Handbook of Water Economics

Principles and Practice

Colin Green

University of Middlesex

WILEY

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Introduction

The relationship of the economy to the environment is as the leaf to the tree. Therefore, the decisions we take concerning the environment, and the effectiveness of the implementation of those decisions, will determine whether or not we achieve sustainable development. Economics, the application to choice, offers a means of understanding the nature of the choices we must make and, through this understanding, of making better choices.

Nowhere is this dependence of society and the economy upon the environment seen more clearly than in relation to water. Traditionally, the start of civilisation is ascribed to the settlements in the valleys of the Euphrates/Tigris, where the combination of fertile river-deposited sediment and readily available water enabled secure food supplies. The same pattern of settlement can be seen in other parts of the world from the Americas (Williams 1997) to Asia (Mendis 1999). That each society depends on water meant that we began very early on to try to modify the water environment for our purposes; the Shaopi reservoir was built around 590 BC, a navigation canal in Guangxi in 219 BC, and Dujiangyan dam in around 200 BC (Xhang 1999). In turn, the inability to manage water successfully, particularly under prolonged drought conditions, has resulted in the death of cultures in the Americas (Williams 1997) and Asia (Postel 1992).

One result of the dependence of society on successful water management is that until very recently water engineers saw their purpose as being to determine what the public need, to determine the best means of satisfying that need, and then to construct the required works. By defining the issue as one of necessity rather than desirability, the question of whether or not the project was desirable was finessed; it was instead inevitable. In turn, the task in water resource planning became one of predicting by how much demand for water would inevitably increase in the future and then providing for this increase. The assumption was that all growth is good as well as inevitable, and that economic and social development will necessarily require a proportionate growth in all inputs, including water.

That the identification of the possible options and the decision as to which is the best option were defined as being part of the engineer's job, led inevitably to both a focus on engineering approaches and to the identification of the best in terms of engineering issues. After all, engineers became engineers in order to build

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things and after all the socially construed role of engineers is to build things. That something could be done became to imply that something should be done. Whilst the result was a number of major engineering triumphs, there were a number of significant failures as well (Adams 1992); a number of expensive projects that had been built to match a predicted growth in demand that did not occur (USACE 1995); a growing recognition of the environmental and human consequences of some projects (Acreman *et al*. 1999); and an increasing questioning of whether some projects were really necessary (Bowers 1983; Reisner 1993). A significant number of projects have also never delivered successfully; in India, only some 70% of hand pumps are estimated to be working at any one time (South East Region 1999) and some 30% of the public latrines in Bombay are out of service (Operations Evaluation Department 1996).

Today, this dependence of development upon water management is even more pronounced. The availability and management of water is increasingly seen as perhaps the defining constraint upon development (World Water Council 2000), with an increasing number of countries reaching conditions of water scarcity. By 2025, IWMI (2000) estimates that 78% of the world's population will live in areas facing some degree of water scarcity. To release this constraint on development will involve major investments: the World Water Council (2000) estimates that annual investment in water management will have to rise to US$180 billion from the current US$70–80 billion in order to reduce the number of people lacking basic water or sanitation and to increase average calorific intake to a minimum of 2750 calories per day. Increasing food production to meet this target and to accommodate population growth is a critical problem. An oft-quoted figure is that it takes 1000 tonnes of water to produce 1 tonne of wheat, although the actual requirement depends upon amongst other things the potential evapotranspiration rate in the region (Rockstrom *et al*. 1999). In turn, whilst each person uses 7 to 100 tonnes of water in their home for drinking, cooking, washing and other purposes, another 1000 to 2000 tonnes of water is required to grow the food that they eat. It does not matter whether this water is delivered directly as rainfall, indirectly by concentrating the runoff from a wider area through rainfall harvesting, or through irrigation. Thus, whilst the average European uses twice their body weight of water in their home each day, the food that they eat has consumed roughly three tonnes of water. Growth in population and a shift toward higher meat consumption translate directly into a demand for more water.

However, it is not just water that is scarce; so, too, over much of the world is arable land, and most of the rest of the land is already in use as forests, wetlands and grasslands. In China, there is approximately 0.10 hectares of arable land per person so that roughly 2.5 square metres of land must supply enough food to feed one person for a day. A major benefit of irrigation is that more than one crop can be harvested in a year; consequently, irrigation in conjunction with high yield varieties and high inputs can yield 8000 kg/ha (Seckler 2000). Thus, 40% of the world's food is currently produced from the 17% of land that is irrigated.

About 50% of the world's population live partly or wholly in arid or semi-arid lands where not only is average rainfall less than 30 cm but there is wide variability in the amounts from year to year. Consequently, the IWMI (2000) estimates that meeting projected food requirements will require an expansion of 29% in the irrigated area together with an increase in irrigated crop yields from a global average of 3.3 to 4.7 tonnes per hectare. Or, alternatively, irrigated cereal yields will need to increase to 5.8 tonnes per hectare if the irrigated area is not to be expanded. Achieving either will require substantial investment. On a more parochial basis, of the £197 billion modern asset equivalent value of the water and wastewater system in England and Wales, £109 billion is the network of sewers (OFWAT 2002a). This is roughly equivalent to £7000 per household. If climate change results in an increase in the intensity of rainfall from the frequent events, as it is reported to have done in the USA (Hurd *et al*. 1996), then the costs of upgrading the network to cope with increased runoff will amount to a significant fraction of the current asset value.

At the same time, almost any intervention in managing water affects the environment either intentionally or incidentally. Globally, an estimated 20% of freshwater fish species became extinct, threatened or endangered in recent decades (Wood *et al*. 2000). We have, however, only recently realised the dependence of the economy on the environment; notably the functional value of the environment (de Groot 1987), and particularly the importance of wetlands (Pearce and Turner 1990). Constanza *et al*. (1997) sought to estimate the global value of the services provided by the environment on the basis of previously published studies. Whilst not too much attention should be given to the resulting values, since the leaf cannot value the tree, their paper further emphasises the dependency of the economy on the environment. Rivers conveniently transport runoff from those usually inhospitable places where there is high precipitation to those areas where it is most useful for human purposes. In addition, for centuries, rivers provided the best transport routes. Similarly, lakes and groundwater store water until we need it.

In the developed world, much of the current investment is going into undoing the damage caused by past intentional or accidental damage to the environment. The modification of the river Rhine for navigation and other reasons (the Upper Rhine has been shortened by 82 km and the Lower Rhine by 23 km) and the reclamation of the natural flood plains for agricultural purposes have created a number of flood problems. The results of the various works on the Rhine have cut the time taken for the flood peak to travel from Basle to Karlsruhe from 2 days to 1 day and from Basle to Maxau from 64 hours to 23 hours. This has tended to increase the risk that the flood peak on the main stem will coincide with that on the downstream tributaries. The discharge for the 200-year return period flood has also increased from 5000 m^3/sec in 1955 to 5700 m^3/sec in 1977 (Bosenius and Rechenberg 1996).

Much of flood management in Germany today is consequently concerned with removing some of these past modifications to the catchments, the river corridors and the river channel itself and to reducing runoff, recreating storage in the flood plain and in restoring the natural form of the river (Bismuth *et al*. 1998). The Flood Action Plan (International Rhine Commission n.d.) is the archetype of this approach. The same principles are being applied to other rivers in Germany: for example, the planned recreation of some 28 wetlands on the Elbe (BMBF 1995). Similarly, in the Netherlands, both the plans for the river Meuse (de Bruin *et al*. 1987) and for the Rhine (Ministry of Transport, Public Works and Water Management 1996) involve the recreation of wetlands and a degree of river restoration. On smaller scales, river restoration, or ‘daylighting’ (Pinkham *et al*. 1999), is increasingly common in other countries (Brouwer *et al*. 2001; Riley 1998). In the USA, a number of dams have now been demolished (Pritchard 2001) and the discharge regimes of others are being modified to provide a more natural variation in the flow regime of the river downstream (Acreman *et al*. 1999).

Already in the UK, the costs of collecting and treating wastewater exceed the costs of providing potable water, and the Water Framework Directive (European Parliament 1999) will further increase these costs in Europe. The salts leached from irrigated soils have caused severe problems (Postel 1993), whilst pesticide and fertiliser residues, along with animal manure, are a widespread problem (Nixon 2000; USEPA 2000). Over-abstraction of groundwater has caused major problems in cities as diverse as Mexico City and Bangkok (Briscoe 1993), and some rivers, of which the Yellow River is simply the best known, also run dry because of over-abstraction (English Nature and the Environment Agency 1999).

In short:

- water is critical to social and economic development,
- over much of the world, both arable land and water are scarce,
- managing water is highly capital-intensive, and capital is also scarce; and
- there are environmental consequences to almost any intervention in the water cycle whilst the economy depends upon the environment.

In turn, water management is about seeking to change risks, to alter either the probability of some event or the consequence of that event whether that event be a drought, a flood, or a pulse of pollution. The individual risks may be vanishing close to zero or to one, but in principle the decisions are always about choosing risks. However, since choices are always about the future, we are seeking to choose the future but the one thing that the rational person can be absolutely certain about is that the future is inherently uncertain. So, we are seeking to make choices about risks under conditions of uncertainty. Indeed, I shall argue later that uncertainty is a precondition for a choice to exist.

Achieving sustainable development therefore requires us to make ‘better’ decisions: to be more successful at avoiding mistakes; to make more efficient use of available resources including water; and to maintain the environment as the necessary support for the economy. But, ‘better’ decisions are not simply technically better; they have to be socially better as well. We need to be more successful in resolving the multiple and frequently conflicting objectives that we bring to decisions; in particular in regard to equity considerations. These objectives explicitly include a regard to gender equality, not least because women are often the principal sufferers from existing water problems (Mehta n.d.). Moreover their position has often been made worse by past projects (Rathgeber 1996) because they were seen as not having separate interests of their own but simply as part of a household production unit (Haddad *et al*. 1997). The adequate resettlement of those who, given the population density across much of the world, will be displaced by a project is now recognised as a question of justice and as necessarily involving that they will have a voice in the decision process (WCD 2000).

From the Dublin Declaration (ACC/ISGWR 1992) onwards, it has been accepted that public involvement in all levels of decision making is both an objective in itself and also essential if management plans are to be successful. Thus, the Government of New South Wales's (n.d.) guidelines on preparing River, Groundwater and Water Management Plans state that 'Community involvement is critical in identifying potential issues, differing values, opportunities and constraints, and available alternatives at a catchment level.' Similarly, in the UK, the DETR (2000) stated that: 'Public participation in making decisions is vital. It brings benefits in making an individual decision and also for democracy more generally. . . . It is also a moral duty. Public authorities work for the public. To do so in a way that the public want and to ensure that they know what the public needs, they must involve the public when they make decisions.'

Adding new objectives and recognising the complexities has made decision making and identification of appropriate options more difficult where the options themselves are more complex. Twenty years ago, designing a flood alleviation scheme was easy: the engineer simply drew a straight line from A to B, built a concrete trapezoidal channel and called it a 'river improvement' scheme. Today, environmentally sensitive solutions can involve sewing together into one integrated system a myriad of small-scale local works.

However, we are of limited intellectual capacity and the decisions that face us threaten to be too complex for us to adequately understand the nature of the choice we must make. In his classic paper, G.A. Miller (1956) reported that experimental studies showed that we could handle no more than seven, plus or minus two, factors at a time. A raft of studies by Tversky and Kahneman (1973, 1981) and others (e.g. Slovic *et al*. 1976) have also shown that our cognitions are affected by all sorts of biases. The purposes of economic analysis are therefore three-fold:

- To simplify the nature of the choice to a level that we can comprehend;
- To enable us to understand the key elements of that choice; and
- To communicate that understanding to all of the stakeholders so as to form a framework in which they can debate, argue and negotiate their concerns.

