthal. (4) Construction of a hydroelectric power station near Wildungsmauer.(The last project is higher inmagnitude compared to the third). Function-Use: Recreation, Habitat.	CV	1993 (June and July)	ATS 1993 a year	2a) 919,80; 2b) 329,25; 3a) 694,9; 3b) 122,21; 4a) 689,85; 4b) 69,63.	River	regional	Austria

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Kreutzwiser, R.	The Economic Significance of the Long Point Marsh, Lake Erie, as a Recreational Resource.	*Great Lakes Resource*, 7(2), 105-110.	1981	Recreational use of Long Point and Point Pelee, Lake Erie. Function-Use: Recreation.	TC	1978	$ / user group / visit.	Value measures sample average consumer surplus per group per visit: 34.85.	lake	local	USA
Kwak, S.J., Lee, J. and C.S. Russell.	''Dealing With Censored Data From Contingent Valuation Surveys: Symmetrically-Trimmed Least Squares Estimation,''	*Southern Economic Journal*, 63(3), 743-750.	1997	Drinking water. Function-Use: Municipal and Domestic Water Supply.	CV	1992	$/ month/ household	Data included follow up questions for respondents reporting zero WTP. These respondents are asked if they would need to be compensated for any changes in water quality. The model was estimated using OLS, Tobit, and a symmetrically-trimmed LS method: 3.12.	ground and surface water	regional	Korea
Kwak, S.J. and C.S. Russell.	"Contingent Valuation in Korean Environmental Planning: A Pilot Application to the Protection of Drinking Water Quality in Seoul,"	*Environmental and Resource Economics*, 4(5), 511-526.	1994	To calculate the WTP for the Seoul's drinking water supply system. Function-Use: Municipal and Domestic Water Supply.	CV	January, 12 to February 6, 1992.	Won, per household and per year.	WTP: 2,603 Won; respondent's attitude toward current tap water quality (1= very good; 5= very bad): 3.597; monthly expenditure for a tap water filtration system (unit= 1000 won): 1.571; monthly expenditure for bottled water: 1.859; dummy for having taken a trip to obtain spring water to use for drinking during last 5 years (1=yes; 0=no): 0.356; subjective estimate of the number of drinking water contamination accidents that might occur in next 5 years if the government takes no action: 3.873; monthly combined bill for water and sewerage service: 4.816.	river	regional	Korea
Kyber, M.	''Impacts for recreational use of waterways caused by pollution and their evaluation in the inspection of scene,''	Technical Research Centre of Finland, Research notes 23: 1981. Espoo, 90 p.	1981	Present value of property along shore area. Water quality affecting average value per square metre of shore areas with summer cottages and permanent dwellings going down to level 3. Function-Use: Water Quality.	HP		%	(a. Level II (good) to level III (satisfactory): market value of on shore real estate fell by 30%; (b. Level II (good) to level IV (passing): market value of on shore real estate fell by 45%; (c. Level II (good) to level V (poor): market value of on shore real estate fell by 55%.	Surface water	national	Finland

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Lansford Jr., N.H. and J.L. Jones.	"Marginal Price of Lake Recreation and Aesthetics: An Hedonic Approach,"	*Journal of Agricultural and Applied Economics*, 27 (1), 212-223.	1995	This study employs a HP approach to estimate the total nonmarket, implicit price of recreational and aesthetic benefits (RA) to residential properties in relatively close proximity to the lakes. Function-Use: Recreation, Habitat.	HP	From January 1988 through December 1990.	In dollars per (square) feet.	Predicted sale prices of house square: (in feet): 1500 for distance from Lake: water front/150 feet/300/450/ 1000/1500 (in thousands of $): 191.0/ 123.8/121.0/119.1/114.6/111.8; 2550: 278.5/182.9/ 179.0/176.3/169.7/165.8; 3600: 367.9/243.9/238.8/ 235.2/226.7/ 221.5. Predicted mean price in current location: 193,444; at 2000 feet: 151,253; estimated RA price: 42,191.	River	regional	USA
Lansford Jr., N.H. and J.L. Jones.	"Recreational and Aesthetic Value of Water Using Hedonic Price Analysis,"	*Journal of Agricultural and Resource Economics*, 20 (2), 341-355.	1995	This study employs a HP approach to estimate the total nonmarket, implicit price of recreational and aesthetic benefits (RA) to residential properties in relatively close proximity to the lakes. Function-Use: Recreation.	HP	From January 1988 through December 1990.	In dollars per (square) feet.	Predicted mean price in current location (in $): 87,964; at 2,000 feet: 74,575; estimated RA price: 13,389. If lake level changes from 680 to 679 feet, the change in predicted aggregate housing price is (in $/Ac.-ft.): 109.98; from 674 to 673 feet: 116.02; from 668 to 667 feet: 122.42; from 662 to 661 feet: 129.04; from 656 to 655 feet: 135.58.	river	regional	USA
Lant, C.L.	"Potential for the Conservation Reserve Program to Control Agricultural Surface Water Pollution,"	*Environmental Management*, 15 (4), 507-518.	1991	This study estimates potential enrollment of streamside and floodplain croplands in a ten-year retirement program in order to gauge the potenial of the Conservation Reserve Program (CRP) as a water-quality improvement policy. Function-Use: Water Quality.	CV	1989	In dollars per acre and per year.	For example: at the present MARR (Maximum Acceptable Rental Rate) in the study area of $70/acre, estimated potential enrollment in filter strips and greenbelts is 27.9% and 25.4% of eligible acres, respectively. These totals could be improved to 37.7% and 29.4% by allowing haying on enrolled acreages or to 41.2% and 38.9% by adding an additional $30/ acre/yr to the annual rental offer.	Catchment	regional	USA
Lant, C.L. and R.S. Roberts.	"Greenbelts in the Cornbelt: Riparian Wetland, Intrinsic Values, and Market Failure,"	*Environment and Planning*, A 22(10), 1375-1388.	1990	The purpose of this study is to investigate the recreational and intrinsic values that Cornbelt residents place upon local streams, rivers, and reservoirs. Function-Use: Recreation.	CV	1987	$ / year	1A) $36,18; 1B) $48,65; 1C) $49,47; 2A) $43,29; 2B) $55,82; 2C) $53,86.	Catchment	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Lant, C.L. and G.A. Tobin.	"The Economic Value of Riparian Corridors in Cornbelts Floodplains: A Research Framework,"	*Professional Geographer*, 41 (3), 337-349.	1989	This paper illustrates how an economically efficient mix of wetlands and cropland on Cornbelt floodplains can be estimated and suggests how such a mix of land uses can be encouraged through appropriate agricultural policies. This research framework was applied to three drainage basins in the agricultural Midwest. Edwards (1), near the city of Aledo, Wapsipinicon (2) near the city of Anamosa, and South Skunk (3), near the city of Ames. Furthermore, the drainage basins were confronted with three types of river quality improvements: (a) poor-fair, (b) fair-good, (c) good-excellent. Function-Use: Recreation.	CV	1989	$ / year	1a) 35,2 ; 1b) 40,5 ; 1c) 24,3 ; 2a) 32,7 ; 2b) 38,5 ; 2c) 28,7 ; 3a) 29,9 ; 3b) 34,9 ; 3c) 35,1.	Catchment	regional	USA
Larson, D.M., R. J. Whale, R.Z. Smith and W.G. Brown.	"Estimated Net Economic Benefits to Visitors of Selected Columbia River Fish Hatcheries,"	Special Report 515, Agricultural Experiment Station, Oregon State University, Corvallis.	1978	Visitation to Columbia River fish hatcheries for educational and recreational purposes. Function-Use: Recreation.	CV	1974	$/ year. $/visitor.	(a. Value represents total benefits to incidental visitors of Spring Creek Hatchery in 1974. Incidental visitors are defined as those whose main purpose for the trip was not to visit the hatchery: 5557; (b. Value represents benefits per incidental visitor to Spring Creek Hatchery in 1974. Incidental visitors are defined as those whose main purpose for the trip was not to visit the hatchery: 0.61.	river	local	USA
Laughland, A.S., L.M., Musser, W.N. Musser and J.S. Shortle.	"The Opportunity Cost of Time and Averting Expenditures for Safe Drinking Water,"	*Water Resources Bulletin*, 29(2):291-299.	1993	Municipal water supply quality. Function-Use: Municipal and Domestic Water Supply.	AB	1989	$/ respondent.	Value is the mean averting costs to respondents who boiled water and hauled in other water to avoid using contaminated water. Value reflects operating costs only: 8.93.	catchment	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Laughland, A.S., W.N. Musser, J.S. Shortle, and L.N. Musser.	“Construct Validity of Averting Cost Measures of Environmental Benefits,”	*Land Economics*, 72 (1), 100-112.	1996	This paper reviews and extends the theoretical relationship between averting costs and WTP. Function-Use: Municipal and Domestic Water Supply.	CV, other	Between 1989 and 1992.	In dollars, per month per household.	Mean WTP for first choice water source: $18.44.	ground water	local	USA
Lingkubi, O. and J.A. Leitch.	“Economic Assessment of Soil Conservation Demonstration Plots in Tondano Watershed, North Sulawesi, Indonesia,”	*Canadian Water Resources Journal*, 21 (4), 403-414.	1996	To evaluate the economic impacts of soil conservation demonstration plots (demplots) on farmers and on the region. Function-Use: Recreation, Municipal and Domestic Water Supply.	CV	1995	Per ha, per year and in rupiahs.	Annualized net present value (ANPV) of the internal effects of demplot soil conservation practices for 25 yrs at 6%: Rp472,800 per ha; without demplots: Rp317,600 per ha. So it provides average annual net returns to farmers of Rp155,200. The NPV of the external benefits of existing demplots (25 yrs; 6%): Rp398 million, for an annual benefit of Rp45 million. The total quantified external benefit of soil conservation practices in all critical areas: Rp2,086 million annually, based on an assumed 10% overall improvement. The benefits of current soil conservation through demplots is Rp45 million annually.	River (watershed).	Regional	Indonesia
Lohman, L.C., G. Milliken, W.S. Dorn and K.E. Tuccy.	‘‘Estimating Economic Impacts of Salinity of the Colorado River,”	Prepared for United States Department of the Interior, Bureau of Reclamation by Milliken Chapman Research Group Inc. Littleton, Colorado.	1988	Effects of salinity of the Colorado River on end users. Function-Use: Agricultural Supply.	DF	1986	Dollars	(a. Value is the lower-bound estimate (allowing higher saline content) of salinity damage to agriculture in 1986: $15612000; (b. Value is the upper-bound estimate (requiring lower saline content) of salinity damage to agriculture in 1986: $25282000.			
Loomis, J.B.	‘‘The Bioeconomic Effects of Timber Harvesting on Recreational and Commercial Salmon and Steelhead Fishing: A Case Study of the Siuslaw National Forest,”	*Marine Resource Economics*, 5, 43-60.	1988	Effect of changes in timber harvest levels on recreational and commercial salmon and steelhead fisheries. Function-Use: Recreation.	MV	1948	Dollars million per 30 years. Dollars per fish.	(a. Reported value is the net present value, at 4% discount rate, of salmon catch by commercial fishing under the minimum management alternative [cessation of logging, building, grazing, and most other active management practices]: 1.69; (b. Reported value is the marginal value per salmon at Westport in Washington. The marginal value of fish was calculated as the change in the consumer surplus divided by the change in total fish population: 35.74.	river	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Loomis, J.B.	“A Bioeconomic Approach to Estimating the Economic Effects of Watershed Disturbance on Recreational and Commercial Fisheries,“	*Journal of Soil and Water Conservation*, January-February , 83-87.	1989	To predict the change in catchable fish populations due to watershed disturbances from road building and timber harvesting. Function-Use: Recreation.	TC	SNF: 1981; GNF: 1980-1984 and 1987.	In dollars and per trip.	Net present value for alternative current direction: sport salmon/ sport steelhead/ commercial salmon/total (in million $): 1.132/3.667/1.274/6.073; timber benchmark: 1.083/3.594/1.259/5.936; fish benchmark: 1.535/3.968/ 1.683/7.186; minimum management: 1.742/4.170/ 2.116/8.028. The economic value of the lost fish ro recreational and commercial anglers is $2 million (30-year period). GNF: the difference between PV of the benefits was: $3.5 million (50-year period).	Beaches and river;	regional	USA
Loomis, J.B.	“Estimation of and Variation in Site Specific Marginal Values for Recreational Fisheries,”	*Journal of Environmental Management*, 29, 183-191.	1989	To demonstrate how site specific marginal values per fish can be estimated using the TCM and to systematically relate the variation in sites marginal fish values to variables in the fishing demand function. Function-Use: Recreation.	TC	1977	In dollars per steelhead.	For rivers with the four lowest and four highest MV per fish (in $): Coos: 18; Chetco: 22; Alsea: 23; Coquille: 34; Clackamas: 176; Salmon: 178; Santiam: 185; Willamette; 333. For example: on the Hood River a decrease in fish stocks resulting in a 10% decrease in recreational steelhead catch causes the MV per fish to rise from 123 to 125.69. An increase results in a 10% increase in recreational steelhead catch results in the MV falling from 123 to 119.84. A similar sensitivity of MV to change in fish catch occurs for the other rivers as well.	River	regional	USA
Loomis, J.B.	“Monetizing Benefits Under Alternative River Recreation Use Allocation Systems,”	*Water Resources Research*, 16 (1), 28-32.	1980	An optimal capacity, when the binding use constraint is ecological damage and monetization of recreational benefits, under alternative means of rationing that capacity, were conceptually and empirically developed. Efficiency was suggested as one of the prime criteria. Function-Use: Recreation.	TC	1977	In dollars, per trip and per capita.	Demand curve: the optimal use is 50 trips (in stead of 211) and the price is $112.67 a trip (permit) rather than zero. In case of a price system: permits would be sold for at least: $112.67; the recreational benefits by this allocation would be appr. $6500 ($800 to the users; $5620 to the taxpayers. Lottery system: the expected value of the lottery is appr. $3690. With regard to Westwater, using the expected value fo the lottery, the equity index would be 0.57 (3690/6500). Thus 43% of the potential benefits are lost to society by adopting a more equitable allocation system.	River	catchment	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Loomis, J.B.	"The Economic Value of Instream Flow: Methodology and Benefit Estimates for Optimum Flows,"	*Journal of Environmental Management*, 24, 169-179.	1987	To present empirical relationships of the magnitude of economic benefits and quantity of instream flow from existing studies which use these techniques. Function-Use: Habitat.	A: CV B: TC	A: CV 1) summer 1978; 2) summer 1978. B: TC 1) summer 1982; 2) n.v.t..	US$ Per year, acre foot and cfs.	A: CV 1) study: the aggregate marginal values per cfs per day range from $ 23.23 for 100 cfs to $4.35 for 400 cfs. Marginal values actually are negative for > 500 cfs for anglers; shoreline users' bids are still $5.57 per cfs per day at 500 cfs and do not drop to zero until about 700 cfs. White-water boating marginal values are $9.55 per cfs per day. Aggregate marginal WTP per acre foot in a given month varies with the level of recreation use and water level. Seasonal average values ($) per acre foot: flow 100 cfs: anglers/ rafters/shore-line users/total: 11.71/ 4.86/ 8.22/24.79; 200 cfs: 8.54/4.86/ 8.22/20.28; 300 cfs: 5.37/4.86 /5.53/ 15.76; 400 cfs: 2.19/4.86/4.19/11.24; 500 cfs: -0.98/4.86/2.83/6.71. B: n.v.t.	A: CV 1) river; CV 2) 9 river B: TC 1) river; 2) river and a fork.	Regional	USA
Loomis, J.B.	"Measuring the economic benefits of removing dams and restoring the Elwha River: Results of a contingent valuation survey,"	*Water Resources Research*, 32(2), 441-447.	1996	WTP for removing dams to restore salmon fishery. Function-Use: Recreation.	CV		Pounds per household per year.	(a. local households: £41; (b. households in the rest of the state: 50; (c. households in the rest of the USA: 47.	river	national	USA
Loomis, J.B. and J. Cooper.	"Economic Benefits of Instream Flow to Fisheries: A Case Study of California's Feather River,"	*Rivers*, 1 (1), 23-30.	1990	Performing a benefit cost analysis of changes in instream flow requires knowledge of how the demand function shifts with changes in flow or flow related variables, such as fish catch. This paper presents a simultaneous system of demand and production equations that explicitely incorporates an instream flow variable. Function-Use: Recreation.	TC	1981-1985	US$	1) $23.00; 2,3,4) They mention "Marginal change per cfs": 2) $72.90; 3) $56.72; 4) $45.70.	river	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Loomis, J.B. and M. Creel.	"Recreation Benefits of Increased Flows in California's San Joaquin and Stanislaus Rivers,"	*Rivers*, 3 (1), 1-13.	1992	Using a survey of California households, a linked site choice and trip frequency model is estimated and used to calculate the recreation benefits to anglers, wildlife viewers, and waterfowl hunters of additional flows in the San Joaquin and Stanislaus rivers by month of the year. Function-Use: Recreation.	TC	1989	Per acre foot of water (6 till 13).	1) $128; 2) $137; 3) $159; 4) $403; 5) $451; 6) $45.22; 7) $71.25; 8) $104; 9) $116.43; 10) $10.83; 11) $12.82; 12) 12.94; 13) $13.45.	River	regional	USA
Loomis, J.B., M. Hanemann, B. Kanninen, and T. Wegge.	"Willingness to Pay to Protect Wetlands and Reduce Wildlife Contamination from Agricultural Drainage,"	in A. Dinar and D. Zilberman (eds.), *The Economics and Management of Water and Drainage in Agriculture*, 411-429.	1991	To survey the WTP of the general population in California for alternative programs to protect and expand wetlands as well as reduce wildlife contamination. Function-Use: Habitat, Agricultural Supply.	CV	1988	Per household, per year and in dollars.	Wetland maintenance: California (mean/90% confidence interval); Valley (mean/90% confidence interval): $152/123-188; $174/157-196; wetland improvements: $251/235-268; $286/255-325; contamination maintenance: $187/177-199; $197/179-216; contamination improvement: $308/289-331; $360/317-415; salmon improvement: $181/171-193; $202/180-231.Mean value per household: wetland maintenance: $154; wetland improvement: $254; contamination maintenance: $188; contamination improvement: $313: salmon improvement: $183.	Wetland	regional	USA
Loomis, J.B., C.F. Sorg, and D.M. Donnelly.	"Evaluating Regional Demand Model for Estimating Recreation Use and Economic Benefit: A Case Study,"	*Water Resources Research*, 22 (4), 431-438.	1986	To evaluate the US Water Resource Council recommendation that regional or multi-site recreation can be relied on instead of single site models by developing the advantages and disadvantages of different types and sizes of regional demand models relative to water resources planning issues needing to be addressed in benefit cost analyses. Function-Use: Recreation.	CV, TC	1983	In dollars per trip.	51 site TCM: per trip/total site: $34.37/$2131; 3 site TCM: $56.15/$3392; 1 site TCM: $66.64/$3205; CVM: $70.11/$3365.	Lake	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Lynne, G.D., P. Conroy and F.J. Prochaska.	"Economic Valuation of Marsh Areas for Marine Production Processes,"	*Ecological Economics*, 1, 335-361.	1981	Marshes in Florida that provide habitat for blue crabs. Function-Use: Commercial Fishing.	MV		Dollars per acre.	Present value of a marginal acre in human food (blue crab) production for the marginal acre is reported: 3.	Wetlands	regional	USA
MacDonald, D., J.C. Murdoch, and H.L. White.	"Uncertain Hazard, Insurance and Consumer Choice: Evidence from Housing Markets,"	*Land Economics*, 63 (4), 361-371.	1987	Investigate behavioural responses to a natural hazard (flooding) by examining residential property values. Function-Use: Flooding.	HP	From 1-1-1985 until 31-3-1985.	Square feet and dollars.	Full-sample: SP: 62,939.6; HSQFT: 1,722.1; OSQFT: 466.3; BATH: 1.81; AIR: 0.79; FIRE: 0.62; HIGH: 0.28; MEDIUM: 0.47; LOW: 0.25; FLOOD: 0.71. Sub-sample: SP: 90,839.3; HSQFT: 2,094.1; OSQFT: 606.92; BATH: 2.2; AIR: 0.82; FIRE: 0.75; FLOOD: 0.56.	river	regional	USA
Mannesto, G. and J.B. Loomis.	"Evaluation of Mail and In-Person Contingent Value Surveys: Results of A Study of Recreational Boaters,"	*Journal of Environmental Management*, 32, 177-190.	1991	Wetland loss Function-Use: Recreation.	CV	Interview data from 29 August to 9 October 1987; Mailing data also in this same period	$, and concerning the mail back list: 25% increase or 50% increase of total delta wetlands	1a) 69.80; 1b) 37.12; 1c) 37.85; 2a) 59.27; 2b) 39.47; 2c) 33.14	Delta LAKE BAY	regional	USA
Mäntymaa, E.	"Some new ideas and preliminary results for using the CVM in measuring the environmental benefits of a lake,"	Paper presented at Autumn Workshop in Environmental Economics in Venice, September 29 - October 5, 1991, 17 p. (unpublished).	1991	The purpose of the research is to put a value on the quality of the environment attached to a lake in monetary terms. Function-Use: Water Quality.	CV		FIM per person annually.	Average WTP to avoid one level poorer water quality: (a. for users: 930; (b. the general public (non-users): 764; (c. forest owners: 464.	lake	local	Finland
McClelland, G.H., W.D. Shulze, J.K. Lazo, D.M. Waldman, J.K. Doyle, S.R. Ellliot, and J.R. Irwin.	"Methods for Measuring Non-Use Values: A Contingent Valuation Study of Groundwater Clean-Up,"	Report, U.S. EPA Cooperative Agreement #CR-815183, University of Colorado, USA.	1992	To value the national benefits of cleaning ground water contamination by leaching from landfills. Function-Use: Municipal and Domestic Water Supply.	CV	1991	US$ per month, per household and per year.	A. $3.95/mo./HH ($47/yr/ HH); B. $1.13 ($14); C. $4.02 ($48); D. 10%: $3.86 ($46), 70%: $13.34 ($160)/ E. $1.34 ($16); F. $7.01 ($84).	Ground water	national	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Mendelsohn, R., D. Hellerstein, M. Huguenin, R. Unsworth, and R. Brazee.	"Measuring Hazardous Waste Damages with Panel Models,"	*Journal of Environmental Economics and Management*, 22, 259-271.	1992	In this study they suggest the analysis of residential panel data as an alternative methodology for measuring the damage hazardous waste sites may have upon surrounding real estate values. Function-Use: Recreation.	HP	1969 till 1988	1989$	1a) -9046; 1b) -0,0837; 1c) -10558; 1d) -0,0747; 2a) -6995; 2b) -0,0704; 2c) -6633; 2d) -0,0311.	Harbour	local	USA
Mendelsohn, R., J. Hof, G. Peterson, and R. Johnson.	"Measuring Recreation Values with Multiple Destination Trips,"	*American Journal of Agricultural Economics*, 74, 926-933.	1992	To develop an alternative method of analyzing multiple destination trips. Function-Use: Recreation.	TC	The trip itineraries of visitors to Bryce Canyon National Park colleced by Haspel and Johnson (1982) is used.	Dollars, time and miles.	Consumer surplus estimates of the value of Bryce: single destination trips with no substitutes: $10.81; single destination trips with substitutes: $9.47; single and multiple destination trips: $16.80.	Canyon. WETLANDS	regional	USA
Middlesex University	''The Evaluation of the Recreational and other Use Values from Alleviating Low Flows,''	NRA R&D note 258.	1994	WTP of anglers for benefits of low flow alleviation. Function-Use: Recreation, Non-use value.	CV		Pounds per angler per visit. £/km/yr.	(a. rural river: 5.5; (b. 9.8; Non-use value for improvements in quality: (c. from very poor to moderate: 144,000; (d. from moderate to good coarse fishery: 15,500.	river	local	United Kingdom
Millham, C.B. and C.F. Culver.	''Energy Loss and Replacement Cost of Navigation of the Snake-Columbia Rivers,''	*Water Resources Bulletin*, 15(6), 1776-1780.	1979	Energy loss associated with river use for navigation instead of power production. Function-Use: Navigation.	RC	1975	$ thousands/ year.	(a. Value measures annual replacement cost of water used for navigation by commercial boaters based on losses at 8 hydroplants in 1975 at 30 mills/ KWH (1 mill = $.001): 2405; (b. Value measures annual replacement cost of water used for navigation by pleasure boaters based on losses at 8 hydroplants in 1975 at 40 mills/ KWH (1 mill = $.001): 890.	river	region	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Miyata, Y. and H. Abe.	"Measuring the Effects of Flood Control Project: Hedonic Land Price Approach,"	*Journal of Environmental Management*, 42, 389-401.	1994	Aim is to measure the effects of a flood control project planned for the Chitose River Basin in Japan by evaluating the reduction in expected physical flood damage derived by construction and improvement of flood control facilities. Function-Use: Flooding.	HP	1990	Yen per Km^2, cm and unit area.	The total annual average cost of the flood control project for the Chitose River (in million yen): case 1: project cost/annual average cost: 0/0; case 2: 96787/4898; case 3: 143225/7247; case 4: 201848/10214; case 5: 267405/13531; case 6: 310366/15705. Total benefit: Ebetsu: 5032.0/146.3; Chitose: 12499.2/ 336.0; Eniwa: 24460.3/497.2; Hiroshima: 8191.5/615.9; Nanporo: 7479.2/138.2; Naganuma: 26390.2/288.4; total: 84052.4/300.5. The corresponding total cost is estimated as 310.4 billion yen and the total estimated benefit computed from the land price variations is 84 billion yen, thus the flood control project under this study may be deemed as a less cost-efficient project.	River basin. Catchment	regional	Japan
Moncur, J.E. and R.L. Pollock.	"Scarcity Rents for Water: A Valuation and Pricing Model,"	*Land Economics*, 64(1), 62-72.	1988	Supply of groundwater. Function-Use: Groundwater Recharge.		Other	Dollars per 1000 gallons.	(a. Estimate is the scarcity present value of 1000 gallons of in-ground water for a model assuming constant marginal extraction cost of $.19 per 1000 gallons and high demineralization costs: 1.58; (b. Estimate is the scarcity present value of 1000 gallons of in-ground water for a model assuming an exponential marginal extraction cost: 1.68.	groundwater	reegional	Hawaii
Mooney, S.	"Relationship Between the Implicit Value of Riverside Property, Environmental Amenities, and Streambank Protection,"	paper presented at the Annual Meeting of the Western Agricultural Economics Association, Reno/Sparks, Nevada, USA.	1997	To estimate the marginal implicit value of planting a trees riparian buffer on residential properties with the objective of reducing stream temperature and improving fish habitat. Riparian and instream restoration/protection programs have received increasing attention as a measure to improve fish and wildlife habitat, stream bank stability and flood protection. Function-Use: Flooding.	HP	1987 to 1996.	US$ per (Square) feet and acres.	Marginal implicit prices of environmental attributes at their mean market values: FRTLGTH marginal price ($/foot of frontage): Model I/II: 60.51/48.41; ACRETREE marginal price ($/square foot of riparian area in trees): -1.40/-1.44.	Watershed. STREAM	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Moore, W.B. and McCarl, B.A.	"Off-Site Costs of Soil Erosion: A Case Study in the Willamette Valley,"	*Western Journal of Agricultural Economics*, 12(1): 42-49.	1987	Off-site sediment costs (soil erosion). Function-Use: Municipal and Domestic Water Supply.	SM		$/ day.	(a. Value is average cost of cleaning sediment/ operating day. Marginal cost estimates were constructed but not reported: 75.84; (b. Value is average cost of sediment per million gallons of water treated. Marginal cost estimates were constructed but not reported: 20.	catchment	region	USA
Muckleston, K.W.	"The Impact of The Floodplain Regulations on Residential Land Values in Oregon,"	*Water Resources Bulletin*, 13 (1), 1-7.	1983	This research sought to resolve some of the ambiguities about the relationship between floodplain regulations and residential land values. Function-Use: Recreation.	HP	For the north Albany study area: 1970-1976; for the Oak Grove study area: 1958-1981.	Dollars.	North Alby area: all regulated parcels (sample size: 45, method M1 (see also 9.1)): comparative mean growth rate: 177; all unregulated parcels (46): 127; all regulated parcels (46, M2): 127; all regulated parcels (45): 142; regulated parcels built during 1970-76 (16, M1): 263; unregulated parcels built during 1970-76 (16): 57; unregulated parcels built during 1970-76 (16, M2): 57; unregulated parcels built during 1970-76 (16): 165; undeveloped regulated parcels (unbuilt, 8, M2): 76; unregulated parcels built during 1970-76 (16): 57. Results for the Oak Grove area: interval 1962-81: categories: unregulated (sample size: 27)/regulated: nonwaterfront(22)/ lake front()13/river front(25): means: 902.5/916.6/955.2/782.8; 1962-69: sample sizes: 27/22/13/25: means: -2.5/-8.9/-25.5/-19.1; 1972-81: sample sizes: 27/22/13/25: means: 440.2/456.9/ 417.2/643.3; 1975-81: sample sizes: 42/41/13/25: means: 208.7/213.2/ 194.6/336.2.	catchment	regional	USA
Mullen, J.K. and F.C. Menz.	"The Effect of Acidification Damages on the Economic Value of the Adirondack Fishery to New York Anglers,"	*American Journal of Agricultural Economics*, 67, 112-119.	1985	To estimate losses in the Net Economic Value (NEV) of the Adirondack recreational fishery. Function-Use: Recreation.	TC	A 1976 survey.	Dollars and miles.	Total NEV for the entire fishery: $31,293,161. The loss to anglers from acidification dammage (acidified streams not included): $1,073,364.	Fishing sites were classified into three categories: cold-water lake, "other" ponded waters and streams.	Regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Naeser, R.B. and L.L. Bennett.	"The Cost of Noncompliance: The Economic Value of Water in the Middle Arkansas River Valley,"	*Natural Resources Journal*, 38(3), 445-463.	1998	Irrigation water value for southeast Colorado and southwest Kansas. Function-Use: Agricultural Supply.	Other	1995	$/ acre foot.	(a. Value represents the average value per acre foot of irrigated water to sorghum production in Southeastern Colorado: 28; (b. Value represents the average value per acre foot of irrigated water to wheat production in Southwestern Kansas: 44. (b.	ground and surface water	regional	USA
Navrud, S.	"Economic evaluation of recreational fishing in the River Hallingdalselv,"	M.Sc. thesis. Agricultural University of Norway. Published in the Norwegian Water Resources and Energy Administration (NVE)'s report series, Information no. 26 (1987), 121 pp.	1984	Recreational value of freshwater angling. Function-Use: Recreation.	TC		NOK per angler per day.	170	river	local	Norway
Navrud, S.	Recreational value of Atlantic salmon and sea trout angling in River Vikedalselv - before regular liming,"	In Navrud, S. (1989): Valuation of Environmental goods - methodological and empirical studies of the effects of acid depositions on freshwater fish stocks. Doctor Scientarium theses 1989:17. Department of Forest Economics, Agricultural University of Norway, Scientific report no. 3/1989.	1988	Recreational value of freshwater angling. Function-Use: Recreation.	TC, CV		NOK per angler per day.	TC: 139-190 CV: 131-187	river	local	Norway
Navrud, S.	"Estimating social benefits of environmental improvements from reduced acid depositions: A Contingent Valuation survey,"	In H. Folmer and E. van der Ierland (eds.): Valuation methods and policy making in environmental economics. Studies in Environmental Science 36; 69-192, Elsevier Science Publishers, Amsterdam.	1989	Non-use values of freshwater fish stocks. Function-Use: Water quality.	CV		NOK per household	Mean annual WTP for increased fish stocks as a result of 30-70% reductions in an European sulphur emissions: 405	Lake, river	national	Norway
Navrud, S.	"Cost benefit analysis of river liming. A case study of river Audna,"	Directorate for Nature Management, Report 1990-6.	1990	Recreational value of freshwater angling. Function-Use: Recreation.	TC, CV		NOK per angler per day.	TC: 214-243 CV: 94-274	river	local	Norway