At the same time, better decisions depend upon better options being created. In the past, there has been a tendency to propose that whatever approach had been adopted in the Netherlands, or for the Mississippi, or for London, should immediately be adopted in Zambia, on the Yangtze and in Buenos Aires. The result has been that the latter countries have been supplied with expensive, inappropriate technologies that fail to work in the local conditions or, in some cases, have created a worse problem than that they were intended to solve. Akuoke-Asibey (1996) describes a rural water supply programme where the investment had effectively to be made three times before a sustainable system emerged; this experience has not been atypical. Many of those heroic projects also had significant, negative consequences, particularly in terms of the environment; the Aral Sea disaster is simply the best known of many failures. So, we have accumulated a history in which there were many projects that failed to deliver what was promised and, when they did, the other unintended or unanticipated impacts of the projects were significant.

However, this past can be painted too bleakly as if the whole history of water management was one of unmitigated failure which self-evidently it has not been. Moreover, we need to remind ourselves that development is not possible without failures; if we only repeat that which has worked in the past, there can be no improvements. If we seek to innovate, there will inevitably be some failures; indeed, we must legitimate failure as a way of learning if we want to innovate. The condition is that the failure should teach us something new and not simply repeat a past lesson. Clare Johnson (2001) paraphrased Al Capone by suggesting that once is a lesson, twice is a failure and thrice is incompetence.

One negative consequence of the history of only partial success has been that some people have sought to preclude some options, particularly dams, from ever being considered. At the same time, the myth of magic bullets has been updated with a new set of bullets, or several sets of bullets. Some of the more promising new options are in danger of being treated uncritically, as if they are always more appropriate than any of the options that have been used in the past. This is precisely the mistake we made in the past. As the World Commission on Dams (WCD 2000) emphasised, we need better ways of making decisions as well as better options.

Better options depend upon the creativity, imagination, experience and skills of designers; here economic analysis cannot help directly. But better options also depend upon the designers' understanding of the nature of the problem and here economics can help because it seeks to clarify what the decision all about, what is the problem and what are our objectives. Better answers often emerge as a result of better questions being asked.

The first and fundamental question that economics keeps asking is: why are we doing this? Again, experience suggests that after a project has been under design and construction for 10–15 years, the primary objective of all involved is to complete it. Again, once it is operational, the project is frequently operated in a particular way because that is what the manual says should be done. The second fundamental question economics asks is: what are the alternatives? There is no point in being against some option unless there exists an option that is in some sense 'better'. Thirdly, it asks: what sacrifices do we have to make for this option? It is a presumption of economics that no choice is painless, that any choice involves a real sacrifice so that if a choice appears painless, it is only because the implications have not been examined. Fourthly, it asks: does it work? Many of the new options proposed as magic bullets turn out only to work in some conditions and to have significant problems. Thus, source control looked superficially to be an attractive way of resolving an urban flooding problem in one city; unfortunately, the city turned out to be so densely developed that implementing source control would involve massive resettlement.

2

What is Economics?

The popular definition of economics is that it is the study of the economy but few dictionaries of economics define the term ‘economy’ although definitions of subcategories such as market and planned economies usually are given. This absence of a definition shows both that economists do not define economics as the study of the economy and the apparent irrelevance of the economy to economics.

But, if economics is not the study of the economy, then it may be asked what it actually is. John Stuart Mill’s (1844) definition of political economy actually came close to defining it in terms of the study of the economy: ‘The science which traces the laws of such of the phenomena of society as arise from the combined operations of mankind for the production of wealth, in so far as those phenomena are not modified by the pursuit of any other object.’ But later definitions of economics focus on the relationship between means and ends. Thus, Robbins (1935) defined economics as being: ‘The science which studies human behaviour as a relationship between ends and scarce means which have alternative uses.’ Similarly, Samuelson’s (1970) definition is: ‘Economics is the study of how men and society end up *choosing*, with or without the use of money, to employ *scarce* productive resources which could have alternative uses, to produce various commodities and distribute them for consumption, now or in the future, among various people and groups in society’ (emphases in the original). On the basis of the definitions of Robbins and Samuelson, then the pithiest definition of economics and that which will be used here is: ‘The application of reason to choice’ (Green and Newsome 1992).

There is a further definition that ought to be mentioned and that is the one given by Hausman (1992): ‘Economic phenomena are the consequences of rational choices that are governed by some variant of consumerism and profit maximization. In other words, *economics studies the consequences of rational greed*’ (emphasis in the original). This is a somewhat aberrant definition in that the claim that economics is solely concerned with greed was explicitly rejected by Alfred Marshall, perhaps the key figure in the development of the dominant paradigm of economic analysis, neoclassical economics. Marshall (1920) wrote: ‘... the splendid teachings of Carlyle and Ruskin as to the right aims of human endeavour and wealth would not have been marred by bitter attacks on economics, based upon

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the mistaken belief that science (economics) had no concern with any motive except the selfish desire for wealth, or even that it inculcated a policy of sordid selfishness.'

2.1 Why Do We Have to Choose?

If economics is defined as the application of reason to choice, this simply shifts the burden to defining choice and reason. Conventionally, reason is essentially regarded as a rigorous, logical framework of argument, whether the argument is internal to the individual or made within a group of individuals seeking to determine what common course of action should be adopted. Conventionally, economics follows Russell (1954) in arguing that the application of reason leads to the choice of the best means of achieving some predetermined objectives: '"Reason" has a perfectly clear and precise meaning. It signifies the choice of the right means to an end that you wish to achieve. It has nothing whatever to do with the choice of ends.' Thus, in neoclassical economics it is assumed that the objectives are givens and choices do not involve a choice of objectives. But, the difficulty of some choices lies precisely in that we have to choose between objectives. However, Kant (1785) argued that we should apply reason to determining what our objectives should be, and concluded that reason dictated that our objective should be duty. It seems reasonable therefore to assume that we may use reason to argue as to the objectives that we should seek to achieve. Furthermore although as Simon (1986) observed '... in economics, rationality is viewed in terms of the choices it produces: in the other social sciences, it is viewed in terms of the processes it employs', here I will refer to rationality purely in terms of a logical, rigorous process of argument. The outcomes of that process will only be consistent with each other if nothing changes in the interim: we neither gain new information nor learn anything.

The neoclassical economic model then asserts that choice is necessary because of the scarcity of resources: this is too narrow a definition of conditions that make choice necessary. For example, I have to make a choice to decide which part of a newspaper to read first and parents have to choose what name to give to a baby. Thus, a choice is necessary whenever the alternatives are mutually exclusive; a choice exists when there are two or more options and only one can be chosen. Conversely, if there is only one course of action, then there is no choice to be made. Equally, even if there are alternatives but one option is clearly to be preferred to all the others then effectively the choice has already been made. For a choice to still exist, the alternatives must compete in some way; it must be possible to argue that at least two options should be preferred to all the others but for a decision not yet to have been reached between the two options. For a choice to still exist, there need to be competing reasons that lead to different conclusions as to which option should be preferred. Once the logical argument leads to the conclusion that one option should be preferred to all others, then the choice is made.

The second condition for a choice to exist is that we cannot decide between the alternatives; we are uncertain as to which option should be preferred where we can define uncertainty as 'an inability to differentiate': in this case, in terms of the order of preference across the alternatives. Once we are reasonably confident that one option should be preferred to all others, then the choice is made.

Therefore, the simplest definition of the conditions under which we have to make a choice is:

$$\text{Choice} = \text{Conflict} + \text{Uncertainty}$$

Thus, we only have to make a choice when the available alternatives are mutually exclusive, the adoption of one precluding the adoption of the others, and it is not self-evident which is the best option to adopt. If all the stakeholders in the decisions are both certain and agreed as to which is the best option then only in the most trivial sense is there a choice to make. So choice is a process through which we seek to resolve the conflict and achieve a level of confidence that one option should be preferred to all other available alternatives. It is a rational process in that a rigorous, logical framework of argument is used to decide which option should be adopted.

If this definition of choice is adopted then a number of results follow:

- We may be falsely confident that one option should be preferred to all others;
- Conversely, we may be falsely uncertain as to which option should be preferred to all others; and
- Some choices may be truly marginal in that the reasons for choosing one option over another are exactly counterbalanced by reasons for making the opposite choice. It may, in short, be impossible to resolve the conflict even if we had perfect information.

However, the neoclassical economic model starts with the assumption of perfect information and then relaxes the conditions to allow choice under imperfect information. But, under the definition of choice just given, if there is perfect information there is no choice to make unless the options are all equally attractive. Consequently, to start with the assumption of perfect information is the least appropriate place to begin an analysis of choice. It is extremely unlikely that we will ever have perfect information and the logical starting point is one of uncertainty and how we may seek to reach a state where we can say with some confidence that one option is to be preferred to all others.

Finally, choices are necessarily always prospective: the choice and its consequences lie in the future. In short, we are always trying to choose a future and choices are between hypothetical futures or expectations of the future. We must make choices on the basis of what we expect will be the consequences of those choices and choices are always about what we 'ought' to do in one or both of the two senses of 'ought': that course of action that logically follows from the argument and that which morally should be done (Beyleveld and Brownsword 1994).

In turn, what I chose yesterday has no force in determining what I should choose today; 'is' does not determine 'ought' in either of the two senses of 'ought'. The choices we have made are no more than history and it cannot be argued that what we choose next should be consistent with what we have chosen before. Indeed, to the extent that we learn from the outcomes of the choices we have made in the past, our choices now and in the future will be different. In consequence, past purchasing decisions are ephemera of only historical significance. Whilst choices should logically be influenced by the lessons learnt from past choices, each choice is a new choice that, in principle, must be made anew rather than be dictated by the past. However, routine and habit, simple unthinking repetition of previous choices, are convenient ways of minimising the effort that must be put into making choices although they are treated with some contempt simply because they do not involve any thought, any rational process of choosing.

2.1.1 Conflict

The available alternatives can be mutually exclusive because of a number of reasons and often a combination of these different reasons (Figure 2.1).

2.1.1.1 Functional equivalence

If I am thirsty then I may choose between a cup of coffee or tea; I would be thought somewhat strange if I took a cup of each and even more so if I choose a cup of mixed tea and coffee. In this case, tea and coffee are functional substitutes although I may have a taste preference for one rather than the other

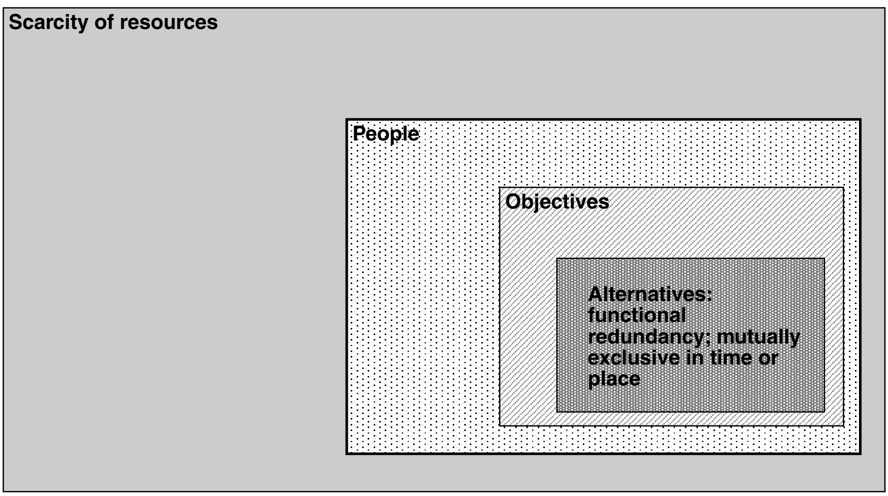

Figure 2.1 *The conflicts that make choice necessary*

at a particular point in time – and a preference that may also depend upon where I am. Similarly, faced with three possible sites from which to pump a given quantity of groundwater, it would be a waste of resources to develop all three.