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Navrud, S.	"Social profitability of liming selected trout lakes in the Adger counties,"	Report for the Directorate for Nature Management, 51 pp.	1991	Recreational value of freshwater angling. Function-Use: Recreation.	TC, CV		NOK per angler per day.	(a. Lake Lauvann TC: 119-151; CV: 76-103; (b. Gjerstadskog Lakes TC: 85-95; CV: 44-65;	lakes	local	Norway
Navrud, S.	"Social profitability of liming River Audna. An extended analysis,"	Report for the Directorate for Nature Management, 35 pp.	1991	Recreational value of freshwater angling. Function-Use: Recreation.	CV		NOK per household per year.	WTP to avoid the extinction of the current salmon and sea trout stocks in River Aunda: 120.	river	local	Norway
Netusil, N.R., W.D. Shaw, E. Huszar, and C. Leversee.	"Potential Economic Impacts of Mine Dewatering in the Humboldt River Basin of Nevada: Preliminary Survey Results,"	unpublished paper, Department of Economics, Reed College, Department of Applied Economics and Statistics, University of Nevada, USA.	1996	This paper describes the preliminary results from a survey designed to evaluate respondents' valuation of mining activities in the Humboldt River Basin of Nevada. Function-Use: Recreation.	CV	1996	For scenario 1 and 2 $ each year for the next 5 years..	1) $96; 2) $80; 2a) $17,35; 2b) $56,69; 2c) $304,91; 2d) $74,52; 2e) $115,29; 2f) $82,92; 2g) $121,59; 2h) $31,28.	River	regional	USA
Olsen, D., J. Richards, and R.D. Scott.	"Existence and Sport Values for Doubling the Size of Columbia River Basin Salmon and Steelhead Runs,"	*Rivers*, 2 (1), 44-56.	1991	This article summerizes the results of an existence valuation study using a state of the art contingent valuation approach, provides a set of initial guidelines to be followed in conducting existence valuation studies, and summerizes the results of a new sport value study for salmon and steelhead fishing in the Pacific Northwest residents to place an existence value on doubling the run. The recommendation is made that existence and sport values should be considered in mitigation and enhancement decisions. Function-Use: Recreation.	CV	1989	US$ per month per person.	1a) 2,21; 1b) 3,39; 2a) 4,88; 2b) 5,82; 3a) 6,18; 3b) 10,25.	River	regional	USA

Bibliographic study characteristics	Study characteristics									
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
O'Neill, C.E. and J. Davis.	"Alternative Definitions of Demand for Recreational Angling in Northern Ireland,"	*Journal of Agricultural Economics*, 42 (2), 174-179.	1988	The effects of three alternative definitions of demand on estimated parameters are explored in a TC-study of aggregate demand for recreational angling. Function-Use: Recreation.	TC	1988	In UK pounds, per visit or per year, in miles and in minutes.	Estimated user benefits (in millions of UK pounds): 1. 9.1; 2. 22.21; 3. 10.66.	lakes, river and beaches.	Regional	Ireland
Oster, S.	"Survey Results on the Benefits of Water Pollution Abatement in the Merrimack River Basin,"	*Water Resources Research*, 13 (6), 882-884.	1977	It is a report on and an analysis of a survey of individuals' WTP for water pollution abatement in the Merrimack River Basin. Function-Use: Recreation.	CV	1973	US$ per year per person	$12	river	regional	USA
Palm Jr., R.C. and S.P. Malvestuto.	"Relationships between Economic Benefit and Sport-Fishing Effort on West Point Reservoir, Alabama-Georgia,"	*Transactions of the American Fisheries Society*, 112, 71-78.	1983	This paper uses a modification to estimate the net worth of the sport fishery at West Point Reservoir, over the first 5 years after impoundment. Function-Use: Recreation.	TC	1976-1980	In dollars per visitor-kilometre, per fishing season and per angler-day.	All anglers: actual expenditures per angler-day/ CS per angler day/ total user-oriented value per angler-day (in $): 7.80/ 8.90/16.90; bank anglers: 4.50/6.20/10.70; boat anglers: 9.60/ 13.40/23.00; bass anglers: 12.40/30.60/ 43.00; crappie anglers: 7.40/10.80/ 18.20.	Reservoirs. Catcnment	catchment	USA
Parsons, G. R. and M.J. Kealey.	"Benefits Transfer in a Random Utility Model of Recreation,"	*Water Resources Research*, 30(8), 2477-2484.	1994	Mean benefit from visiting lakes in Wisconsin - random utility model based on travel costs only. Function-Use: Recreation.	RUM		Pounds per visit.	1	lakes	regional	USA
Pate, J. and J.B. Loomis.	"The Effect of Distance on Willingness to Pay Values: A Case Study of Wetlands and Salmon in California,"	*Ecological Economics*, 20, 199-207.	1997	This paper examines the issue of geographical distance to determine if distance negatively affects willingness to pay values. Function-Use: Habitat.	CV	1991	US$ per year per person	Total benefits (aggregate in millions): 1a $175; 1b $2,2357; 1c $81; 1d $203; 1e $102; 2a $190; 2b $2,490; 2c $62; 2d $175; 2e $105.	Wetland	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Patrick, R., J. Fletcher, S. Lovejoy, W. Van Beek, G. Holloway, and S. Lovejoy.	"Estimating Regional Benefits of Reducing Targeted Pollutants: An Application to Agricultural Effects on Water Quality and the Value of Recreational Fishing,"	*Journal of Environmental Management*, 33(4), 301-310.	1991	Recreational fishing benefits from reductions in water pollution from agriculture. Function-Use: Recreation.	TC	1980	$ / year	Value represents aggregate benefits from a 10% reduction in total suspended solids runoff: 3698651.	catchment	regional	USA
Pearson, M.	"Recreational and Environmental Valuation of Rutland Water,"	Chapter 5, unpublished PhD thesis, University of East Anglia, Norwich.	1992	WTP to maintain water quality at a standard high enough to support boating and recreational activities. Function-Use: Recreation.		1992	Pounds per household per year.	18.83	reservoir	local	United Kingdom
Phaneuf, D.J., C.L. Kling and J.A. Herriges.	"Valuing Water Quality Improvements Using Revealed Preference Methods When Corner Solutions are Present,"	*American Journal of Agricultural Economics*, 80(5), 1025-1031.	1998	Recreational fishing and water quality. Function-Use: Recreation, Water Quality.	TC	1990	$/angler/ season.	Value is the compensating variation associated with a 20% reduction in toxins at all sites. The value reflects both direct-use and non-use (not existence) values: -116.45.	lakes	regional	USA
Piper, S.	"Regional Impacts and Benefits of Water-Based Activities: An Application in the Black Hills Region of South Dakota and Wyoming,"	*Impact Assessment*, 15, 335-359.	1997	To estimate the regional impacts and benefits of irrigated agriculture, water-based recreation and municipal water supplies to households in the region and to present the potential incremental, or marginal, effects from changes in water supplies in the Black Hills region. Function-Use: Recreation, Agricultural Supply, Municipal and Domestic Water Supply.	TC	1991	In dollars, per visitor and per year.	Benefits from irrigation are $54.40 per irrigated acre or $21.75 per acre-foot of water. Benefits per visit is: $20.10 per visit. OLS: WTP (month)/WTP (year)/ WTP for the entire region (in $): 5.53/66.36/ 4.20 million; WLS: 5.07/ 60.84/3.85 million; Tobit: 6.12/73.44/4.65 million; weighted tobit: 7.67 /92.04/ 5.82 million.	River	regional	USA
Poe, G.L.	"Valuation of Groundwater Quality Using a Contingent Valuation Damage Function Approach,"	*Water Resources Research*, 34 (12), 3627-3633.	1998	To estimate a damage function for nitrate exposures based on actual water test results of individual wells. Function-Use: Municipal and Domestic Water Supply.	CV	Year of study: 1998.	Dollars, mg/L and years.	n.a	Individual wells. GROUND WATER	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Poe, G.L.	"Valuation of Groundwater Quality: Contingent Values, Public Policy Needs, and Damage Functions,"	Working Paper 97-22, Department of Agricultural, Resource, and Managerial Economics, Cornell University, USA.	1997	This paper argues that there is an inherent incompatability between groundwater contingent valuation research as it has developed in the last decade, and groundwater management policy and benefits transfer needs. This paper provides the results from a groundwater contingent valuation study that tested individual wells for nitrates, and then solicited WTP values for a groundwater protection program. Function-Use: Municipal and Domestic Water Supply.	CV	1997?	If nitrate level in groundwater exceeds the government health standard of 10 mg/l NO3-N.	Range of mean value: $1 - $999	ground water	local	USA
Poe, G.L. and R.C. Bishop.	"Application of a Convolutions Approach to Measuring the Differences in Benefit Measures from Dichotomous Choice Contingent Valuation,"	Working paper, selected for the annual meetings of the American Agricultural Economics Association, USA.	1992	To calculate the WTP for measures to reduce actual levels of ground water contamination. Function-Use: Municipal and Domestic Water Supply.	CV	1991	In dollars, per household per year.	Stage I: no info/no prior test: $223/ HH/yr; no info/prior test: $246/HH/ yr; info/no prior test: $708/HH/yr; info/prior test: $355/HH/yr. Stage II: no prior test: $168/HH /yr; prior test: 355/HH/ yr.	Ground water	regional	USA
Poe, G.L. and R.C. Bishop.	"Measuring the Benefit of Groundwater Protection from Agricultural Contamination: Results from a Two Stage Contingent Valuation Study,"	Staff Paper Series, Department of Agricultural Economics, University of Wisconsin-Madison, USA.	1992	This paper reports the preliminary results of a two-stage contingent valuation study of groundwater protection. Attention is focused on how information affects the value on "bright-line" government standards. Function-Use: Municipal and Domestic Water Supply.	CV	1990	US$ per annum	1) $257,1; 2) $269,3; 3) $414,8	ground water	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Poe, G.L. and R.C. Bishop.	"Valuing the Incremental Benefits of Groundwater Protection when Exposure Levels are Known,"	*Environmental and Resource Economics*, 13, 341-367.	1999	Little progress has been made towards linking stated WTP measures with actual groundwater contamination levels. Function-Use: Municipal and Domestic Water Supply.	CV	1999	US$	The mean nitrate level was 5.90 mg/l. Appr. 16% of the tests exceeded government standared of 10 mg/l. Descriptive statistics of model variables (n-205): LIVEPAST (categorical variable for no. of yrs of residence in PC; 0= <1yr; 1= 1-5 yrs; 2= 6-10 yrs; 3= 11-15 yrs; 4= > 15 yrs): 2.38 (1.01); OWNAGE (categorical variable: 1= <18; 2= 18-44; 3= 45-64; 4= >64): 2.71 (0.77); DSEX (binary variable: 0= male; 1= female): 0.38 (.49); DCOLLEGE GRAD (binary variable for college graduate: 0= no; 1= yes): 0.26 (0.43); DFARM (binary variable for involvement in farming; 0= no; 1= yes): 0.20 (0.40); DAVTPERM (binary variable for permanent averting activities of installing a purification system or carrying water from another source; 0= no; 1= yes): 0.03 (0.19); DBOTWAT (binary variable for purchase of bottled water for health reasons; 0= no; 1= yes); 0.01 (0.12); NONUSE (categorical variable for nitrate health concerns about other people living today and future generations; 2= not concerned to 8= extremely concerned): 6.71	ground water	regional	USA
Poor, J.	"The Value of Additional Central Flyway Wetlands in Nebraska's Rainwater Basin Wetland Region,"	Unpublished paper, Department of Agricultural Economics, University of Nebraska-Lincoln, USA.	1997	The objective of this study is to apply the CVM to estimate the value to the people of Nebraska, of government acquisition and/or management programs to increase the current amount of Rainwater Basin (RWB) wetlands. Function-Use: Habitat.	CV	The summer of 1996.	Dollars and per year.	Mean WTP: $126.79.	wetland	regional	USA
Posford Duvivier.	"Engineering Estimates of Flood Control Benefits, in Markandya and Rhodes,"	*Environmental Valuaton Studies in Europe*, Mimeo.	1990	UK National Rivers Authority proposed a flood alleviation scheme for the Thames Valley. Object was to estimate benefits from the scheme. Function-Use: Flooding.	CV		Pounds per household per year.	4-6 for reduced risk level, amounting to present value at 6% and 50-year time horizon of £2.5-3.7million for approx. 40,000 households.	river	regional	United Kingdom