If the extent to which two or more options are near perfect substitutes for each other is one reason why we can be forced to choose, it is easy then to become confused between different types of substitution. If I ask for a drink and am offered a pair of shoes, I would be surprised. We can distinguish between at least three different possible forms of substitution:

- functional substitutes;
- utility substitutes (the pleasure gained from one is equivalent to the pleasure gained from the other so that having one compensates for the other);
- exchange substitutes (one can be bought or sold for the other).

Thus, whilst I gain utility from both cups of coffee and pairs of shoes and I can sell a pair of shoes to buy a cup of coffee, a pair of shoes is of no use to me when I am thirsty. The danger is, as occurs in some economic analyses, that what starts as an assumption of one form of substitution then subtly glissades into another. In particular, collective choices are typically about functional equivalence, they are specific, e.g. the choice is about whether and how to provide a potable water supply rather than simply about increasing the sum of utility.

The concept of utility substitution is fundamental to neoclassical economic analysis but should not be confused with a lack of differentiation. One pair of shoes quite obviously can provide greater utility than another; Lancaster (1966) argues that a good, such as a pair of shoes, is a bundle of attributes each of which attributes is more or less desirable. In turn, there can be no constraints of the functional form of either the utility function with respect to an attribute, nor on the functional relationship of the utilities for the different attributes, nor as to the rate at which one good can be substituted for another. There is by now a very large literature covering utility theory and its measurement (e.g. Hull *et al*. 1987).

In fact, in making individual choices we can readily accommodate both a lack of functional equivalence for individual goods (e.g. someone will not regard someone else's wedding photographs as being in any way a substitute for photographs of their own wedding) and quite complex utility functions. It is only necessary to make the wider assumptions of universal utility substitution when economists seek to argue that individual choices and markets achieve the optimum.

2.1.1.2 Space

One fundamental reason why two options are mutually exclusive is that they cannot exist in the same space; a reservoir and climax forest cannot occupy the same space. Nor can two people sit on the same chair with any comfort. Similarly, I cannot go on holiday to two different places nor can a meadow be used for pasture and planted with a crop of wheat. Again, it is not possible to have a 60 cm diameter and 90 cm diameter water main in the same trench since to place both pipes would be equivalent to having the capacity of a 108 cm diameter pipe.

2.1.1.3 Time

Similarly, the need to choose is often because of the constraints of time; we may be able to afford to rent two videos but cannot watch both of them tonight. Consumption is thus time constrained (Soule 1955) and the extent to which resources can be sacrificed to gain time is extremely limited. Indeed, in Western societies, we might argue that consumption is ultimately constrained more by the availability of time than by income. That there are more things we could do, and would like to do, than there is time to do them. The need to choose whether to visit the National Gallery or Hampstead Heath, for example, arises not because we cannot afford to do both but because we do not have the time to do both.

Most goods are time rivals: the time required for the consumption of one cannot simultaneously be used to consume another. Thus, it is not possible to watch television and weed the garden at the same time. Others are not time-rival goods and may be consumed simultaneously: most activities are apparently compatible with simultaneously listening to music. Equally, some goods are joint-time goods: drinking beer, reading a book and lying on the beach being one possible example.

Goods differ in their time availability. Some, like newspapers and many foods, are ephemeral: these only have a utility if they are consumed within a relatively short timespan. Others are only available for short periods of time; examples include television programmes and hot, sunny days. Yet others, such as landscapes are essentially permanently available although their utility will often vary over time depending upon other variables, notably the weather, the time of day and the mood of the children.

Moreover, only a few goods can be consumed in discontinuous time segments; most require a discrete segment of time. Thus, whilst a newspaper or book can be put down and picked up later, a meal or holiday requires one continuous period of time.

Consequently, one of the major problems faced by the consumer is the time scheduling of consumption. The availability of the good and the time to consume it must be matched: the individual must maximise utility by choosing that good which has the highest value from those available in that time period. Consequently, the opportunity cost of consumption is the utility that would have been gained from the next most desirable consumption within that time period.

Furthermore, the individual's time is already subject to a schedule which is relatively fixed before consumption can be considered. Patterns of sleep cannot be easily changed into amounts or timings in order to take advantage of consumption opportunities. Similarly, the timing of consumption must conventionally be arranged around the timing of work, or school, or in families. Thus, one possible reason for the popularity of video-recorders is that these enable goods which are only available at a single point in time, television programmes and films, to be stored until either time, or the most appropriate time, is available for their consumption.

Few economists have paid any attention to this question although geographers (Carlstein 1982) have been concerned. But as Soule (1955) noted, it is arguable that increasing consumption is constrained primarily by the time available, and by the problems of time-scheduling consumption, rather than by resources. Local recreation is perhaps particularly constrained by time, the decision being which visits to undertake in the time available rather than by income since parks, coasts and rivers typically involve no entrance charge and the resource costs of travel on foot are negligible. Similarly, the resource costs of reading a book, watching the television or listening to the radio or hi-fi are also negligible once the book, television or radio has been bought. The decision of which of these activities to undertake is thus likely to be governed by consideration of what other activity could be undertaken in the same period of time rather than by comparing the resource costs. As Table 2.1 shows, a considerable proportion of a household's time is spent in such activities and on the input side of a household's life, one set of decisions that must be made is between committing the time to the activity (e.g. DIY, cooking) or buying in the service.

Table 2.1 *Household time and expenditure allocation*

Category of expenditure	Amount per week (£)			Time per week (hrs)	
				Full-time working	
	Total	Durables	Flows	Woman	Man
Work				32.50	36.95
Travel to work				4.83	8.23
Breaks				2.90	3.60
Total work				40.23	48.78
Sleep				56.33	56.48
Motoring and bicycles		23.80			
Motoring: spares and accessories		1.70			
Motoring: insurance and taxation, repairs		12.70			
Fuel etc.			17.60		
Fares and other travel costs			9.50		
Total travel		38.20	27.10		
Housing, gross rent		24.90	12.80		
Water			4.20		
Repairs, maintenance and decoration		8.90			
Professional fees		2.20			

(*continued overleaf*)

Table 2.1 *(continued)*

Category of expenditure	Amount per week (£)			Time per week (hrs)	
				Full-time working	
	Total	Durables	Flows	Woman	Man
Other services			3.70		
Fuel, light, power			11.90		
Telephone			8.40		
Total housing services		36.00	41.00		
Meal preparation				5.00	2.15
Food for home consumption			41.40		
Washing up				1.63	2.15
Laundry				2.88	0.13
Tidying				0.98	0.38
Laundry, shoe repairs and dry cleaning			0.70		
Cleaning				2.20	0.20
Total housework		0.00	42.10	12.69	5.01
Clothing			22.00		
Furniture and fittings		26.00			
Operating, maintenance, repairs		3.60			
Kitchen/garden equipment		5.00			
Leather and travel goods, jewellery, watches etc.		2.10			
Shopping				4.90	4.03
Other household/garden				0.83	2.10
Total household durables and consumables		36.70	22.00	5.73	6.13
Eating in the home				5.40	5.13
Personal care			9.40	7.25	5.08
General childcare			2.60	0.95	0.58
Playing/teaching				0.40	0.28
Total personal and childcare		0.00	12.00	14.00	11.07
Greetings cards, stationery, paper goods			2.30		
Leisure goods		19.70			
Watching TV				11.23	18.38
Reading				3.48	1.65
Relaxing				6.83	2.60
Alcohol			15.00		
Tobacco			6.10		
Crafts and knitting/sewing				1.60	1.65
Pets			3.00		
Total home leisure		19.70	26.40	23.14	24.28

Table 2.1 *(continued)*

Category of expenditure	Amount per week (£)			Time per week (hrs)	
				Full-time working	
	Total	Durables	Flows	Woman	Man
Subscriptions			1.10		
Seeing family/friends				9.00	8.00
Sports			0.60	0.48	1.65
Clubs/societies			2.70	3.23	3.58
Pubs				0.23	0.95
Meals out/cinema			20.50	0.58	0.53
Other leisure services including holidays			46.10		
Miscellaneous			7.60		
Other			2.00	2.53	1.95
Total outside leisure		0.00	80.60	16.05	16.66
EXPENDITURE TOTAL	385.70	130.60	251.20		
Savings and defensive expenditures	23.50				
Structural insurance	3.90				
Medicines, prescriptions etc.	4.70				
Total	32.10				
Council tax, domestic rates	11.30				
Income tax	70.40				
National Insurance	18.40				
Savings and investments	10.40				
Repayment of debts	3.10				
TOTAL TAX	113.60				
TOTAL	531.40				

Sources: Anderson *et al*. (1994); National Statistics (n.d.).

Time is equally crucial in production although it was left to operations research rather than economics to identify its importance. Thus, the origin of linear programming lies in time scheduling different tasks between machines so as to maximise profitability (Williams 1967). Time allocation is similarly a critical issue in irrigation management; for a given quantity of water in a reservoir, the varying needs of the crops for water as a function both of the time in their growing cycle and the predicted weather, how much water should be released at what point in time, given that once released it will no longer be available? A similar problem confronts managers of potable water reservoirs; at what time should restrictions on releases and hence cutbacks in supply be announced?

The time and space constraints are linked; the mutual exclusivity in space constraint can be relaxed if we allow the same space to be occupied at different times or we can occupy different spaces at different times. Whilst famously we cannot be in two places at the same time, we can be in two places at different times: I can go on holiday to two different places at different times. This is, however, to assume that the two different times are perfect substitutes for each other. Frequently they are not: next year's labour is often no substitute for the same quantity of labour now unless, for example, it does not matter whether the scheme is constructed this year or next year. Equally obviously, time is not reversible.

Hence, an issue is the extent to which there is path dependency over time in the occupation of space; who occupies a chair at this moment in time has no necessary effect on who can occupy that chair in a subsequent moment in time. Similarly, the use of a field for pasture this year does not affect its potential use for growing wheat next year; conversely, the conversion of the meadow from pasture to wheat means that it will take longer to convert that field back to pasture and particularly to a meadow. Equally, maintaining an area as a climax forest does not prevent its conversion to a reservoir at some future date; conversely, once the area is converted to a reservoir, it will take between 100 and 1000 years before it can be re-established as a climax forest, depending upon the predominant species of trees.

If there can be a question as to the extent to which one future time is substitutable for another, the degree to which one point or area of space is substitutable by another can also be important. The extent to which they are substitutable depends in part on the activity concerned; a mountainside at 6000 metres is not realistically a substitute for a flood plain for growing arable crops. Soil, topography, microclimate and the availability of water are all characteristics that can determine the suitability of an area or point of land for a particular purpose. Moreover, location, the relationship of that area of land to other activities is also usually important; estate agents often claim that location is the primary determinant of house prices. These are self-evident points but it is not unknown for policies to be proposed that implicitly assume that there are near perfect substitutes for particular areas of land. For example, that habitats could be re-established elsewhere or that development should not be allowed on flood plain land but forced to take place elsewhere. Similarly, in the case of the climax forest and the reservoir, there may be nowhere else a climax forest could develop, even given sufficient time to elapse. Again, the assumption that in response to climate change, ecosystems can simply move or be moved uphill and towards the polar regions assumes that the soil and other conditions are similar there to those in the areas where the ecosystem is currently established.

A key characteristic of the precautionary principle (O'Riordan and Cameron 1994) is then to keep open as many futures as possible to avoid making choices that create path dependency.

2.1.1.4 Objectives

Russell's (1954) assertion that the use of reason is limited to the choice of means to some ends assumes that our objectives are givens, perhaps through religious authority, or have been determined before and outside of any choice as to ends. Thus, that there can be a complete separation of the discussions of means and of ends: that we can determine what we should do prior to and in the absence of any knowledge of what we can do. Moreover, either that there are no possible conflicts between the choice of action that each of our objectives should cause us to adopt, or that any such conflicts have already been resolved prior to any choice actually being confronted.

However, sometimes the objectives we bring to a choice are mutually exclusive; achievement of any one objective necessarily means that we have to sacrifice the achievement of another. Thus, Sen (1992) has argued that the problem with equality is that one form of equality can only be achieved by sacrificing another form of equality. Alternatively, there may simply be no available option that is superior to all others against all of our objectives although in principle there could be such an option. Choices that self-evidently involve a conflict of objectives are the most difficult which we face: the agony of the judges asked to decide in the case of conjoined twins was self-evident, given the choice between an operation to separate the twins that would necessarily result in the death of one and not operating and the strong probability that both would die.

2.1.1.5 People

Once more than one person is involved or affected by a decision then potentially there is a conflict between those people as to which option should be chosen. At the simplest level, the balance of gains and losses to each person is unlikely to be identical for each person; we differ in our preferences not least as a function of age, physical, cultural (Schwartz and Thompson 1990) and psychological differences (Seligman *et al.* 1994). Since choices are about the future then a key question is: how is the future created, how does the world work? The diagram adopted by cultural theorists (Schwartz and Thompson 1990) is insightful: differences in the views as to how to choose the future between groups are described as a reflection of their fundamental views as to whether the world is inherently stable, inherently unstable, or locally stable. At the one extreme lie the 'contrarians' who believe that it will always turn out all right in the end and hence there is no need to worry since if technology creates problems, technology will then solve those problems.

People may equally disagree as to the likelihoods of the potential outcomes of each option and differ in the degree to which they are risk averse or risk seeking; what is an acceptable risk to one person may be quite unacceptable to another. Hull *et al.* (1987), for example, observed that managers from the oil industry found 50–50 gambles implausible because they never experienced as good odds as those. Conversely, managers from other industries considered that the odds that oil industry managers face every day were quite unacceptable.

Nor is there likely to be an option that is a Pareto optimum (Pearce and Turner 1990) in that it leaves all people at least as well off as they were before and nobody worse off. But more importantly, we may disagree as to the objectives that we ought to pursue in making the choice. Since choices are always about the future, we always have to decide what we ought to do, and the logical 'ought' and the moral 'ought' are frequently bound together. Collective choices are then seldom solely between different means to an agreed end but involve arguments about what ought to be the ends we seek to achieve. However, choices are usually between different means and it has been observed that what is important is to decide upon the means. Thus, it is possible for agreement to be reached on the means even when we continue to disagree on the ends to be pursued. Spending too much time debating the ends can be counter-productive, simply establishing that we disagree about these, when it may be possible to reach agreement as to what to do.

2.1.1.6 Resources

Mutual exclusivity in time or place and conflicting objectives are internal constraints to choices in project appraisal. They force the choice between the available options; even if infinite resources were available, it will not be possible for a reservoir and a climax forest to occupy the same space. Similarly, even if I had an infinite income, I still could not go to the theatre and the cinema at the same time. In collective decisions in particular, resource scarcity is an external constraint: it may be possible to determine the best option in each of a number of different choices but resource scarcities preclude us from adopting all of those best options. For example, if there were to be universal agreement both that education policy A is preferable to education policy B and also that health care policy M is preferable to health care policy N, resource constraints might still limit us to choosing between the combinations of A plus N or B plus M. However, the choice between A or B and M or N is almost certainly about conflicts between the objectives we want to achieve and disagreements between people as to what importance should be attached to achieving each objective. Thus, these choices would remain even if we had infinite resources.

In choices about project prioritisation, programmes or policies, it is this resource scarcity which forces the choice; nothing precludes the provision, for example, of potable water supplies to all villages in an area except the scarcity of some resource where that resource might be money or the availability of skilled technicians.

2.1.1.7 The nature of value

In everyday language, if we ask someone what are their values, there is usually a long pause and then they say something about justice, democracy or religion:

in common parlance, values refer to ends (Boulding and Lundstedt 1988). But economics uses value in different senses and it is possible to distinguish between two different bases for value:

1. Value in itself, and
2. Instrumental value.

Adam Smith, for example, adopted the first approach by using a cost of production theory of value and Ricardo, as did Marx, developed a labour theory of value: the value of a good is given by the cost of producing that good. On the other hand, neoclassical economics is associated with the instrumental theory of value: the value of something is its contribution to the achievement of some objective. In the case of neoclassical economics, this objective is the maximisation of the individual's utility so economic value is subjective and, importantly, a good can have a value without having a price. Indeed, in economic analysis money is simply used as a yardstick or numeraire by which to assess the relative values of different actions.

The neoclassical economics definition of value in instrumental terms has two major implications:

- It is actions rather than things that have value; and
- An action necessarily has as many values as objectives are brought to that choice of action.

First of all, it is implied that it is actions that have value rather than the thing involved in the action itself. Thus, wearing a hat has values relating to keeping off the rain, keeping my head warm, keeping my bald patch from being sunburnt, and so forth. Similarly, eating food assuages hunger and gives pleasure; and it is watching television that has a value: the value of a television is given by the expectations of the programmes it will then be possible to watch. The value of things, such as hats, food and a television, is then an imputed value based on the expectation of the actions that can be undertaken with it in the future. It is a function of the likelihood of different actions being undertaken and the contribution of each action to the achievement of each objective. The thing itself has no value outside of expectations of future actions in which it can be used.

These actions are all necessarily in the future although the relevant future may be very short-term; an ice cream is usually bought with the expectation of eating it immediately whereas a bottle of wine may be bought to lay down for many years. Thus, it is possible to talk about the value of a 'thing' only in terms of the potentiality for action associated with that thing, a form of expected value.

Secondly, since value is defined in instrumental terms, an action has as many instrumental values as are the objectives engaged by that choice of action. Hence it is not possible to argue that an action only has an economic value unless economic value is defined so widely as to cover all possible objectives. Even then, only once those objectives are completely ordered hierarchically can an action be taken as having a single value. The neoclassical economics definition of economic value, as the contribution of some action to maximising the individual's utility, is then either one possible value, or utility must be expanded to include all of the individual's objectives. In addition, the neoclassical economic definition of value obviously means that value is subjective: value lies in the eye of the beholder. The neoclassical model also requires the assumption to be made that an individual has developed a utility function which defines how all possible acts of consumption will contribute to this overarching objective of utility and has done so in advance of making any actual choice.

Because the value of a thing is imputed by the individual's expectations of the actions that can be undertaken with it or for which it is necessary, quite clearly the imputed value of that thing can vary markedly between individuals and the market in turn may be highly segmented. Thus, to a vegetarian a beefburger will have no value at all except in so far, for example, in that it can be used to keep a fractious niece happy.

If an action has as many values as objectives are brought to a decision, then a critical question is: which objectives are engaged by the decision? In neoclassical economics, it is assumed that the individual and individuals define the objectives and, conveniently, each have predefined a completely ordered utility function. In turn, in neoclassical economic analysis, in collective choices, the only objective considered is some aggregate of individual utilities where the potential Pareto improvement, or Hicks–Kaldor compensation principle, is conventionally taken to be the appropriate aggregation function. It is usual to make some reference to equity (in the relatively trivial sense of income distribution) but equity is not considered to be an objective to be considered in making the collective choice. But the problem even with recognising equity is that it raises the question: where does this objective come from? In neoclassical economics it is assumed that value is given solely by the individual, it measures individual preference, the contribution of that action to the individual's utility function. For equity to be accepted as an objective in collective choices, it is then necessary to ask why the individual should bring equity to a choice outside of his or her utility function. By treating equity as a separate objective, it has been assumed that it does not form part of the individual's utility function, that the individual's utility function does not include some form of altruism, nor that the individual experiences a duty with respect to other people. If the individual's utility function does include altruism or normative components, then neoclassical economic theory dictates that such elements should be considered in collective choices except in so far as to do so would involve double-counting.

In practice, two different issues are involved. Firstly, the assumption that values are solely given by individual preference is itself a moral claim that can be disputed and which cannot be treated as axiomatic. In particular, Islam (Khalid and O'Brien 1992) is centred around duties to other people and other species and so the economic question is what ought we to do rather than what do we want to do? Again, deep ecologists (e.g. Naess 1993) argued that other species have an inherent value by right of existence. More widely, deep ecologists are asserting that some thing can have a value in itself; they only differ from the classical economists in their conclusion as to the basis through which that value is derived. It would also seem that some other things may have a value in themselves: some people collect the teeth of their children or their first shoe, whilst many people build up collections of photographs. Whilst the act of collecting the tooth or shoe or of taking a photograph may be argued to have an instrumental value, once acquired, that tooth, shoe or photograph would seem to have a value in itself. So, similarly does a grave. The potential problem with things that have a value in themselves is that they are not then substitutable by anything else either in functional terms or in utility terms.

Secondly, whilst the individual can have objectives in isolation, in any community a second set of objectives has to be created that refers to relations between individuals. Thus, children are commonly taught not to be greedy, to share their toys, not to fight, to be polite and other principles that define relationships between individuals. So, for example, equity is explicitly about the relationships between individuals; it refers either to what ought to be the relationships between individuals or to what relationships are necessary if the community is to be maintained. In general, these objectives concerning relationships between individuals can have very little scope for expression in individual choices concerning the consumption of priced goods, except in so far, for example, as the individual has a choice to buy Fair Trade coffee or tea as opposed to coffee or tea produced through conventional trading channels. But in collective choices, these objectives can be central, as can the argument as to the trade-off that ought to be made between these objectives and also between these objectives and individual preference. Collective choice is inherently about what ought to be the weight we give to different objectives, including those with regard to the relationships between individuals, in the choice in question.

This conflict can exist even when these objectives and the relationships between them are taken to be predefined prior to any actual choice (Section 2.1.1.4). In turn, neoclassical economics seeks to avoid discussion of these issues by implicitly assuming that there are natural laws (Beyleveld and Brownsword 1994) that govern these relationships. Thus, it is conventional to refer to property rights instead of relationships between individuals, assuming that some entitlements and obligations necessarily follow from the possession or use of some property. However, if public involvement in decision making is a principle accepted as a defining basis for the sustainable management of water (ACC/ISGWR 1992), then the objectives we bring to a decision and the trade-offs we make between them, are necessarily socially constructed out of the dialogue, argument and negotiation that makes up that process of public involvement.

Where does this leave economics and the way in which economic analysis can usefully be undertaken? To sum up, I have argued here and earlier that:

- It is actions that have value and that goods have only imputed values except for a probably limited class of goods that have a value in themselves.
- Because actions can contribute to the achievement of multiple objectives, any action can consequently have multiple values.
- The achievement of an objective can have resource implications without that objective being a component of economic efficiency (Section 2.1.1.6).
- Equity is relative rather than absolute (Section 2.1.1.7).
- Two important reasons why choices have to be made are that our objectives are in conflict or because we disagree about what weight should be given to those objectives (Section 2.1.1.4).
- In turn, choices often are about what we ought to do rather than simply about what individuals want to do.
- Thus, values in collective choices emerge from the process of social negotiation rather than being predefined.

These arguments should not be seen as destroying the basis of economics since to make such a claim would be to argue that reason has nothing to contribute to choice. What they do imply is about the nature and purpose of economics. The rationale for economics is then to inform the social dialogue and to provide a framework for that dialogue; economics cannot be mechanistic and optimising but must instead provide a transparent and rigorous framework of analysis that focuses upon the reasons why we must make any particular choice and the implications of adopting each of the different courses of action open to us. The emphasis must be upon creating an understanding of the nature of the choice.