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Postle, M. and S. Carpenter.	"Freshwater Ecosystem Services,"	In Nature's Services, Dailey, G. (ed.), Island Press, Washington DC.	1997	WTP for low flow alleviation. Function-Use: Freshwater replenishment, Recreation.	CV		£/m³ of water.	(a. fisheries benefits in a river in Colorado: 0.01; (b. river recreation: 0.04.	River, reservoir	regional	USA
Powell, J.R.	"The Value of the Groundwater Protection: Measurement of Willingness-to-Pay Information, and Its Utilization by Local Decisionmakers,"	Unpublished Ph.D. dissertation, Departmet of Agricultural Economics, Cornell Univeristy, USA.	1991	To elicit values based on respondents subjective perceptions of ground water contamination. Function-Use: Municipal and Domestic Water Supply.	CV	1989 (MA: midsummer; NY and PA early fall).	In dollars, per year and per household.	Means of WTP-question for all data: $61.55/HH/ year; for history of contamination: $81.86; for no history of contamination: $55.79; for private $14.04 greater than public, but public more concerned.	Ground water	regional	USA
Powell, J.R., D.J. Allee, and C. McClintock.	"Groundwater Protection Benefits and Local Community Planning: Impact of Contingent Valuation Information,"	*American Journal of Agricultural Economics*, 76(5), 1068-1075.	1994	To investigate the use of CV information as a tool to persuade local government decision makers to implement water supply protection policies. Function-Use: Municipal and Domestic Water Supply.	CV	n.v.t.	Dollars, per household and per year.	CV survey: mean WTP: $61.55/ household/year;.	Ground water	regional	USA
Provencher, B. and R.C. Bishop.	"An estimable dynamic model of recreation behaviour with an application to Great Lakes angling,"	*Journal of Environmental Economics and Management*, 33(2), 107-127.	1997	WTP for angling on Lake Michigan Function-Use: Recreation.	CV		Pounds per person per trip.	(a. derby trip: 60; (b. non-derby trip: 25.	lake	local	USA
Provencher, B. and O. Burt.	"A Private Property Rights Regime for the Commons: The Case for Groundwater,"	*American Journal of Agricultural Economics*, 76(4), 875-888.	1994	Rights to ground water resource stocks.	OM	1989	Dollars millions	(a. Estimate is expected value under central control regime, a system where a regulatory agency allocates water optimally over time: 577.2; (b. Estimate is expected value under private property rights regime where firms are granted tradeable permits for groundwater stock: 574.6.	ground water	regional	USA
Qui, Z.Y. and T. Prato.	"Economic Evaluation of Riparian Buffers in an Agricultural Watershed,"	*Journal of the American Water Resources Association*, 34(4), 877-890.	1998	Nonpoint source pollution control functions provided by riparian buffers. Function-Use: Agricultural Supply.	OM		US$	Net economic value of riparian buffers when 3 ppb of atrazine concentration in stream water (ACSW) is required: 64389.	catchment	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Radford, D. *et al.*	"An economic valuation of salmon fisheries in Great Britain,"	CEMARE Report No. 16, Centre for Marine Resource Economics, University of Portsmouth.	1991	Total expenditure by anglers on recreational fishing activities. Function-Use: Recreation.	other		Pounds per angler per day. Pounds per angler per year.	(a. 17.18; (b. 548.	river	Regional	United Kingdom
Ready, R.C., J. Malzubris, and S. Senkane.	"Use of Contingent Valuation to Value Environmental Improvements in a Transition Economy: Water Quality Improvement in Latvia,"	Agricultural University of Norway, Norway.	1997	The purpose of this study is to estimate the benefit that Latvian residents would receive from a typical Program 800+ investment - in case an improvement in handling and treatment of sewage in a medium-sized town. Program 800+ is the implementation of an ambitious package of infrastructure investments in over 800 smaller and medium sized towns in Latvia. This is done by a case study in which two sections were discussed: (1) drinking water quality, and (2) sewage treatment and water quality in the Gauja River, and. A second goal of this study was to assess the performance of the CV method in this transition economy (Latvia). Function-Use: Municipal and Domestic Water Supply.	CV	1996	Us dollars per month (1 $ = 2 LET Lats)	1) $0,30 2) $0,125	river	local	Latvia
Renzetti, S.	"Evaluating the Welfare Effects of Reforming Municipal Water Prices,"	*Journal of Environmental Economics and Management*, 22, 147-163.	1992	Municipal and industrial water use. Function-Use: Industrial Supply.	SM	1986	Dollars per 1,000 cubic meters.	(a. Value is equilibrium price in 1986 dollars for commercial uses of water under peak load pricing method in the winter: 4.4; (b. Value is equilibrium price in 1986 dollars for industrial uses of water under 3rd degree price discrimination pricing method in the summer: 140.1.	Ground and surface water	national	Canada

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Ribaudo, M.O.	''Water Quality Benefits from the Conservation Reserve Program,"	USDA Economic Research Service, Agricultural Economic Report no. 561.	1989	Water quality benefits from removal of highly erodible cropland from production. Function-Use: Agricultural Supply.	DF	1986	Millions of Dollars	Value is an estimate of the present discounted off-site water quality benefits to irrigation ditches resulting from the reduced pollutant discharges from 23 million acres of cropland under CRP: 23.	Ground and surface water	national	USA
Ribaudo, M.O. and J.E. Epp.	"The Importance of Sample Discrimination in Using the Travel Cost Method to Estimate the Benefits of Improved Water Quality,"	*Land Economics*, 60 (4), 397-403.	1984	The question in this study is: can it be assumed that the benefits they will receive from an improvement in environmental quality are the same as those for the recreationists who remain? Function-Use: Recreation.	TC	1982	In dollars, per year and per number of trips.	Mean level of benefits for current users: $123.00; for former users: $97.00.	lakes and bays.	Regional	USA
Ribaudo, M.O., C.E. Young, and D. Epp.	"Recreation Benefits from an Improvement in Water Quality at St. Albans Bay, Vermont,"	ERS Staff Reprt No. AGES840127, Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture, Washington, D.C., USA.	1984	This report presents research results estimating the dollar value of recreation benefits, which would result from improving the water quality in St. Albans Bay, Vermont. Function-Use: Recreation.	CV, TC	1982	In dollars 1982 per capita.	A: 1) $54; 2) $40 B: Improvement of water quality over 10 years: discount rate: 3.9%/ 7.875/ 11.8 (in 1,000 $): 4,375/3,622/ 3,058; over 50 years: 11,730/6,662/ 4,531. Maintenance of current water quality over 10 years: 1,113/922 /775; over 50 years: 2,972/1,688/1,148.	Bay	regional	USA
Rich, P.R. and L.J. Moffitt.	"Benefits of Pollution Control on Massachusetts' Housatonic River: A Hedonic Pricing Approach,"	*Water Resources Bulletin*, 18 (6), 1033-1037.	1982	This paper illustrates one mode of analysis for estimating the benefits of water pollution control projects. çRecreation, Municipal and Domestic Water Supply.	HP	Assessors records of 1957-1975.	In dollars and per acres.	Benefit estimate suggests a postabatement property value increase of appr. $37 per occupied acre ($31 for nonriparian land).	River	regional	USA
Roberts, R.K., P.V. Douglas and W.M. Park.	''Estimating External Costs of Municipal Landfill Siting Through Contingent Valuation Analysis: A Case Study,"	*Southern Journal of Agricultural Economics*, 23(2), 155-165.	1991	Groundwater contamination, smell, noise, and traffic resulting from proximity to a landfill. Function-Use: Water Quality.	CV	1988	$/ household/ year.	Value is the additional annual household WTP to avoid a landfill in the community for respondents who relied on well water (additional amount in comparison to respondents who depended on piped city water): 141.	ground water	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Roberts, L.A. and J.A. Leitch.	"Economic Valuation of Some Wetland Outputs of Mud Lake, Minnesota, South Dakota,"	Agricultural Economics Report No. 381, Department of Agricultural Economics, North Dakota State University, USA.	1997	The purpose of this study was to approximate some economic values of Mud Lake, a managed "wetland" on the border between Minnesota and South Dakota, to proveide information to promote more efficient and effective management of Mud Lake and its wetlands. This is done by evaluating some selected outputs: flood control, water supply, fish and wildlife habitat, recreation and aesthetics, and disamenities to water quality. The CVM was used to valuate fish and wildlife habitat, recreation, and aesthetics. Water quality was valued by estimating the extra costs of water treatment, floodcontrol by damages prevented, and water supply by estimating a residual return to public wear utilities. Function-Use: Recreation, Flooding.	CV	1995	$ per year per acre	Flood contol: total: $440; Water supply/ conservation: $94; WTP regarding fish/wildlife habitat, recreation, and aesthetics: 1) $7; 2) $8, 3) $6.	Lake	regional	USA
Roberts, L.A. and J.A. Leitch.	"Economic Valuation of Some Wetland Outputs of Mud Lake, Minnesota, South Dakota,"	Agricultural Economics Report No. 381, Department of Agricultural Economics, North Dakota State University, USA.	1997	To estimate some economic values of Mud Lake. Function-Use: Flooding, Habitat, Recreation, Water Quality.	CV	year of data: 1996	$ per year per acre	Total Benefits: Annual flood control benefits: $2.2 million ($440 per acres per year); water supply benefits: appr. $94,000 ($94); fish and wildlife habitat, aesthetics and recreation benefits estimated to be appr. $102,000 ($21); water quality degradation costs: $180,000 ($180); total benefit: $2,396,000. Aggregated dollar value was appr. $2,216,000 ($375) with a capitalized value of about $36,933,000.	Lake, wetland	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Roe, B., K.J. Boyle, and M.F. Teisl.	"Using Conjoint Analysis to Derive Estimates of Compensating Variation,"	*Journal of Environmental Economics and Management*, 31, 145-159.	1996	To derive estimates of Hicksian compensating variation from conjoint analysis ratings data by using several approaches. Function-Use: Recreation.	CV	1991	In dollars and per day.	Mean compensating variation: Program A (see 6.5.2): linear tobit/nonlinear tobit/ad hoc, rankings logit/linear binary logit (in $/day): 22/52/55/30; program B: 65/163/175/37; program C: 49/134/ 143/33; program D: 60/178/121/ 26; program E: 63/164/ 162/32.	River	local	USA
Rolfsen, J.	"Recreational value of Atlantic salmon and sea trout angling in parts of river Gaula in 1990,"	M.Sc. thesis, Agricultural Univerty of Norway.	1991	Recreational value of freshwater angling. Function-Use: Recreation.	TC, CV		NOK per angler per day.	TC: 440-607; CV: 321.	river	local	Norway
Rollins, K.	"Wilderness Canoeing in Ontario: Using Cumulative Results to Update Dichotomous Choice Contingent Valuation Offer Amounts,"	*Canadian Journal of Agricultural Economics*, 45, 1-16.	1997	To demonstrate empirically how using cumulative results from returned surveys to update contingent valuation offer amounts can improve the efficiency of estimates. Function-Use: Recreation.	CV	The 1993 canoeing season.	In dollars, per day and per trip.	Model 1: increase in general trip costs/ increase in permit fee: $63.42/24.44; model 2 (increase in total trip costs/permit fee): A: $67.37/$22.35; Q: $65.82/$28.63; K: $66.76/$21.59; model 3: this ranged from 3 days to > 20 days: $75.99-$15.42/$27.06-$15.32.	river	regional	Canada
Rollins, K. and W. Wistowsky.	"Benefits of Back-Country Canoeing in Ontario Wilderness Parks,"	*Journal of Applied Recreation Research*, 22 (1), 9-31.	1997	This study reports on an application of non-market valuation to an activity with which it has not previously been applied: wilderness canoeing n Ontario. Function-Use: Recreation.	CV	1993	In dollars, per person, per day and per trip.	Mean WTP for "same trip": all parks/AP/QP/KP (in $): 66.40/67.37/ 65.82/66.76; trip length: ranged from 3 days to > 20 days: 75.99 to 15.42. Mean WTP for "Back-Country Permit": 26.38/22.35/ 28.63/21.59; trip length: 27.06 to 15.32.	river	regional	Canada
Rosenthal, D.H.	"The Necessity for Substitute Prices in Recreation Demand Analyses,"	*American Journal of Agricultural Economics*, 69, 828-837.	1987	How much are CS estimates affected by the way in which substitute recreation sites are incorporated into the TCM? Function-Use: Recreation.	TC	High quality aggregate data was used and collected during the summer of 1982.	Dollars and number of visits.	Average CS per person, per trip: a. 7.10; b. 2.81; c. 4.04. Mean square: within sites method: 53.63; within sites residual: 2.05; nonadditi-vity: 7.58; balance: 1.76.	Reservoirs. Catchment	regional	USA