Nor does it mean that we should abandon numbers where they are useful; they are a useful means of simplifying that which would otherwise be too complex to comprehend. In turn, it is the understanding about the nature of the choice that gives meaning to numbers: what was too complex should be reduced to the self-evident, it being the process of analysis rather than the number which is important. At present, too often, the derivation of a number seems to result instead in the end of thought. The test of economics is thus what we learn about the nature of the particular choice we must make.

2.1.2 Uncertainty

Water management is about changing risks (Section 2.1.3), where we commonly have a great deal of uncertainty concerning the magnitude of those risks. In turn, risk and uncertainty are two different concepts. Uncertainty is an inability to differentiate between a range, continuous or discrete, of different possibilities. Although risk and uncertainty appear similar in nature, uncertainty is fundamentally different from risk; the opposite of uncertainty is information which is formally defined as that which destroys uncertainty (MacKay 1969).

The simplest example of uncertainty is when we are asked to call 'heads' or 'tails' when a coin is tossed. We can define the risks when tossing a fair coin exactly; the probabilities of a head or tails are both equal to 0.50. In consequence, a fair coin is defined as one where there is uncertainty as to what course of action to adopt: there is no rational basis for calling heads or tails. Thus, the coin is fair precisely because there is no rational basis for calling heads or tails. We are and should be uncertain what to do precisely because the risks are known exactly: we should be rationally uncertain. The only uncertainty about the risk is then whether the coin is fair. If we can be confident that the coin is biased, then we can eliminate the uncertainty as to whether to call heads or tails: as soon as we can be confident that the probability of throwing a head is at least 0.5001, we know what to do. Similarly, if the outcome of throwing heads is to lose £100 000 and the outcome of throwing tails is to lose £1, we should also always call tails even if the coin is fair. If we can remove uncertainty either as to the probability or the outcome, we remove uncertainty about what to do. Therefore, the crucial issue is whether the decision maker should rationally be uncertain rather than whether the world is uncertain.

We can define a decision maker who is uncertain, after Green, Nicholls and Johnson (2000), as being in 'a state of doubt as to what to do'. When they are in such a state, we can call this 'decision uncertainty'; the decision maker is unable to differentiate between the options in terms of a preference between those options. In turn, a decision maker can be rationally uncertain for two different reasons:

- They don't know, or
- They cannot decide.

We may be uncertain because we are uncertain about the state of the world now and in the future, or because we cannot resolve the conflict that is the reason that the choice has to be made. This 'uncertainty in the world' is inherent, only a god being able to have perfect information. Because uncertainty in the world is a universal problem when taking decisions, it is decision uncertainty that is more important.

However, even perfect information about the future would not mean that the decision maker would necessarily cease to be uncertain. When someone says that they can't decide between ordering the steak or the salmon, it is because they cannot decide what they would like most rather than a lack of knowledge about the steak and the salmon. Similarly, it is rational to be uncertain when the arguments for each of two options are equally balanced. Clearly, whilst uncertainty about the state of the world now and in the future can be a cause of decision uncertainty, the fundamental question is whether the decision maker ought to be uncertain which course of action to adopt. Not infrequently we can be very uncertain about the world without this uncertainty implying that we ought to be uncertain as to what to do.

2.1.2.1 Uncertainty in the world

Choices are always about selecting a future; the only difference between choices is how immediate is this future. When I am deciding whether or not to watch a particular television programme, I am dealing with an immediate future although that choice may also have implications for a longer term future. For example, I have now watched the penultimate episode of one television series in three different countries but seen the final episode in none. Had I known that this would happen, it might have influenced my decision as to whether to start watching the series.

To predict the future, we need to know both the relevant state of the world now and also the causal processes that are operating. However, often we are uncertain about the state of the world now. There are usually measurement errors, or parametric uncertainty (Blockley 1980); what Penning-Rowsell *et al.* (1992) described as 'what we know we don't know'. In addition, there is the possibility that the model which we are using to measure the state of the world now is itself either incomplete or simply wrong. Blockley (1980) termed this 'systemic' uncertainty and in Penning-Rowsell *et al.* (1992) is described as 'what we don't know that we don't know'.

Thus, typically, the length of a streamflow gauging record for a stretch of water course will be much shorter than the return period of the drought or flood whose severity it is intended to predict. Estimates of the flood or drought flows are then estimated by applying some statistical distribution to the data. If the distribution function is inappropriate, then so will the estimate of the magnitude of the flow for that return period. Thus, as described in Chapter 22, the original estimate of the probable maximum flood (PMF) for the Macchu II dam was out by a factor of five. Similarly, Moench *et al.* (2001) sought to establish whether groundwater levels were declining on a worldwide basis but discovered that there is inadequate data on present and past levels of groundwater to be able to draw any conclusions.

Nor are we likely to be certain that we understand all of the processes and interactions involved in the system; for this reason, Holling (1978) argued for the adoption of an adaptive management approach. Given that there is uncertainty about the present and also about the processes, it follows that we have to be uncertain about the future state of the world. As Lord Keynes remarked: 'all prediction is difficult, predicting the future is particularly difficult.' In turn, if predicting the future is difficult then the approach developed by Holling and others (Gunderson 1999; Walters 1986) is to argue that we should instead recognise that the one thing about which the rational individual can be certain is that the future is uncertain. This being so, then the issues are then:

- How should we choose when we know that we are uncertain? And
- Knowing that we are uncertain, what options should we choose?

2.1.2.2 Change

Because water management is capital intensive, and hence adaptation is slow, water resource projects have to be based on expectations about the medium-term future. Our expectations about that future then depend both upon our incomplete knowledge of the present and our equally incomplete understanding of the causal processes that create change. The greater the rate at which change is occurring and will occur, the more critical the understanding of the causal processes involved.

If change is occurring or is predicted to occur, then there are three questions:

- Do we understand the causal processes involved that both create the change and determine responses to that change?
- Does understanding necessarily imply the ability to predict change? And
- Does that understanding imply only quantitative changes will occur?

Typically, the future is simply predicted to be the same as yesterday only bigger: for example, when a trend series analysis of water demand is used to predict the demand for water in 20 years' time. The basic assumption is that change is continuous but well-behaved so that, in principle, we could be pretty certain about the future. But, these methods are not based on any causal model of the nature of the change; they are strictly descriptive models of the present extended into the future (Section 14.5). Hence, a causal model should be expected to perform better. But, the background to the development of the concept of adaptive management in ecology (Holling 1978) is that we do not understand the causal mechanisms in some instances and if we do not understand them, we cannot predict the outcome with any reliability.

Secondly, a change may necessarily mean that the future must be different from the past and equally, in some cases, these changes will be very large indeed. For example, in an economy growing at 7% per annum, a rate that has been typical of the tiger economies of Asia, the economy will be seven times as large as it is now in 30 years' time. Since it is impossible to scale up the inputs to the economy by a factor of seven, the structure and nature of the future economy in those countries will necessarily be radically different to that which exists now. Rather than quantitative change, a qualitative change will necessarily have to occur.

It is qualitative changes that are the most important. The driver for the development of adaptive management in ecology was the recognition that ecological systems may have more than one stability zone and a change may cause a leap from one zone to another (Gunderson 1999). At the extreme, the term 'surprise' has been introduced (Brooks 1986; Gunderson *et al.* 1995) to refer to that which was not or could not be foreseen in advance so that when such an event does occur, the initial response is incredulity. It is the nature of surprises that as soon as an example can be worded, then that example is foreseen and it ceases to be a surprise. So a surprise is not a low probability event, it is one for which there was no prior probability at all since it was not foreseen because our models are incomplete or false. The ozone hole was such a surprise and therefore it was necessarily discovered by accident.

Finally, the very purpose of choice is to choose the future and thus to take action to change the future. So, for example, a reason for introducing charges for wastewater is to induce technological innovation that will result in lower treatment costs. In turn, other people's attempts also to choose the future increase the uncertainties and affect the likelihood that we will be successful in our attempt to choose the future. By our collective actions, we change the future and so to predict the future reliably, we need to know both what everyone else is doing now and what they will do in the future. In turn, the only rational conclusion that can be drawn is that the future is inherently uncertain: we do not and cannot know the future.

2.1.2.3 Uncertainty in the mind

Uncertainty and risk are two different things; when we toss a coin, we can define the probabilities of a heads and a tails being thrown, but, as already noted, it is because there is no rational reason for expecting one outcome rather than the other that defines the coin as being fair.

Decision uncertainty exists to the extent to which it is not possible to have a preference between the different courses of action that are open to the decision makers. Since it is only possible to adopt a single course of action, decision uncertainty only exists to the extent to which it is not possible to clearly determine a rank order of preference across the two best options. We can be very uncertain about the order of preference across the remaining options but if we are able to be confident that the two best options are preferable to all other options, our uncertainty between the remaining options is irrelevant.

What is important is whether or not the decision makers ought to be uncertain as to which course of action to adopt out of those known to them. The decision makers may rationally be uncertain if all of the alternatives are equally attractive or unattractive, or if the 'best' alternative depends upon the very uncertain state of the future world. Conversely, they may be irrationally certain, often because they have arbitrarily excluded some options or some objectives from consideration. They may also be irrationally uncertain: they are unable to make up their minds as to which is the best option, often because the choice is so complex that it is difficult to see through the complexity to the core of the decision. One of the primary purposes of economic analysis is then to reduce this irrational uncertainty.

Choices are always about the future and there are two quite different paradigms in an uncertain future (Box 2.1). The first, the car journey analogy, treats uncertainty as essentially degenerate risk; uncertainty can then be reduced to risk through collecting further information and undertaking further research. Uncertainty is treated as if it solely derives from parametric uncertainty, and the means

Box 2.1 Managing under Uncertainty: Two World Views

There are two models of decision making under risk and uncertainties. Each defines the problem in entirely different ways of thinking and recommends different strategies for dealing with the risks and uncertainties.

The first model is analogous to a car journey to a known destination using a good, detailed map. Firstly, you plan the journey from beginning to end. After you set out, you keep track of your position on the map and use the road signs to confirm which turnings to make as each junction is reached. If you take a wrong turning, the map and road signs will sooner or later indicate this to you, and you can plan a new route to reach your destination. In other words, the journey can only follow a finite number of predetermined choices.

The second model takes a sea voyage of discovery (e.g. Magellan or Captain Cook) as the parallel. There are no maps because the oceans have neither been mapped nor have any features to be mapped and the final destination is vague and uncertain. Instead, a clock and sights are used to determine the ship's present location and from that the course is plotted. The helmsman is then ordered to follow a particular compass heading, and makes constant small adjustments as currents, waves and wind force the ship off course. At fixed intervals, the actual position of the ship is recalculated from sun and stars, and a new course plotted allowing for the actual position. Head winds will mean that it is sometimes impossible to sail directly in the intended direction and discoveries of land will result in the intended direction being changed in order to investigate that land and to restock with water. A lookout is required to watch out for land, rocks and other dangers, and a leaded line is used when it is thought that the ship is entering shallow waters.

Source: Green et al. *2000.*

recommended (Greeley-Polhemus Group 1992) to take account in decision making of that uncertainty that cannot be removed through more information and further research is based upon Monte Carlo simulations. Probability distributions are assumed for the key variables, and ideally the interdependencies of the key variables are taken in account. In the case of benefit–cost analysis, the result of the Monte Carlo simulation is to generate a probability density function for the benefit–cost ratio. The drawbacks of this approach are firstly that it treats decision uncertainty as arising solely from uncertainty in the world. Secondly, that it is necessary to make assumptions about the nature of the probability density functions (Haas 1997) and the interdependencies between the uncertainties associated with each parameter. However, if I am uncertain about the expected value of a parameter, I am even more uncertain about the functional form of the probability density function and the standard deviation of that function. Thirdly, it excludes systemic uncertainty. The results of applying this approach are usually two-fold; most importantly the analyst can be left with an irrational state of certainty about uncertainty. In addition, the outcome is likely to be that the benefit–cost ratio lies somewhere between a small number and a large number which is pretty much what we knew in the first place.

The alternative paradigm, that developed by Holling (1978) and others (Walters 1986), asks what do we do when we know that we are uncertain, that uncertainty is inherent to decision making and the largest uncertainties are in terms of systemic uncertainties? This is the Captain Cook analogy (Box 2.1). Adaptive management (Holling 1978) closely parallels the Captain Cook analogy by working on the basis that we should keep track of where we want to go but the most important objective is to avoid being wrecked upon an uncharted shoal or reef. Equally, we can expect to be blown off course at different times.

These two visions of uncertainty are part of wider different paradigms. In one world view, the future is knowable but with confidence limits; and systems are regarded as generally linear, homeostatic and optimising, the world is seen as a clock. Neoclassical economics clearly has this view of the world but then so too do many other disciplines. In many ways it is equivalent to the view of physicists prior to the development of quantum theory. The second view tends to view systems are complex, nonlinear and chaotic in nature, neither having a single stability domain nor being homeostatic. As a nonlinear system, they are liable to make sudden transitions from one stability zone to another, a behaviour sometimes characterised in terms of catastrophe theory (Woodcock and Davis 1978), and now usually known as chaos theory (Stewart 1990). Chaos theory in turn can be seen as simply one aspect of discovery of the necessary indeterminacy of the world of which other manifestations are Gödel's theorem as to necessary incompleteness of axiomatic systems (Hofstadter 1980), and Heisenberg's uncertainty principle in quantum physics (Barrow 1999). Smithson (1985) delightfully labels the overarching concept that includes uncertainty as 'ignorance'. All this is well away from the clockwork world of conventional economics (Ormerod 1994) where optimisation and homeostasis, and hence stability, are assumed to be natural.

Adopting the Captain Cook model, then there are a number of implications for both the way in which we logically should make choice and as to the nature of the options that we should then adopt. The emphasis is on decision uncertainty and not uncertainty in the world since the latter is part of the very stuff of decision making. It directs attention to managing the entire range of possible events.

The implications for the way in which we make decisions are:

- To forget optimality: optimality requires that we know everything important and know it both accurately and precisely; since we know neither, pursuing optimality is illogical.
- Instead, we need to consider how the different options will fail and the consequences of failure.
- We need to undertake sensitivity analyses at the beginning of what should be an iterative, learning process of design and decision making. The purpose of the sensitivity analysis is to identify the critical variables that influence which options should be adopted. It is these variables upon which we should

concentrate our efforts to refine the remainder of the design and decision process. In general, the critical parameters are those concerning high frequency events that occur early in the life of the project. For example, the duration of the construction period can be more important than the capital cost because no benefits will come on-stream until the project is substantially completed.

- At the end of the project, we should carry out a robustness analysis (Penning-Rowsell *et al*. 1992); to determine whether the values of the critical parameters influence the rank order of preference across the options. Does our necessary uncertainty about the world mean that we should be uncertain as to what to do?
- The precautionary principle should be applied in the sense that we should be adverse to creating path-dependent futures, when the possible rate of adaptation will necessarily be slower than the rate of change or where the change will be catastrophic.
- Interventions have to be treated as experiments (Holling 1978) through which we hope to learn more about the systems in which we are intervening. In turn, this means that the making of mistakes by institutions has to be legitimated; if nothing new is tried then we will not learn anything. But if we try new things, some will inevitably not be successful. Equally, the only way in which we could avoid making mistakes is if we had perfect information about the future and this is precisely what we do not have and cannot have. Thus, mistakes must be accepted provided that they teach us something new rather than the action being a repeat of an error that we had made previously.

In turn, the options that we should choose will often be characterised by one or more of the following features:

- When they fail, they will do so slowly and relatively benignly without failure occurring either suddenly or being catastrophic when it occurs.
- The option will be either robust, that is, it can cope with conditions outside of its designed range, or resilient (Gunderson 1999; Holling 1973; Ludwig *et al*. 1997) where resilience involves the capacity to be adjusted to changes in conditions. Concrete is, for example, robust whilst rubber is resilient. What we cannot have is an option that is both robust and resilient; this is equivalent to asking for rubber concrete. Equally, we cannot guarantee that there will be any option that is either robust or resilient.

2.1.3 Risk

'Risk' is commonly used in a number of different meanings: as a synonym for probability, as one for expected value (probability times outcome), or to refer to potentially harmful events of different kinds. Since a risk is always a 'risk of', this mixed usage is almost inevitable, although 'risk' is only used in relation to undesirable events. Thus, whilst we may refer to a risk that it will rain, we do not talk of a risk that it will be sunny.

The purpose of almost all water projects is to change either the probabilities of some events or the consequences of those events. For example, a benefit–cost analysis of two maintenance regimes for sewers or water mains is likely to include one involving replacement or renovation prior to failure and an alternative of replacement on failure, the costs of each regime being compared to the risks of failure. A wastewater treatment programme will reduce the probability that an event will occur which will have temporary or long-term impacts on the receiving water. These probabilities will seldom if ever change from one to zero, so the analysis will necessarily require a basic understanding of probability theory in the form of reliability engineering (Kaufmann 1972) including the concepts of event and fault trees (Watson 1989; Clark and Tyrer 1987). Moreover, these probabilities are likely to change over time as existing structures decay or conditions change: for example, as the catchment is developed or climate changes occurs.

In many cases, however, the only source of the estimated probabilities of the different outcomes will be engineering judgement; statistical data is often not available. For example, whilst there are several hundred thousand kilometres of flood embankments worldwide, and theoretically (Wolff 1997) it is quite straightforward to predict the likelihood that a dike will fail before it is overtopped as a function of ground and foundation conditions, together with the structure of the dike itself, there is virtually no data with which to estimate the probability that any particular dike will fail. Similarly, when a tunnel is being proposed as part of a project, a critical parameter in determining the costs can be the probabilities that the works will overrun either or both time and budget. Again, whilst the theory is not complex (Isaksson 1998), there is an absence of statistical data with which to apply that theory (Isaksson 2001). In general, water management has traditionally been undertaken with the minimum amount of data; estimates of leakage from water mains are often given as the difference between what it is guessed is put into supply less the amount that it is guessed is consumed. Similarly, flows in sewers and particularly estimates of the surface water runoff are seldom available. What data that is available is often inaccurate; for example, water meters are prone to underestimate water usage and meters measuring flows in water mains may be accurate to $\pm10\%$. Again whilst an appraisal of the benefits of replacing or renovating a sewer system or water mains will require an assessment of the likelihood and consequences of the failure of both the existing system and the proposed system, methods of assessing the probability of failure (Green *et al.* 1989a) give qualitative rather than quantitative results. In turn, collecting data is expensive so that a question that may need to be addressed is: what is the value of collecting data? (Chapter 22).

The situation is usually somewhat better with regards to hydrology; there is usually some data as to rainfall or streamflows or regional models (NERC 1975) that can be applied to the river in question. However, when predicting future flows, the conventional approach has been to assume that the future is an extension of the past. Thus, the usual method of predicting the flow with a probability of occurrence of 0.01 per year is to take the available length of record of streamflow gauging, fit one or another probability function to that frequency count and use that probability function to estimate the magnitude of the flow with a probability of 0.01. Two obvious potential problems are then as to which probability function should be fitted to the data and the length of record that is available. However, more especially this approach involves assuming that there have been no changes over time and hence the complete historical record can be used to estimate the risk now and in the future. In addition, it involves estimating the probability of the flow rather than of the events that could give rise to that flow. For example, floods are the result of a combination of the precipitation event and the antecedent conditions, and the consequences of the precipitation event may themselves depend upon the pattern of movement of the precipitation event. Thus, the consequences of a rain front moving down a river can be different from those of a front that moves up the catchment: movement in one direction or the other is likely to increase the risk that the flood peaks from the tributaries and main stem coincide.

In the case of floods, dynamic simulation methods of calculating the probabilities of flooding are being developed that take account of antecedent conditions (Calver 2001): if the soil is already saturated as a result of previous rainfall, a greater proportion of rainfall will run off than if the soil is relatively dry. More generally, even if it cannot be applied in detail, a dynamic approach should be adopted where it is sought explicitly to identify changes over time in probabilities. Rather than the natural state being one of stasis, it is preferable to assume that the natural state is one of change and rather than talking in terms of 'risk' it may be more helpful to speak of managing 'variability', change over time. We can then identify three different patterns of change over time:

- Cyclical: the seasonal cycle is an obvious one but other longer period cycles may also be present (e.g. as a result of El Niño).
- Trend: changes in precipitation, runoff or flows may be occurring either because of climate change or changes to the catchment.
- Random: the problem with apparently random changes is that such changes can be generated through the operation of causal but nonlinear systems. Systems exhibiting chaotic behaviour are often defined by quite simple functional forms but their behaviour at least superficially appears to be random (Gleick 1987).

The obvious difficulty is that if the length of record is insufficient to enable good predictions to be made assuming no changes over time, it is unlikely to be adequate to identify any changes over time. It is likely therefore to be necessary to see whether there are any indications that critical parameters have changed or to ask local residents whether they believe that there have been such changes.

Not only is most of water management about changing the probabilities or outcomes of events, it is also generally about buffering systems of concern to humans from perturbations arising from climatic or other factors. The whole purpose of water resource management is thus generally to reduce the risk that seasonal and other variations in rainfall seriously reduce the availability of water for human use: to reduce the degree of variability in supply. Beck (1996) then argues that it is necessary to consider both the whole spectrum of perturbations to the system and the effect of human intervention on those initial perturbations. Thus, for wastewater and surface water management, he argued that it is necessary to consider the way in which management changes the frequency and severity of perturbations in the water quality as a result of surface water runoff. This can then be taken as a general model and applied to water quantity (Figure 2.2). The function of all water management is to cope with *all* the natural perturbations in the system so as to maintain the state of the environment and/or the economy within some limits. Beck's approach can then be extended to apply to the quantity side of water management (Chapter 14).

Taken together, the adoption of a conceptualisation of the systems to be managed in dynamic terms and Beck's approach mean that we should stop thinking exclusively in terms of probabilities. It reinforces the need to adopt the approaches outlined in Section 2.1.2.3. Conventionally, in the case of floods, some design standard of protection is determined either by fiat, as in the case of the Netherlands (Huisman *et al.* 1998) or on the basis of a benefit–cost analysis (DEFRA 1999). What will happen if a more severe flood then occurs is ignored. This approach is exemplified by the drawing of lines on maps to represent the extent

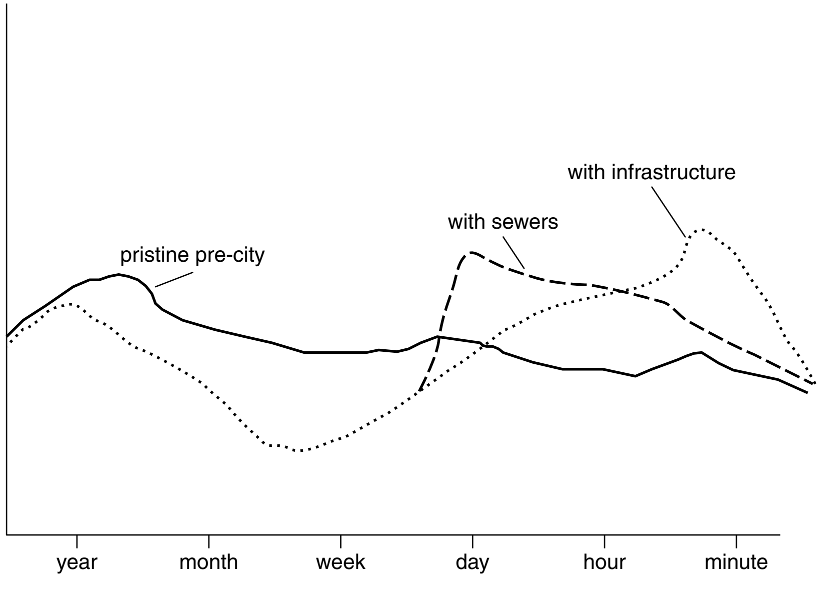

Figure 2.2 *Water quality and perturbations. Source: Beck 1996*

of the flood either with a specified return period or the largest known historical flood. In reality, there is neither a significant difference in the risk and consequences of a flood on either side of that line nor can that line be located with any degree of certainty; it becomes a line for the sake of having a line. Similarly, water resource planning is typically based upon some design standard drought.