Bibliographic study characteristics	Study characteristics									
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Russell, C.S. and W.J. Vaughan.	''The National Recreational Fishing Benefits of Water Pollution Control,''	*Journal of Environmental Economics and Management*, 9(4), 328-354.	1982	Fishing. Function-Use: Recreation.	TC		$ millions. $ per fisherman.	(a. Value is the total benefits, in millions of 1973 dollars, of water pollution control under the ambient water goal of Federal Water Pollution Control Act. Travel time was valued at average wage rate: 966; (b. Value is the total benefits per fisherman, in 1973 dollars, of water pollution control under the ambient water goal of Federal Water Pollution Control Act. Travel time was valued at 0: 7.3.	catchment	national	USA
Sanders, L.D., R.G. Walsh, and J.B. Loomis.	"Toward Empirical Estimation of the Total Value of Protecting Rivers,"	*Water Resources Research*, 26 (7), 1345-1357.	1990	To develop and apply a procedure for measuring the WTP for river protection. Function-Use: Recreation.	CV	1983	Percent of insurance premium, dollars and years.	Aggregated total WTP for the 3 most valuable rivers: appr. $46 million; for the 7 most valuable rivers: appr. $88 million; for the 11 study rivers: $113 million; 15 most valuable rivers: $120 million. The PV of total benefits/cost from protection of the 3 most valuable rivers in the state are estimated as $599/ $27.2 million, incl. About $113 million recreation use/ $16.7 million for the oppor-tunity cost of foregone water development projects and $486 million preservation value/ $10.5 million of management and other opportunity costs. PV of benefits/cost rises to $1119/$47.5 million with designation of the 7 most valued rivers and to $1430/ $57.3 million with desig-nation of the 11 study rivers. The PV of benefit/cost is forecast to rise to a maximum of about $1521/$69.5 million with designation of 15 rivers, incl. 4 rivers not yet studied.	River	regional	USA
Scancke	''Recreational fishing in River Tinnely,"	M.Sc. thesis. Department of Economics, University of Oslo.	1984	Recreational value of freshwater angling. Function-Use: Recreation.	TC		NOK per angler per day.	170	river	local	Nroway
Schreiner, D.F., D.A. Willett, D.D. Badger and L.G. Antle.	''Recreation Benefits Measured by Travel Cost Method for the McClellan-Kerr Arkansas River Navigation System and Application to Other Selected Corps Lakes,"	Report for Water Resources Support Center, U.S. Army Corps of Engineers. Contract Report 85-C-1.	1985	Recreation benefits. Function-Use: Recreation.	TC	1975	thousands $.	Value represents estimated annual aggregate recreation benefits for the entire McClellan-Kerr Arkansas River Navigation System: 50800.	lakes	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Seller, C., J.R. Stoll, and J.P. Chavas.	"Validation of Empirical Measures of Welfare Change: A Comparison of Nonmarket Techniques,"	*Land Economics*, 61 (2), 156-175.	1985	In this study the TCM and two variants of the CVM are used to estimate the value of recreational boating in East Texas. This is done to address the comparative validity of estimates derived from alternative valuation methods under similar conditions or problem settings. Under what circumstances is each method most appropriate? Function-Use: Recreation.	CV, TC	1980	A: In dollars and per annual boat ramp permit. B: In dollars, per year, miles/ gallon and per household.	A: OEF: when area under demand curve is used: gross surplus values: a. $9.06; b. $8.87 and d. $3.81; the average expenditures on a launch fee each year were: a. $17.71; b. $7.78 and d. $6.09. The net average CS (integrated) is: a. -$8.65; b. $1.09 and d. -$2.28. When mean WTP was used, the average surplus figures are: a. -$0.87; b. $6.21; c. $11.17 and d. $5.40; CEF: a. $39.38; b. 35.21; d. 13.81. B: Average CS for each lake: a. $32.06; b. $102.09; c. $24.42; d. $13.01.	lake	regional	USA
Shabman, L., and K. Stephenson.	"Searching for the Correct Benefit Estimate: Empirical Evidence for an Alternative Perspective,"	*Land Economics*, 72 (4), 433-449.	1996	To compare residential flood risk reduction benefit estimates from the property damages avoided (PDA), hedonic price and contingent valuation (CVM) techniques. Function-Use: Recreation, Flooding.	HP, CV	A: 1) n.v.t.; 2) property transactions sold between 1980 and 1990. B: 1) n.v.t.; 2) fall of 1987.	US$ - Dependent on Study	A: The HP technique generated the largest estimates, with the gap between the estimates greatest for the most flood prone areas. Mean estimates: HP: $1,333; PDA: $597. B: CVM (lump-sum): $314. Mean CVM bids: Flood Zone (FZ): all bids/excl. uncertain bids/excl. uncertain & protest bids: FZ<.05: 115.00/143.75/230.00; .02<FZ<=.05: 203.33/ 305.00/381.25; .01<FZ<=.02: 980.00/ 980.00/1,225.00; .002<FZ<=.01: 223.08/ 241.67/322.22; .0001<FZ<=.002: 240.00/ 272.72/428.57; all FZ: 313.70/369.35/520.45. Annual payment bids: the 16 positive bidders who were not registered to vote had stated they would be WTP on average about $124 each year for 15 years. Controversely, those who actually voted stated a WTP of about $93 each year	river	regional	USA
Shafer, E.L., R. Carline, R.W. Guldin, and H.K. Cordell.	"Economic Amenity Values of Wildlife: Six Case Studies of Pennsylvania,"	*Environmental Management*, 17 (2), 669-682.	1993	The objective of this study is to estimate the economic amenity values of six different kinds of wildlife viewing and catch-and-release trout fishing opportunities in Pennsylvania. unction-Use: Recreation.	CV, TC	1987 and 1988.	In dollars, per visitor day, per miles and per trip.	A: a. average expenditures ($) per visitor day: actual/ substitute/net expenditure per visitor per day: 13.80/ 15.66/1.86; b. 9.14/4.32/ 4.82; c. 5.83/18.36/12.53; d. 2.28/5.83/3.57; e. 11.85/ 32.28/20.43; f. 1.60/5.30/ 3.70. Net economic value per visitor: c. 12.53; d. 3.57; e. 20.43; f. 3.70. B: Net economic value per visitor ($): a. 44.50; b. 16.10.	river	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Shaw, D., Y.L. Chien, and Y .M. Lin.	"An Alternative Approach to Combining Revealed and Stated Preference Data: Evaluating the Water Quality of the River System in Taipei,"	Institute of Economics, Academia Sinica, Nankang, Taipei, Taiwan.	1998	To develop an alternative empirical model framework to combine both the revealed and stated preference information in a coherent utility-theoretical way. Function-Use: Recreation.	CV, TC	A: 1995 B: Survey was conducted in 1995, but information was asked about income, number of trips, etcetera in 1994.	In US$, per year and per person.	A: Estimated WTP for water quality from boatable to fishable: use/ nonuse/total value (US$): 1/56.67/ 57.67; for water quality from fishable to swimmable: US$ 36.30/ 56.67/ 92.96. B: Mean of the TC: US$20.83; average estimated number of trips: water is boatable: 1547; water is fishable: 1552; water is swimmable: 1724.	River	regional	Taiwan
Shilling, J.D., J.D. Benjamin, and C.F. Sirmans.	"Adjusting Comparable Sales for Floodplain Location,"	*The Appraisal Journal*, July, 429-436.	1985	How values a housing market flood-plain locations in the selling prices of single-family residential housing? Function-Use: Recreation, Flooding.	HP	December 1982 to February 1984.	Square feet.	The mean sale price was $75,000.	River	regional	USA
Schultz, S.D. and B.E. Lindsay.	"The Willingness to Pay for Groundwater Protection,"	*Water Resources Research*, 26 (9), 1869-1875.	1990	To elicit household total WTP for a hypothetical groundwater protection plan. Specific independent variables (socio-economic characteristics) were also included. Function-Use: Municipal and Domestic Water Supply.	CV	During the summer of 1988.	US$ per year.	Mean WTP of $129 (associated with the truncation level at the highest bid offered ($500). Heard/not heard of groundwater pollution problems: 0.76; knowledge of the causes of groundwater pollution problems: 0.71.	ground water	regional	USA
Silvander, U.	"The willingness to pay for fishing and groundwater in Sweden ,"	Dissertation 2, Swedish University of Agricultural Sciences, Dept. of Economics, Uppsala, Sweden, 77 p.	1991	Potential benefits of reducing excess nitrogen loss from agriculture. Function-Use: Recreation, Water Quality.	CV	1989	Swedish Kroner per person.	(a. Nitrogen loss (angling): 350; (b. Nitrogen loss (groundwater): 370.	Ground and surface water	national	Sweden