Instead, the necessary uncertainty approach is concerned with managing all events. In an ideal world, we would filter out all the extreme perturbations rather than the small magnitude, high frequency events. This is seldom possible so instead the focus of attention should be on what will happen when an extreme perturbation occurs or the core management strategy fails for another reason. So, in following droughts the lesson is learnt that it is necessary to have a drought management plan (AWWA 1992; Environment Agency 2000a; National Drought Mitigation Center 1996); in the case of California, this requires the utility planning for a 50% drop in water resources (California Urban Water Conservation Council 1994). Similarly, where there is a significant population of risk, dams are designed to be able to pass the probable maximum flood (National Research Council 1985).

3

The Nature of the Economy

The popular view of economics is probably that it is the study of the economy. However, this is not what economics is about to economists; indeed, if you look at dictionaries of economics, you will not usually find the term ‘the economy’ defined at all. Curiously, terms such as ‘market economy’ and ‘planned economy’ typically are defined even though these are particular instances of the general term economy. Equally, this omission is odd given the enthusiasm for economists to make recommendations as to how a national or the global economy should be run.

One possible definition of the economy is then: ‘*The social organisation whereby resources are converted to intermediate products, capital stock and final consumption*.’ This definition is sufficiently wide as to embrace the specific cases of market and planned economies. For the neoclassical economist it has the profound disadvantage of placing social relations at the centre of the economy but it does contain the neoclassical concern with the conversion of resources into consumption. An economy is then a relationship in the form of the conversion of some stocks and flows into other stocks and flows.

In abstract terms, we can then express the nature of the flows that relate the economy to consumption and the environment (Figure 3.1). A fraction of the output of the economy is reinvested in the form of production durables (e.g. machine tools, roads); a second fraction is reinvested to increase the skills of the workforce; and a further fraction is reinvested into technological innovation. The balance of the output is in the form of direct consumption (e.g. cans of beer) and of consumption durables (e.g. houses, televisions); notably, whilst the former are effectively priced at the point of consumption, the latter are not.

The economy is conditional upon the environment, the natural endowment, both drawing all the raw materials and energy from the environment and depending upon the natural endowment for food stuffs and water. A proportion of human consumption in the widest sense is taken directly from the environment in the form of, for example, walks by the river or sunbathing on the beach. In turn, the natural endowment can be categorised as shown in Table 3.1.

In each case, the stock yields a flow and using Hicks’ (1946) definition of income in terms of a flow that does not deplete capital, in Table 3.1, the two

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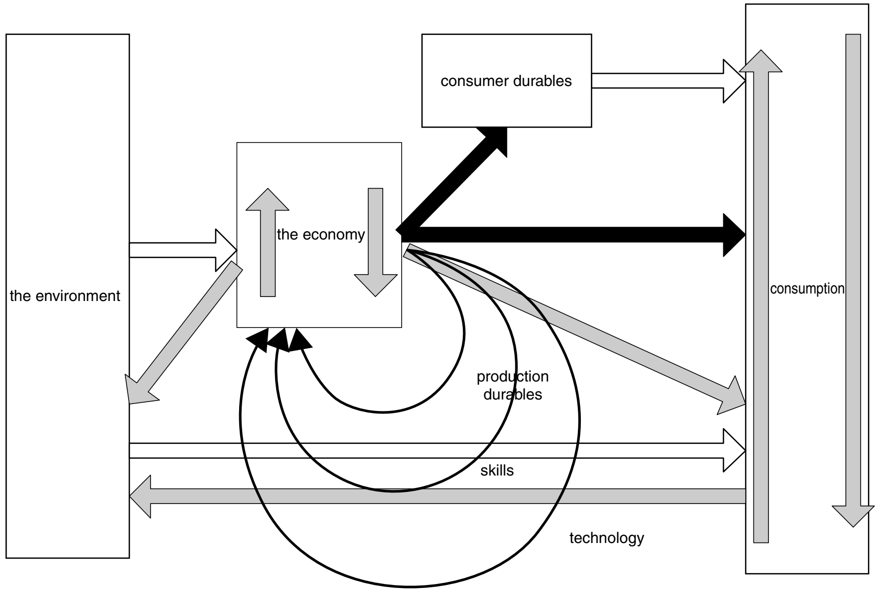

Figure 3.1 *The economy and the environment*

Table 3.1 *Resources*

	Depletable	Nondepletable
Self-renewing	Forestry, soil, fisheries, aquifer, crops (stock)	Solar energy, water (in long term), wind energy and other forms of energy that ultimately are driven by solar energy (flow)
Nonself-renewable	Fossil fuels, minerals, fossil aquifer (stock)	Land (stock)

cells on the main diagonal represent capital. Thus, capital can be defined as that which generates indefinitely some level of income by which it is not depleted. However, in the case of depletable resources, the rate at which they are harvested can exceed the rate of self-renewal.

In formulae terms, the total output that the economy can achieve can then be expressed as:

$$O = f(NE \times H \times X)$$

where:

O is the total output.
NE is the natural endowment.

H is human inputs in the form of labour and reinvestment (e.g. in production durables).
X is skills, social capital, technology.

The relationship is multiplicative, no output is possible unless there are some natural resources. The function in this equation is the economy; it represents how well these inputs can be put together. Thus, economists usually argue that a market economy is more efficient than a centrally planned economy: the same combination of technology, skills, the natural endowment and labour yields a higher value output. We can further refine the definition of the economy given earlier; the economy is composed of and defined by the formal institutional structures and informal social structures, the latter usually being termed 'social capital' (Woolcock 1998).

Inverting Hick's definition of income in this way to define capital, it follows that production durables are not capital: they naturally wear out, not only through use but also through natural processes such as rust, degradation through ultra-violet action and other forms of chemical and physical decay. To describe roads, machine tools and computers, for example, as 'human capital' is thus strictly incorrect and in Hicksian terms, the only true parallel to money capital is these two components of the natural endowment. Consequently, if 'soft' sustainability (Pezzey 1989) is couched in terms of substitution of trees by computers, it is strictly incorrect because the capital base is being reduced.

However, if sustainable development is defined not in terms of maintaining a constant level of capital but instead of being able to at least maintain a given level of consumption indefinitely, equivalent to maintaining a Hicksian income, then a reduction in the capital base of the economy can potentially be substituted by enhancements in the state of technology and/or improvements in the level of skill. In each case, this will be achieved to the extent to which we can do more with less. A basic condition for sustainable development is therefore the output–input ratios for depletable resources and the efficiency of energy conversion in particular. The rate of conversion to the use of nondepletable resources then needs to match the rate of draw down of depletable nonrenewable resources.

3.1 What is Output?

We can then define *technical efficiency* as the ratio of output or consumption relative to use of resources; to maximise $O/(NE \times H)|X$ whilst *efficiency* is defined as the ratio of the achievement of our objectives relative to all of the resources consumed. The problem is that we have good measures only of the divisors but not of either output and consumption nor of the objectives we seek to achieve. Instead, measures of gross domestic product (GDP) or net domestic product are usually used instead. Unfortunately, the GDP family of measures are no more than a form of double entry book-keeping for national economics, an accountancy rather than an economic measure that measures only money flows within the economy. As a system of double entry book-keeping, where resource use and output are equal it is necessarily impossible to assess the technical efficiency of an economy either over time or relative to other economies. Equally, since it only includes priced consumption and the use of priced resources, unknown proportions of resource use and consumption are excluded at any given point in time. Both the labour inputs and outputs of subsistence agriculture are thus necessarily excluded, along with housework and DIY activities on the resource side. On the consumption side, over time the real value of goods may change: the performance of household durables has increased over time whilst the real price has fallen (Mishan 1993). Similarly, only a proportion of consumption is priced at the point of consumption and a significant proportion of people's time is taken up with unpriced consumption (Section 2.1.1.3). Thus, playing with one's children is excluded from the consumption side of the analysis; similarly, whilst visits to brothels will notionally at least be included in the GDP figures, sex which is not accompanied with a monetary payment is not.

The GDP family of indicators is subject to a range of other well-known problems (Mishan 1993); for example, the inclusion of defensive expenditures, those incurred in order to reduce or avoid damage, such as national defence, police and fire services, and sanitation services. In addition, the depletion of capital enters the GDP as a positive amount rather than being subtracted from it: the unsustainable harvesting of forests appears as a positive item rather than being subtracted from it (Daly and Cobb 1990). Thus, various efforts are being made to provide an adjusted index of economic output and attempts are being made to extend the GDP family of measures to provide a more comprehensive accounting system (Bartelmus 1994).

However, the fundamental problem is that we do not have a comprehensive measure of output or consumption but only a measure of priced inputs and consumption. In addition, when considering output and efficiency, there are three further problems to be considered:

- frictional losses,
- externalities, and
- changes in capital.

3.1.1 Frictional losses

In the ideal world of the economist, supply and demand would automatically match each other without either party incurring any costs in achieving this match. In the real world, there is a lot of frictional resistance to be overcome in achieving this match: transaction costs are significant. Anything which does not have a value itself as a form of consumption is then a frictional cost. Thus, in the ideal world, transport costs would be zero. The products of government are more complex and depend upon what responsibilities have been given to government. A significant part of government spending is often in subsidies to different sectors of the economy with agriculture almost invariably being subsidised. Governments typically also invest heavily in the 'X' factor, bearing all or most of the costs of education and a high proportion of the costs of research. Whatever the outputs of government, the objective is to maximise their output relative to the resource costs involved; consequently, simply reducing the costs of government need not increase efficiency. These two cost elements can make up a significant proportion of GDP. Overall, in the USA, between 14% (Rhode Island) and 31% (Wyoming) of the GDP of the individual states is composed of transport and government costs.

Similarly, in so far as retailing does not generate consumption in itself (e.g. the act of shopping rather than the goods brought gives pleasure), retailing and distribution are a frictional cost. Again, in the ideal economic world, retailing costs would be zero. The financial sector provides some consumption goods (e.g. pensions, insurances) and also carries out some rather more problematic activities (e.g. speculative foreign exchange dealing).

The problem in each case is that the technical efficiency of the economy is higher than if the sector or activity did not exist, but the sector itself is not necessarily efficient and ideally the resources required for the sector, outside for any pure consumption provided by the sector, would be zero. Thus, the difference between the actuarially expected cost of insurance and the retail price of insurance is a measure of inefficiency, as is the difference between the cost of borrowing and the interest payable on savings. In each case, only the value of the consumption provided should be included in the measure of output; everything else is a frictional cost.