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Singh, B. R. Ramasubban, R. Bhatia, J. Briscoe, C. Griffin and C. Kim.	"Rural Water Supply in Kerala, India: How to Emerge From a Low-Level Equilibrium Trap,"	*Water Resources Research*, 29(7), 1931-1942.	1993	Improvements in water supply systems in a developing nation. Function-Use: Municipal and Domestic Water Supply.	CV		Rupees/ household/ month. Rupees/ household.	(a. Value is the average maximum WTP for monthly water tariff of respondents not connected to existing improved water source if cost for connecting to the water source was fixed at 100 rupees per household: 8.7; (b. Value is the amount that respondents not connected to the improved water system would be WTP, in monthly tariffs, if the water system was greatly improved: 9.7.	Ground and surface water	local	India
Singsaas, T.	"Estimating the economic value of recreational fishing for Atlantic salmon and sea trout in the river Gaula in 1990,"	M.Sc. thesis, Department of Economics, University of Oslo, 70 pp.	1991	Recreational value of freshwater angling. Function-Use: Recreation.	TC		NOK per angler per day.	217-339	river	local	Norway
Smith, V.K.	"Selection and Recreation Demand,"	*Journal of Agricultural Economics*, 70 (1), 29-36.	1988	To consider the implications of the treatment of selection effects, such as those associated with using on-site surveys, for estimates of TC demand models based on microlevel data. Function-Use: Recreation.	TC	1981	In dollars, per trip and per household.	Average TC during the year preceding the survey for users of each site: from P5 to P5/P1/P7 (in $): 0.55/0.87/1.45; from P1 to P5/P1/P7: 1.48/1.24/1.79; from P7 to P5/P1/P7: 0.95/0.98/1.00. All of the CS estimates fall between $0.38-$1.67 per trip; for the semilog models the range is: $0.38 (Poisson)-$1.08 (truncated ML); for a selected sample (from a one-site survey) it ranged from: $0.55-$1.08; comparison of OLS estimates, using the equivalent of an on-site sample vs a one- or two-effect selection model, it ranged from $0.77-$0.90.	river, lake	regional	USA
Smith, V.K. and W.H. Desvouges.	"The Generalized Travel Cost Model and Water Quality Benefits: a Reconsideration,"	*Southern Economic Journal*, 52, 371-381.	1985	Water quality improvement effects on demand for water based recreation sites. Function-Use: Water Quality.	TC	1977	$/ person/ season.	(a. Value measures estimated benefits for a water quality improvement from boatable to swimmable conditions at Arkabutla Lake, MS using an OLS model: 274.2; (b. Value measures estimated benefits for a water quality improvement from boatable to fishable conditions at Benbrook Lake, TX using a ML model: 6.53.	rivers, lakes, catchment	regional	USA
Smith, V.K. and Y. Kaoru.	"The Hedonic Travel Cost Model: A View from the Trenches,"	*Land Economics*, 63 (2), 179-192.	1987	To evaluate the Hedonic Travel Cost (HTC) model. Function-Use: Recreation.	TC	1981	In dollars per individual.	Models with negative prices: zone definition 1 (in $): 3.53; 2: 2.91; 3: 3.42; 4: 2.79. Models without negative prices: 1: 5.73; 2: 4.80; 3: 6.11; 4: 4.40.	river	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Smith, R.J. and N.J. Kavanagh	''The measurement of benefits of trout fishing: preliminary results of a study at Graftham water,"	Great Ouse water authority, Huntingdonshire, Journal of Leisure Research, 1, pp. 316-32.	1969	Estimation of the benefits of trout fishing at Graftham reservoir. Function-Use: Recreation.	TC	1967	Pounds	39,944	reservoir	local	United Kingdom
Sorg, C.F. and J.B. Loomis.	"Economic Value of Idaho Sport Fisheries with an Update on Valuation Techniques,"	*North American Journal of Fisheries Management*, 6, 494-503.	1986	The purposes of this study are to refine the conceptual framework of valuation by identifying and clarifying the values generated from fishery recreation, identifying refinements in the travel cost and contingent value methods that have been made since Gordon et al. (1973), and report results of a 1983 survey measuring cold-water and warmwater fishing values and to compare them to other studies. Function-Use: Recreation.	CV, TC	1983	US$ per trip; US$ per day.	A: **(I):** 1a) 22,52; 1b) 14,25; 1c) 31,87; 1d) 35,30; 2a) 16,35; 2b) 12,02; 2c) 24,26; 2d) 26,16; 3a) 31,45; 3b) 20,29; 3c) 41,36; 3d) 39,14. **(II):** 1a) 39,71; 1b) 21,02; 1c) 51,03; 1d) 53,88; 2a) 19,36; 2b) 11,39; 2c) 22,45; 2d) 28,45; 3a) 45,71; 3b) 19,13; 3c) 57,14; 3d) 48,57. B: CWF: mean net WTP per trip/per day for current conditions (in $): 42.93/25.55. WWF: 42.18/26.36. SHF: 27.87/14.29. Mean variable cost per trip: CWF/WWF/SHF: 37.05/ 24.62/ 72.21.	n.v.t.	regional	USA
Steinnes, D.N.	"Measuring the Economic Value of Water Quality: The Case of Lakeshore Land Method,"	*The Annals of Regional Science*, 26(2), 171-176.	1992	This study will be confined to estimation of a first stage hedonic equation for property values. It will value land rather than houses. Besides, this paper uses lakes which are all incorporated areas in Northern Minnesota and so community differences are minimal. Function-Use: Water Quality.	HP	1960-1970	US$	1a) 206; 1b) 3295,96; 1c) 10,70 2a) 3383,79; 2d) 73,77; 2e) 3159,69; 2f) -571,71; 3a) 1,99; 3g) 2235,34.	Lake	regional	USA
Steinnes, D.N.	"Measuring the Economic Value of Water Quality: The Case of Lakeshore Land,"	*The Annals of Regional Science*, 26, 171-176.	1992	This study, by employing a sample of lakes and considering only land values, tries to overcome many methodological and empirical problems inherent in previous studies. Function-Use: Water Quality.	HP	1960-1970	In dollars, per lot or per front foot.	WSCD: the number of feet below the surface. Specification 1.: an additional foot of WSCD will raise the value of a lot $206.00; specification 2. Shows the value of all lots to be: $3383.79; 3. Shows the value of a front foot to be $1.99Xaverage front feet per lot (121): $240 per lot.	Lake	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Stenger, A. and M. Willinger.	"Preservation Value for Groundwater Quality in a Large Aquifer: A Contingent - Valuation Study of the Alsatian Aquifer,"	*Journal of Environmental Management*, 53, 177-193.	1998	The Alsatian aquifer is the largest aquifer in Western Europe and supplies groundwater for almost all households in Alsace, without any treatment in most areas. The main objective of this paper is to compare the WTP of households living in polluted areas with those having access to preserved quality. Results are persented of a CVM study of the Alsatian aquifer Function-Use: Recreation, Municipal and Domestic Water Supply, Agricultural Supply.	CV	1993	FF1993 per year per household	1) 617FF; 2) 612FF; 3) 692FF	ground water	regional	France
Stenger, A. and M. Willinger.	"Preservation Value for Groundwater Quality in a Large Aquifer: A Contingent - Valuation Study of the Alsatian Aquifer,"	*Journal of Environmental Management*, 53, 177-193.	1998	To compare the WTP of households living in polluted areas with those having access to preserved quality. Function-Use: Recreation, Municipal and Domestic Water Supply, Agricultural Supply.	CV	1993	In FF, per household and per year.	Average monthly income was 12,736FF. The observed mean WTP: 617FF/HH/yr. The different regressions done with the stated WTP for the open-ended method give mean WTP estimates between 610 and 709FF. Alternative estimates of mean WTP: E[WTP]1 (unbounded mean expected WTP): 1374FF; E[WTP]2 (bounded by zero): 1545FF; E[WTP]3 (truncated mean at the maximum bid level): 723FF. Turnbull mean: 692FF (dichotomous-choice method).	River	regional	France
Stevens, T.H., S. Benin and J.S. Larson.	"Public Attitudes and Economic Values for Wetland Preservation in New England,"	*Wetlands*, 15(3), 226-231.	1995	Wetlands in New England. Function-Use: Flooding.	CV	1993	Dollars per respondent.	(a. Value is the high end estimate of respondents' yearly WTP to protect New England wetlands that provide flood protection, water supply and pollution control: 80.41; (b. Value is the low end estimate of respondents' yearly WTP to protect New England wetlands that provide flood protection, water supply and pollution control: 73.89.	wetlands	national	New England

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Steever, WJ., M. Callaghan-Perry, A. Searles, T. Stevens and P. Svoboda.	''Public Attitudes and Values for Wetland Conservation in New South Wales, Australia,"	*Journal of Environmental Management*, 54(1), 1-14.	1998	Wetland conservation. Function-Use: Habitat.	CV	1996	Australian dollars/person/ year for 5 years.	(a. Value represents median WTP for the pooled sample. Value from the pooled sample omits those respondents who did not express WTP: 100; (b. Value represents aggregate value for wetlands in New South Wales, Australia, assuming a WTP per household of A$17.10 and 2.23 million households in the state: 38.	wetland	regional	Australia
Stone, A.	''Valuing wetlands: a contingent valuation approach,"	Paper presented at the 35th Annual Conference of the Australian Agricultural Economics Society, February 11-14, University of New England, Armidale.	1991	Mean annual WTP for wetland protection. Function-Use: Habitat.	CV		£/ha.	85-109.	wetland	Regional	Australia
Strand, J.	''Valuation of freshwater fish populations as a public good in Norway. Result from a survey,"	Department of Economics, University of Oslo, Working paper, 111 pp.	1981	WTP to avoid total extinction of freshwater fish in Norway due to acid rain, over a period of about 10 years. Function-Use: Water Quality.	CV	Late 1970s	Norwegian Kroner per year per person.	Average WTP: 1700-2750.	Lakes, rivers	national	Norway
Strand, J.	''Valuing benefits of recreational fishing in Norway: the Gaula case,"	In Carlsen, A.J. (ed.) 1987: Proceedings UNESCO Symposium on Decision Making in Water Resources Planning, May 5-7, 1986, Olso; 245-278.	1981	Recreational value of slamon fishing in Gaula. Function-Use: Recreation.	TC	Late 1970s	Norwegian Kroner per angler per day.	335	river	local	Norway
Sun, H., J.C. Bergstrom, and J.H. Dorfman.	"Estimating the Benefits of Groundwater Contamination Control,"	*Southern Journal of Agricultural Economics*, 24(2), 89-107.	1992	Estimating an option price for groundwater quality protection. Function-Use: Municipal and Domestic Water Supply.	CV	October and November 1989	In dollars, per household and per year.	Computed from logit model: no info: $1,062/HH/yr; characteristics info: $1,014/ HH/yr; service info: $956/HH/yr; full info: $949/HH/yr. The mean option price of groundwater pollution abatement: $641 (using Cameron's approach). Means for log model: $998/HH/yr; linear model: $930/HH/yr; empirical model: $961/HH/yr.	Ground water	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Sutherland, R.J.	"A Regional Approach to Estimating Recreation Benefits of Improved Water Quality,"	*Journal of Environmental Economics and Management*, 9, 229-247.	1982	To develop a methodololy for estimating the recreation benefits of improved water quality at a single site, for numerous sites within a region and for an entire region. Function-Use: Recreation.	TC	1976	In dollars per visitor day and per person.	Total regional incremental benefits: swimming/ camping/fishing/boating/ total recreation benefits (in $): 3,816,046/3,419,736/ 6,866,510/4,646,121/ 18,748,413; total regional existing benefits: 61,892,794/ 116,074,504/ 112,151,049/ 87,078,353/377,196,700.	River and beaches. RIVER AND LAKES	regional	USA
Sutherland, R.J. and R.G. Walsh.	"Effect of Distance on the Preservation Value of Water Quality,"	*Land Economics*, 61 (3), 281-291.	1985	The problem of estimating the effect of distance on the preservation value of water quality at a recreation site. Function-Use: Recreation.	CV	Summer 1981.	In years, dollars, bequest, existence and option values.	Option value: $10.71; Existence value: $19.88; Bequest value: $26.37; Recreation use value: $7.37; Total value: $64.16. Mean distances: Montana: 184; Washington: 416; Oregon: 735; Idaho: 611; North Dakota: 845; South Dakota: 971; Wyoming: 712; British Columbia: 558; Alberta: 403; Saskatchewan: 637.	Lake, river	regional	USA
Talhelm, D.R., J.E. Hanna, and P. Victor.	"Product Travel Cost Approach: Estimating Acid Rain Damage to Sportfishing in Ontario,"	*Transactions of the American Fisheries Society*, 116, 420-431.	1987	The objective of the acid rain evaluation was to estimate demand and supply equations for angling and then to show how much total consumer surplus from angling would change as acid rain reduces the supply of angling. Function-Use: Recreation.	TC	1983	In Canadian dollars and per capita angler-days.	CS per angler day (in Canadian $): fishing product 1: 11; 2: 10; 3: 13; 4: 18; 5: 11; 6: 6; 7: 128; 8: 13; 9: 10; total: 17.	Lake	regional	Canada
Tapsell, S. M., Tunstall, 1S. M., Costa, P. L. and Fordham, M.	''Ravensbourne River Queen's Mead Recreation Ground Survey,"	Final Report, Reading: Environment Agency.	1992	WTP for recreational values. Function-Use: Recreation.	CV		£/user/visit. £/resident/ visit. £/user/visit. £/resident/ visit.	Present condition: (a. 1.88; (b. 1.45; Recovery to full river condition: (c. 3.31; (d. 3.16.	river	local	United Kingdom
Tay, R.S. and P.S. McCarthy.	Benefits of Improved Water Quality: A Discrete Choice Analysis of Freshwater Recreational Demands.	*Environment And Planning*, 26(10), 1625-1638.	1994	Water quality improvements and their effects on recreational fishing. Function-Use: Recreation.	TC	1985	Cents / trip	(a. Value measures the benefits per fishing trip to anglers from a 1% reduction in oil in the water: 4.93; (b. Value measures the benefits per fishing trip to anglers from a 1% reduction in copper in the water: 25.25.	catchment	national	USA

Bibliographic study characteristics	Study characteristics									
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Tervonen, J., E. Alasaarela, and R. Svento.	"Household Water Quality and Consumer Welfare: An Application to the City of Oulu,"	*Aqua Fennica*, 24 (1), 83-92.	1994	This study presents an application of environmental economics designed to assist municipal water management to choose between two alternative investments for improving the quality of household water. Function-Use: Municipal and Domestic Water Supply.	CV	1993	FIM per member of household, per year.	1) FIM 308; 2) FIM 323.	River	local	Finland
Tihansky, D.P.	"Economic Damages From Residential Use of Mineralized Water Supply,"	*Water Resources Research*, 10(2), 145-154.	1974	Damages from use of mineralized residential water. Function-Use: Municipal and Domestic Water Supply.	DF	1970	$ billions/ year. $/ person/ year.	(a. Value is the total annual damages to U.S. households from using mineralized water. This estimate accounts for complete removal of water constituents and is derived from mean values of household unit damage observations: 1.75; (b. Value is the annual damages to U.S. households per capita from using mineralized water. This estimate accounts for complete removal of water constituents and is derived from mean values of household unit damage observations: 8.6.	Ground and surface water	National	USA
Torell, L.A., Libbin, J.D. and M.D. Miller.	" The Market Value of Water in the Ogallala Aquifer"	*Land Economics*, 66(2), 63-175.	1990	Market value for the water in storage in the Ogallala Aquifer. Function-Use: Agricultural Supply.	HP	1979-1986	Dollars per acre.	(a. Represents the average value of water per acre of irrigated farmland from 1979 to 1986 in Nebraska: 545; (b. Represents the average value of water per acre of irrigated farmland from 1979 to 1986 in southern Colorado: 282; (c. Represents the average value of water per acre of irrigated farmland from 1979 to 1986 in New Mexico, Oklahoma, Colorado, Kansas, and Nebraska: 455.	Ground water	local	USA

Bibliographic study characteristics	Study characteristics									
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Turner, R.K., C. Folke, I.M. Gren, and I.J. Bateman.	"Wetland Valuation: Three Case Studies,"	in Perrings, C., Z.-G. Mäler, C. Folke, C.S. Holking, and B.-O. Jansson, eds., 1995, Biodiversity loss, Economic and Ecological Issues, Cambridge University Press, 129-149.	1995	To discuss the significance and value of wetlands in relation to the valuation studies and to a sustainable use of natural capital. (Bateman et al., 1992: to assess the monetary value (WTP) of conserving the Broads via a protection stategy designed to mitigate the increasing risk of flooding due to the long term deterioration of flood defences). Function-Use: Recreation, Flooding.	CV	1991	In UK pounds per household and per year.	On-site survey: mean OE (WTP): 77 UK pounds per household per year. IB: 84 UK pounds; mean DC (WTP): 244 UK pounds per household per year. Mail survey: "Near-Broadland residents": 12.45 UK pounds per household and for the "Elswhere GB residents": 4.08 UK pounds per household.	Wetland	regional	United Kingdom
Ulibarri, C.A., H.S. Seely and D.B. Willis.	''Farm Profitability and BUREC Water Subsidies: An LP Look at a Region,"	*Contemporary Economic Policy*, 16(4), 442-451.	1998	Irrigation water used for agriculture in Kern county. Function-Use: Agricultural Supply.	OM		Dollars per acre foot.	(a. Value represents the profit per acre-foot of water for almonds production using a hose drag irrigation system on a farm using only 20% Central Valley Project water: 106.6; (b. Value represents the profit per acre-foot of water for sugar beet production using a furrow irrigation system on a farm using only 20% Central Valley project water: 39.81.	ground and surface water	regional	USA
Ulleberg, M.	''The recreational value of fishing for Atlantic salmon and sea trout in the River Stordalselv,"	M.Sc. thesis, Agricultural University of Norway.	1988	Recreational value of freshwater angling. Function-Use: Recreation.	TC		NOK per angler per day.	235-311	river	local	Norway
van Kooten, G.C.	''Bioeconomic Evaluation of Government Agricultural Programs on Wetlands Conversion,"	*Land Economics*, 9(1), 27-38.	1993	Wetlands providing migratory waterfowl habitat and recreation opportunities. Function-Use: Agricultural Supply.	OM	1988	Dollars per acre per year.	Marginal value of waterfowl habitat as cropland per acre year is reported. Government subsidy of $4.50 per bushel of grain and an average yield of 30 bushels/ acre were assumed (land has no livestock value).: 37.97.	wetland	regional	Canada, USA

Bibliographic study characteristics	Study characteristics									
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Vaughan, W.J. and C.S. Russell.	"Valuing a Fishing Day: An Application of a Systematic Varying Parameter Model,"	*Land Economics*, 58 (4), 450-463.	1982	The objective of this study is to estimate the value, in average WTP terms, of a day of freshwater recreational fishing differentiated by fish species sought. Function-Use: Recreation.	TC	1979	In dollars, per person and per day.	Average surpluses: Trout: TC1: excluding resource costs (CS)/ including resource costs (WTP): 10.96/15.60; TC2: 19.49/ 24.09. Catfish: TC1: 7.00/10.62; TC2: 12.48/ 16.03. For example, an increase of one fish per angler above the mean catch of trout (4.7 fish per person) raises average WTP above the TC1 value of $15.60 by $0.45. An increase of one catfish per angler above the mean catch (4.2 fish per person) raises average WTP from $10.62 to $10.93, an increase of $0.31 per person.	Lake	regional	USA
Walsh, R.G., D.M. Johnson, and J.R. McKean.	''Benefit Transfer of Outdoor Recreation Demand Studies, 1968-1988,"	*Water Resources Research*, Vol.28, No.3, March, [Special Section: Problems and Issues in the Validity of Benefit Transfer Methodologies.	1992	This study analysed the determinants of variations in 287 separate estimates of mean unit values obtained from 120 studies of recreational benefits - based on both the travel cost method (TCM) and the contingent valuation method (CVM). Function-Use: Recreation.	CV, TC		Pounds per day.	WTP of recreationalists for Camping: 16.88 Picnicking: 15.00 Swimming: 19.88 Sightseeing: 17.56 Boating – motorised: 27.32 Boating – non-motorised:42.14 Hiking: 25.17 Cold water fishing: 26.51 Anadramous fishing: 46.75 Non consumptive fish + wildlife: 19.22 Wilderness average – all activities +: 21.28 Others: 29.39	Surface water	national	USA
Walsh, R.G., R. Aukerman and D. Rud.	''Economic Value of Benefits From Recreation at High Mountain Reservoirs,"	Colorado Water Resources Institute, Technical Report 14.	1979	Recreation at high mountain reservoirs. Function-Use: Recreation.	CV	1978	$/ person/ day.	(a. Average WTP per person per day in 1978 $ for use of a small high mountain reservoir area is reported: 32.19; (b. WTP in 1978 $ to participate in recreational activities at low mountain reservoirs when water level is at 75% of maximum is reported: 57.54.	reservoirs	regional	USA
Walsh, R.G., R.K. Ericson, J.R. McKean and R.A. Young.	''Recreation Benefits of Water Quality: Rocky Mountain National Park, South Platte River Basin, Colorado,"	Colorado Water Resources Research Institute, Colorado State University-Fort Collins, Technical Report 12.	1978	The effect of water quality on recreation. Function-Use: Recreation.	CV	1973	$ / day	(a. Value measures the sample mean WTP to avoid a decrease in water quality in going from their 1st choice photo to the 2nd: 0.68. (b. Value measures the sample mean WTP to avoid a decrease in water quality in going from their 1st choice photo to the 6th: 5.42.	river	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Ward, F.A.	"Economics of Water Allocation to Instream Uses in a Fully Appropriated River Basin: Evidence from a Mexico Wild River,"	*Water Resources Research*, 23 (3), 381-392.	1987	To identify the potential recreation demand for instream flows. Function-Use: Recreation.	TC	May to August 1982.	Dollars, cfs and acre feet.	The extra evaporation losses of about 1000 ac ft would only cost about $40,000 annually while returning a direct instream benefit of about $950,000 in a normal year or $550,000 in a high runoff year. Water supplies remain virtually constant; only the storage timing changes. Annual benefits by minimum streamflow level, using TCM: 50 cfs: anglers/boaters/total ($/yr): 333,307/0/333,307; 100: 441,608/0/441,608; 250: 485,046/0/485,046; 500: 607,016/0607,016; 1000: 483,938/1,122,803/1,606,016; 2000: 482,783/2,056,972/2,539,755; 4000: 324,949/1,824,632/2,149,581.	River	regional	USA
Ward, F.A.	"The Demand for and Value of Recreational Use of Water in Southeastern New Mexico,"	Research report 465, Agricultural Experiment Station, New Mexico State University, Mexico.	1982	To determine the economic benefits associated with the recreational use of water at four lakes and to demonstrate how these benefits can be measured by use of the TCM. Function-Use: Recreation, Agricultural Supply.	TC	January 1 to August 31, 1979.	Dollars, years and miles.	Assumed hourly value of time ranged from zero to $30.00, respectively. Scenario 1.: site a.: from $23.37 to $39.78; b.: from $31.90 to $92.04; c.: from $10.36 to $30.39; d.: from 24.91 to $76.86. Scenario 2.: a.: from $23.37 to $ 39.78; b.: $32.81 to $92.43; c.: from $10.36 to $30.39; d.: from $35.47 to $98.61. Scenario 3.: a.: from $ 23.37 to $39.78; b.: from $32.14 to $92.14; c.: from $10.36 to $30.39; d.: from $28.06 to $ 83.25.	lake	regional	USA
Ward, F.A., B.A. Roach, and J.E. Henderson.	"The Economic Value of Water in Recreation: Evidence from the California Drought,"	*Water Resources Research*, 32 (4), 1075-1081.	1996	How do recreational values change with reservoir levels? Function-Use: Recreation.	TC	1983-1985	Dollars, acre foot and miles.	n.a	river	regional	USA
Weatherford, G.S.	''Water Economics on the Farm,"	Ch. 5 in Water and Agriculture in the Western U.S., G.S. Weatherford (ed.) Boulder, CO: Westview Press.	1982	Water for agricultural use. Function-Use: Agricultural Supply.	Other		Dollars per acre foot.	1976 Value represents the high end water right price observed per acre foot in the Gila-San Francisco Basin, New Mexico: 3000; (b. Value represents the low-end water right price per acre foot of water in San Juan Basin, New Mexico: 500.	Basins	local	New Mexico

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Weithman, A.S. and M.A. Haas.	"Socioeconomic Value of the Trout Fishery in Lake Taneycomo, Missouri,"	*Transactions of the American Fisheries Society*, 111, 223-230.	1982	The objective of this paper is to determine the socioeconomic value of Lake Taneycomo fishery for rainbow trout. The study uses TC and replacement cost of fish and an income multiplier. ç Recreation.	TC, other	From 1 June 1978 to 31 May 1979.	In dollars and per visit.	The area under the site-demand curve represents CS or benefits derived by anglers in excess of their expenses and equals: $2.9 million.	Lake	regional	USA
White, P.C., K.W. Gregory, P.J. Lindley and G. Richards.	"Economic Values of Threatened Mammals in Britain: A Case Study of the Otter Lutra lutra And the Water Vole Arvicola terrestris,"	*Biological Conservation*, 82(3): 345-354.	1997	Preservation of the otter Lutra lutra and the water vole Arvicola terrestris. Function-Use: Habiat.	CV	1996	Pounds/ person/ year.	(a. Value is the mean annual individual WTP in British pounds for an action plan to restore both the otter and water vole populations: 10.92; (b. Value is the mean annual individual WTP in British pounds for an action plan to restore the water vole population: 7.44.	river	regional	United Kingdom
Whitehead, J.C.	Measuring Willingness to Pay for Wetlands Preservation with the Contingent Valuation Method.	*Wetlands*, 10(2), 187-201.	1990	Preservation of a bottomland hardwood forest wetland. Function-Use: Habiat.	CV	1989	$/ household / year.	Value measures mean WTP for wetland preservation estimated from log-linear form of model: 6.31.	wetland	local	USA
Whitehead, J.C.	"Benefits of Quality Changes in Recreational Fishing: A Single-Site Travel Cost Approach,"	*Journal of Environmental Systems*, 21 (4), 357-364.	1991	This study extends the TC literature on valuing quality improvements by measuring the benefits of improved quality in a single-site recreation demand model. Function-Use: Recreation.	TC	1990	In dollars and per trip.	CS: annual benefits of recreation quality improvements: 10% improvement: change in CS: $14; 25%: $34; 50%: $73.	River	regional	USA
Whitehead, J.C.	"Environmental Interest Group Behavior and Self-Selection Bias in Contingent Valuation Mail Surveys,"	*Growth and Change*, 22(1), 10-21.	1991	Wetland preservation. Function-Use: habitat.	CV	1989	$/ person/ year.	(a. Value is the average WTP per person/ year in the general sample for the preservation of the Clear Creek wetland area (assuming 15% of the general population belongs to an environmental interest group): 4.12; (b. Value is the average WTP per person/year in the environmental interest group sample for the preservation of the Clear Creek wetland area: 42.83.	wetland	local	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Whitehead, J.C.	"Measuring Use Value from Recreation Participation,"	*Southern Journal of Agricultural Economics*, 24 (2), 113-119.	1992	The purpose of this study is to provide a method by which use value can be estimated solely from the participation decision. Opposed to recreation demand studies in which a two step valuation method is used (first estimating conditional recreation participation probabilities and then intensity of use decisions). Function-Use: Recreation.	TC	1990	US$ per trip	1) $5,16; 2) 5,93; 3) 6,40; 4) 7,49.	Ground water	regional	USA
Whitehead, J.C. and G.C. Blomquist.	"Measuring Contingent Values for Wetlands: Effects of Information About Related Environmental Goods,"	*Water Resources Research*, 27(10), 2523-2531.	1991	Wetland preservation. Function-Use: Recreation.	CV	1989	$/ person/ year.	(a. Value is the mean WTP per respondent for the reclaimed wetland lake as a replacement for the Clear Creek wetland after surface coal mining (80 respondents in this subsample): 8.13; (b. value is the mean WTP per respondent for the reclaimed grassland as a replacement for the Clear Creek wetland and the undisturbed, nearby Henderson Sloughs was the related environmental good (72 respondents in this subsample): 16.61.	wetland	local	USA
Whitehead, J.C. and P.A. Groothuis.	"Economic Benefits of Improved Water Quality: A Case Study of North Carolina's Tar - Pamlico River,"	*Rivers*, 3 (3), 170-178.	1992	This study uses the CV method to measure the economic benefits of best management practices used to reduce agricultural nonpoint source pollution in the Tar-Pamlico River in eastern North Carolina, USA. Function-Use: Recreation.	CV	1991	$ amount each year.	$1.62 milion each year. (MEDIAN)	river	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Whitehead, J.C., T.J. Hobans and W.B. Clifford.	''Measurement Issues with Iterated, Continuous/Interval Contingent Valuation Data,''	*Journal of Environmental Management*, 43, 29-139.	1995	Improved water quality. Function-Use: Habitat.	CV	1990	Dollars per person per year.	(a. Value is expected WTP to protect the Albemarle-Pamlico Estuarine System. Uses interval data regression with a quadratic functional form. Upward biasing effect of starting point bias corrected in the estimation: 23.55; (b. Value is expected WTP to protect the Albemarle-Pamlico Estuarine System. Uses interval data regression with a linear functional form. Upward biasing effect of starting point bias is corrected in the estimation: 27.05.	estuary	regional	USA
Whittington, D., J. Briscoe, X. Mu, and W. Barron.	"Estimating the Willingness to Pay for Water Services in Developing Countries: A Case Study of the Use of Contingent Valuation Surveys in Southern Haiti,"	*Economic Devlopment and Cultural Change*, 38 (2), 293-311.	1990	Their research objective was to see if contingent valuation surveys could, in fact, be used in developing countries to develop useful estimates of WTP for water services. A village in southern Haiti was the field site of our study. Function-Use: Municipal and Domestic Water Supply.	CV	1986	Dollars, per month	1a) 1.2; 2a) 1.08; overall mean (1a and 2a) 1.14; 1b) 1.5; 2b) 1.34; (1b&2b) 1.42; 3a) 1.08; 3b) 1.2; 3c) 1.14; 4a) 1.34; 4b) 1.48; 4c) 1.42	river	local	Haiti
Willis, K.G.	''Valuing non-market wildlife commodities: An evaluation and comparison of benefits and costs,''	*Applied Economics*, 22, 13-30.	1990	WTP for the preservation of the current state of the wetlands. Function-Use: Recreation, Habitat.	CV		£/ha.	(a. total use value: 44; (b. total non-use value: 807.	wetlands	regional	United Kingdom
Willis, K.G., G.D. Garrod, and C.M. Saunders.	"Benefits of Environmentally Sensitive Area Policy in England: A Contingent Valuation Assessment,"	*Journal of Environmental Management*, 33, 105-125.	1995	Determining the benefits the public derives from ESAs and assessing whether ESAs are efficient, by comparing the costs of ESA provision against their benefits to the general public. Function-Use: Habitat.	CV	1992	UK pounds, per household and per year.	Open-ended payment card (these were used later): 1) WTP additional taxes: residents/visitors/ general public: 27.52/ 19.47/36.65; 2) residents/ visitors: 17.53/11.84. Using Simpson's rule mean WTP: 138.37 per household (3.8 times > 36.65). The WTP values for all ESAs were apportioned out by people's utility for the different ESAs. This procedure resulted in a WTP value of: 1.98 per household per year (South Downs) and 2.45 per household per year (Somerset Levels and Moors).	River	regional	United Kingdom

Bibliographic study characteristics	Study characteristics										
Author(s)	**Title**	**Bibliographical details**	**Year**	**Issue addressed in study/ General Function-Use Identification**	**Valuation technique**	**Year of data collection**	**Measurement unit**	**Estimated value characteristics: Mean / Total**	**Water system: Groundwater/ surface water**	**Spatial scale**	**Country**
Willis, K.G. and G.D. Garrod.	"The Benefits of Alleviating Low Flows in Rivers,"	*Water Resources Development*, 11 (3), 243-260.	1995	To assess the benefits of low-flow allevation (LFA) along the River Darent in Kent. Function-Use: Recreation, Municipal and Domestic Water Supply.	CV	1993	In UK pounds, per household and per year.	a. 1/2/3 (in UK pounds): 18.45/ 15.06/17.18; b. 1/2/3: 12.32/9.76/ 12.92; c. 1/2/3: 10.19/7.16/3.85; d. 1/2/3: 6.25/4.85/3.00.	river and aquifers. AQUIFER - GROUND WATER	regional	United Kingdom
Willis, K.G. and G.D. Garrod.	"Valuing Landscape: A Contingent Valuation Approach,"	*Journal of Environmental Management*, 37, 1-22.	1993	To measure the benefits conferred on society by particular landscapes. This study assesses the preferences for and the values of different landscapes, which could arise in the future. Function-Use: Recreation.	CV	Last four months of 1990.	In UK pounds at 1990 prices	Aggregate WTP to preserve today's landscape is the number of visitors (plus residents) multiplied by their respective average WTP, multi-plied by the proportion of the relevant population who gave this landscape as their first preference choic. This provides an aggregate WTP measure of 41,762,560 pounds for visitors and 118,910 pounds for residents for today's landscape. For conserved landscape the figures are: 40,134,080/ 73,663; planned: 5,308,560/ 8,280; abandoned: 2,470,000/ 2,164; sporting: 1,346,800/ 5,528; wild: 17,100,000/ 18,409. The net benefits from interventionist landscapes exceed non-interventionist ones by 66.5 million pounds per year.	River and waterfalls.	Regional	United Kingdom
Willis, K.G. and G.D. Garrod.	"Valuing Open Access Recreation on Inland Waterways: On-Site Recreation Surveys and Selection Effects,"	*Regional Studies*, 25 (6), 511-524.	1991	To estimate the value of non-priced informal recreational use of waterways. Function-Use: Recreation.	CV, TC	July, August and September 1989.	UK Pounds per visit	Mean number of visits or frequency of use per year: holiday hire boats: 1.2; canoeing: 6.1; unpo-wered craft: 5.3; other powered boats: 3.6; restaurant or trip boat: 1.7; fishing: 17.7; other informal uses: 18.2.	river	regional	United Kingdom
Willis, K.G. *et al.*	"The value of canals as a public good: The case of the Montgomery and Lancaster canals,"	*Countryside Change Working Paper*, 5, Countryside Change Unit, University of Newcastle, Newcastle.	1990	Canal and waterway informal recreation. Function-Use: Recreation.	TC		UK Pounds	Average consumer surplus per visitor: (a. canal 1: 0.29; (b. canal 2: 0.32.	canal	local	United Kingdom

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Wilman, E.A. and R.J. Pauls.	"Sensitivity of Consumers' Surplus Estimates to Variation in the Parameters of the Travel Cost Model,"	*Canadian Journal of Agricultural Economics*, 35, 197-212.	1987	The objective of this paper is to investigate the sensitivity of the consumers' surplus estimates, generated by the TCM, with respect to 3 factors: 1. The treatment of substitute sites; 2. The treatment of time costs; 3. Whether or not possible truncation bias is eliminated. Function-Use: Recreation.	TC	1984	In dollars, per day and per round trip.	LDS a.: L (omitted variable) excl/incl: 251,765/ 269,000 ; LDS b.: 288,499/ 338,016 ; SDS a./b.: 245,381/317,998; LD a.: L excl/incl: 499,670/535,716; LD b.: 969,794/1,042,000; SD a./b.: 412,929/830,717.	River	regional	Canada
Young, C.E. and F.A. Teti.	"The Influence of Water Quality on the Value of Recreational Properties Adjacent to St. Albans Bay, Vermont,"	ERS Staff Report No. AGES831116, Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture, Washington D.C., USA.	1984	To determine whether water quality affected the value of properties located adjacent to St. Albans Bay, Vermont. Function-Use: Recreation.	HP	1976 through 1981.	In dollars per unit.	The estimates indicate that properties located outsite the bay sell for appr. $4,200 more than properties located adjacent to the bay. The average residential property located along the bay sells for appr. $4,500 less than similar properties outside the bay. When water quality at point 6 was improved to the level of water quality at point 8, the increase in value of properties located near point 6 would be appr. $3,600.	Bay.	Regional	USA
Young, R. and S. L. Gray.	"Valuation of Water in Industrial Uses,"	Ch. 7 in Economic Value of Water: Concepts and Empirical Estimates. Department of Economics, Colorado State University, Fort Collins. Final Report to the National Water Commission. Report No. NWC-SBS-72-047.	1972	Water used in industrial uses. Function-Use: Industrial Supply.	MV		Dollars per acre foot.	(a. Estimate measures the value of water for processing uses in the mineral industry in Arizona (high estimate): 6.52; (b. Estimate measures the value of water for processing in the chemical industry in Monterey, Mexico: 22.81.	river	regional	USA
Young, R. and S. L. Gray.	"Valuing Water for Inland Waterways Navigation,"	Ch. 12 in Economic Value of Water: Concepts and Empirical Estimates. Department of Economics, Colorado State University, Fort Collins. Final Report to the National Water Commission. Report No. NWC-SBS-72-047.	1972	Navigation and transportation on inland waters. Function-Use: Navigation.	MV	1969	$/ acre foot.	(a. Value of water used for navigation in the lower Mississippi River is reported: 1.64; (b. Value of water used for navigation in the Illinois waterway is reported: 33.48.	rivers	regional	USA

Bibliographic study characteristics	Study characteristics										
Author(s)	Title	Bibliographical details	Year	Issue addressed in study/ General Function-Use Identification	Valuation technique	Year of data collection	Measurement unit	Estimated value characteristics: Mean / Total	Water system: Groundwater/ surface water	Spatial scale	Country
Young, R. and S. L. Gray.	"The Value of Water for Hydroelectric Power Generation,"	Ch. 13 in Economic Value of Water: Concepts and Empirical Estimates. Department of Economics, Colorado State University, Fort Collins. Final Report to the National Water Commission. Report No. NWC-SBS-72-047.	1972	Water used in hydropower generation. Function-Use: Hydropower generation.	Other		$/ acre foot.	Reports long run value of water used in hydropower generation in Intermountain region. This value is applicable for planning power projects and applies to potential projects where capital costs can be avoided if water is diverted to an alternate use: 0.19.	river	regional	USA
Ziegler, J.A. and S.E. Bell.	"Estimating Demand for Intake Water by Self-Supplied Firms,"	*Water Resources Research*, 20(1), 4-8.	1984	The value of water as a firm input. Function-Use: Industrial Supply.	MV		Cents per 1,000 gallons of intake water.	(a. Value represents the average cost of 1000 gallons of intake water. Measures of intake water price include the costs of acquisition, treatment, and disposal: 12.64; (b. Value represents the additional (marginal) cost of 1000 gallons of intake water. Measures of intake water price include the costs of acquisition, treatment, and disposal: 22.78.	rivers	regional	USA

FAO TECHNICAL PAPERS

FAO WATER REPORTS

1 Prevention of water pollution by agriculture and related activities, 1993 (E S)
2 Irrigation water delivery models, 1994 (E)
3 Water harvesting for improved agricultural production, 1994 (E)
4 Use of remote sensing techniques in irrigation and drainage, 1995 (E)
5 Irrigation management transfer, 1995 (E)
6 Methodology for water policy review and reform, 1995 (E)
7 Irrigation in Africa in figures/L’irrigation en Afrique en chiffres, 1995 (E/F)
8 Irrigation scheduling: from theory to practice, 1996 (E)
9 Irrigation in the Near East Region in figures, 1997 (E)
10 Quality control of wastewater for irrigated crop production, 1997 (E)
11 Seawater intrusion in coastal aquifers – Guidelines for study, monitoring and control, 1997 (E)
12 Modernization of irrigation schemes: past experiences and future options, 1997 (E)
13 Management of agricultural drainage water quality, 1997 (E)
14 Irrigation technology transfer in support of food security, 1997 (E)
15 Irrigation in the countries of the former Soviet Union in figures, 1997 (E) (also published as RAP Publication 1997/22)
16 Télédétection et ressources en eau/Remote sensing and water resources, 1997 (F/E)
17 Institutional and technical options in the development and management of small-scale irrigation, 1998 (E)
18 Irrigation in Asia in figures, 1999 (E)
19 Modern water control and management practices in irrigation – Impact on performance, 1999 (E)
20 El riego en América Latina y el Caribe en cifras/ Irrigation in Latin America and the Caribbean in figures, 2000 (S/E)
21 Water quality management and control of water pollution, 2000 (E)
22 Deficit irrigation practices, 2002 (E)
23 Review of world water resources by country, 2003 (E)
24 Rethinking the approach to groundwater and food security, 2003 (E)
25 Groundwater management: the search for practical approaches, 2003 (E)
26 Capacity development in irrigation and drainage. Issues, challenges and the way ahead, 2004 (E)
27 Economic valuation of water resources: from the sectoral to a functional perspective of natural resources management, 2004 (E)

Availability: October 2004
Ar – Arabic
C – Chinese
E – English
F – French
P – Portuguese
S – Spanish
Multil – Multilingual
* Out of print
** In preparation

27
FAO WATER REPORTS

Economic valuation of water resources in agriculture

From the sectoral to a functional perspective of natural resource management

Agriculture is coming under more and more pressure to justify its use of the world's freshwater resources and to improve its productive and environmental performance. The allocations of raw water to agriculture (and the allocations within the agriculture sector) all need to be negotiated in a transparent way. This report reviews the large set of literature on the subject and makes the case for the adoption of a functional approach to water valuation as a basis for such negotiation.

ISBN 92-5-105190-9 ISSN 1020-1203
9 789251 051900
TC/M/Y5582E/1/10.04/1000

27

Economic valuation of water resources in agriculture — From the sectoral to a functional perspective of natural resource management

FAO