3.1.2 Externalities

We have already seen that a significant problem in assessing the efficiency of an economy is the existence of unpriced resource use and unpriced consumption. Another and special case of unpriced flows is then externalities: the positive or negative impact of one person's actions on another so as to either change the amount or value of resources available to that person or to change the enjoyment they gain from consumption. As shown in Figure 3.1, there are a multitude of possible externality relationships between the environment, the economy and consumption. Pollution is the obvious example of an externality and water management is riddled with externalities of one kind or another. In turn, there have been a large number of studies of the magnitude of these externalities. These range from estimates of the total loss to the nation (Table 3.2) from water pollution through the damages resulting from a particular incident, by way of estimates of specific categories of losses or benefits, to estimates of the benefits of improvement resulting from a specific scheme. Estimates of the losses from particular events, such as the Amoco Cadiz disaster, have also been calculated (Bonnieux and Rainelli 1991). Many studies in several countries have been undertaken

Table 3.2 Estimates of national water pollution costs

Country		Loss per year
Germany	potable water	780 DM million
(1991)	groundwater	4.1 to 6.9 DM billion
(1986)	measurable damage to rivers and lakes	greater than 17.6 DM billion
Italy	coastal waters	6.0 billion lire
(1974)	inland waters	19.0 billion lire
France (1978)		10 150 FF million
The Netherlands (1990)		300–930 Dfl million

Sources: Court 1987; Kuik *et al.* 1991; Muraro 1974; Wicke 1986; Winje *et al.* 1991.

which assess one of the streams of benefits resulting from pollution abatement, particularly the recreational benefits (e.g. Bonnieux and Rainelli 1991; Smith and Desvouges 1986). Overall, these analyses indicate that out of stream recreational uses contribute, on average, the largest component of the benefits of water quality improvements where a reduction in water quality can be seen as the consequence of the externalities associated with discharging untreated or poorly treated wastewater, runoff from agricultural land, and other actions.

The standard response of economists is then to argue that these externalities should be internalised to the individual who created them through the imposition, in the case of a negative externality, of some charge and a subsidy being given in the case of positive externalities. This charge or subsidy should be exactly equal to the economic value of the externality: a Pigovian tax (Pearce and Turner 1990) should be adopted. Theoretically, it can be shown that such taxes would be more efficient than other means of controlling externalities, notably regulations (Baumol and Oates 1988). However, there are then a number of problems with applying the Pigovian tax approach and these are discussed in Sections 11.2 and 15.5.

3.2 What is 'X'?

In different forms, the nature of the 'X' factor has been of pervasive concern for at least 100 years when the UK in the nineteenth century became concerned to identify and remedy the reasons why the UK economy was being outpaced by first the German and then the US economies (Hobsbawn 1969). Thus, the 'X' factor is seen as critical both in terms of identifying what this magic factor actually is and more importantly, how to engineer it into a society, or a firm, or another form of institution.

What it does is to provide some capacity to change both in terms of changing itself and to adapt to changes in conditions. It is the capacity to create change and to adapt to change that is crucial. In terms of the definition given earlier, this capacity would seem to be the economy itself: the differences in the efficiency of economies and their capacity to expand and adapt being given by the nature of the individual economies, the social organisation. This at least is consistent with the tendency of economics to provide tautological explanations.

This 'X' factor may also be said to correspond to Homer-Dixon's 'ingenuity' (Homer-Dixon 2001) and there are also a range of other partial explanations including technology, institutional arrangements and different forms of social capital. The 'X' factor is then multidimensional in character and three different characteristics have been put forward as partial or complete explanations of the 'X' factor:

- technology,
- institutions, and
- social capital.

There can be some questions about classification, for example, is joint stock banking (Kemp 1978) a technology or an institution? But semantics are not what is important here; either the 'X' factor is one or several of these factors in combination or it is the way that they are put together.

3.2.1 Technology and skills

Technology is the obvious candidate. For example, in 1788, it took 7 tons of coal to make 1 ton of pig iron; in 1810, 5 tons; and in 1840, 3.5 tons; similarly, the amount of pig iron required to make a long bar reduced from 30–35 cwt at the beginning of the nineteenth century to 26–27 cwt in the 1840s (Deane 1979). Similarly, in 1900, it took 1 tonne of water to produce 1 kg of paper in Europe; by 1990, this had fallen to 64 kg per kg and more recently it has fallen further to 20–30 kg, with 1.5 kg per kg being achieved in some instances (von Weizsacker *et al*. 1997). Crop breeding (Figure 3.2) is consequently a technology (Heiser 1990); since 1910, yields of wheat in the UK have increased by 250% to 8 tonnes per hectare and in the USA yields have increased by nearly 200% to 3 tonnes per hectare.

Pohoryles (n.d.) concluded that in its first 20 years, growth in agricultural productivity was equally the result of changes in the factors of production and of the 'X' factor. However, in the last 20 years, changes in the tangible factors accounted for only 4% of the improvement in agricultural productivity and intangible factors for the remainder. Further he concludes that over the last 18 years, whilst agricultural water use has remained basically static, the real value of agricultural output has increased by a factor of 2.9. Therefore, in the Negev, he concludes that a 10% reduction in water availability could result in a reduction of only 1.1% in agricultural incomes.

If technology is so important, then a critical question is whether we can decide what to invent and innovate or whether invention occurs randomly, the nature of

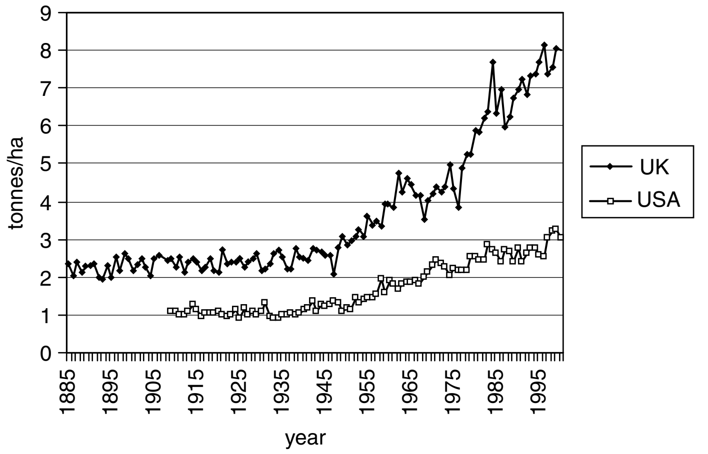

Figure 3.2 *Increase in wheat yields. Source: USDA/NASS 2001*

the inventions that occur being essentially outside of human control. Endogenous growth theory (Romer 1990, 1994) argues that we can, to a greater or lesser extent, influence the areas and direction of technological innovation rather than technological change being something that appears out of the blue. Thus, we can both choose those areas in which technological change is required and influence the rate of progress of technological change. Equally importantly, it implies that we choose where technological change will not occur by directing effort in other directions. In a way endogenous growth theory is a self-evident truth in that the two world wars saw very rapid technological innovation in weapons design, notably in aircraft technologies. At the start of the First World War, an aeroplane was barely capable of flying the English Channel; four years later, aircraft technologies had developed to the point where flying the Atlantic was possible.

One consequence of endogenous growth theory is that policy changes cause technological change and indeed perhaps this should be their main intent. For example, pollution regulation creates a market for pollution abatement technologies, induces technological change, and creates economies of scale in the production of pollution abatement equipment. The performance of a policy measure is then given partly by its effectiveness in inducing technological change and the adoption of that technological change. One consequence is that the costs of pollution abatement have frequently proved to be substantially below the costs initially estimated (Putnam, Hayes and Bartlett Inc. 1980).

Invention and innovation are created by people so the reinvestment in skills and technological innovation is potentially a virtuous circle; more skills not only enable the available technologies to be utilised effectively but also result in the development of new technologies. Using best available knowledge appropriate to the area in question can significantly improve efficiency. Jacobs and Asokan

(2000) report that whilst average output per hectare in the USA and India varies between 1.7 and 5 for different crops, the productivity on some trial farms in India was approximately doubled simply by providing the local farmers with the knowledge available to US farmers.

3.2.2 Social capital

> '... *norms and networks that enable people to act collectively*' (Woolcock and Narayan 2000).

Social capital is variously defined in two different but interlinked ways: as social norms such as trust, the absence of corruption (e.g. Inglehart 1997) that reduce both the frictional costs of exchanges and the risks involved in entering into those exchanges. Secondly, in terms of informal networks (Woolcock and Narayan 2000) that promote the sense of community out of which social norms are established and enforced. The first definition refers effectively to the nature of the social norms that are established. The second in part sees informal networks as in themselves ways of establishing support networks that create claims on resources of others and can prevent access by other groups to particular resources. Such informal networks have been found in many poor communities.

The shift back to farmer-managed irrigation systems and to community-based water and sanitation systems is then both an attempt to exploit social capital and also an attempt to create social capital which can then be mobilised for other purposes.

3.2.3 Institutions

Institutions are argued to be critical to effective water management. Turton and Ohlsson (1999) argued that when demand is small relative to the natural endowment, institutions do not matter. However, once a country utilised more than 15–20% of its annual renewable water, Falkenmark and Lundqvist (1998) argued that complex institutional arrangements are required. Therefore, two important questions are: what institutional structures are most effective? And how can we implement such structures?

The problem is then how to design institutions that can actually deliver such integrated management; Ostrom (1990) and others (Gibbs and Bromley 1989) have been investigating how institutions work. However, the problem with institutions is that their actions must be governed by a set of rules; indeed, this rule structure defines an institution. Thus, Scott (1995) gives the following definition: '*Institutions consist of cognitive, normative, regulative structures that provide stability and meaning to social behaviour*.'

Institutions are defined by formal or informal rules not least to provide accountability and predictability. For these reasons, it is as important to define what they cannot do as much as what they can do. For accountability, it must be clearly established what an institution may do and what it may not do, and also how it is to go about deciding and implementing those actions. Predictability is related to accountability but it is quite important that institutions behave in a predictable way, that when a farmer is thinking of applying for an abstraction licence, the farmer can make a reasonable prediction of whether or not a licence is likely to be issued.

That they are rule-defined in turn makes it difficult for an institution to change; it can change its internal rules but the external rules are fixed. Moreover, if an institution is defined by its rules then it is difficult for an institution to learn because learning means changing its rules. In turn, these external rules can be very difficult to change, particularly where they are defined by the national constitution. Secondly, amongst those rules are those that define the geographical boundaries of the institution and also its functional boundaries. Those geographical boundaries are typically also fixed by historical, cultural and political factors; and catchment boundaries are only incidentally consistent with the boundaries defined in those terms or those likely to promote efficiency in the delivery of other services such as education, policing or health. Hence, it is unlikely that there will be one set of institutional boundaries that are ideal for all purposes. As will be argued in Chapter 23, integrated catchment management is not enough; it has to be integrated into a whole series of other national and regional policies. We have, in short, to create holistic catchment management through boundaried institutions.

In turn, in assessing the performance of institutions, it would be helpful to have some measure of the difficulties of water management in that country; if Turton and Ohlsson are right, institutional structure only becomes important when management becomes difficult. Two obvious measures of the pressures are then population density and arable land per capita (Green, Parker and Tunstall 2000), with the ratio of potential evapo-transpiration requirement to precipitation (Chapter 14) being the most important water constraint. On the output side, in the absence of any economic measure of consumption or efficiency, GDP/km^2 is a rough measure of how hard the natural endowment is being worked, and the extent of that natural endowment (Green, Parker and Tunstall 2000). As it stands, it is not possible to make comparisons between countries as to the institutional effectiveness of each. In consequence, recommendations as to the best form of catchment management (Section 10.1) and of service delivery (Section 10.2) have to be tentative.

3.2.3.1 Markets

The core claim is that competition will act in the public interest, Adam Smith (1986) famously arguing that when co-operation would be against the public interest, then the answer was to force the producers to compete through the introduction of a competitive market. Conversely, self-interest drives producers towards seeking to cooperate since if a producer cannot achieve a monopoly, to be part of a cartel is then the next best means of reducing risk and increasing profitability. In turn, markets are a means to an end and not an end in themselves, nor are markets a means of establishing what our ends, our objectives, should be. When competition is desirable in order to achieve our ends, then a competitive market can be structured so as to achieve these ends; it needs to be structured since our objectives and those of the individual producers will generally be different.

This then is the negative reason for ensuring competition. There are two positive reasons. Firstly, in a stable environment, some producers will be more efficient than others and hence produce at a lower cost. These producers will force the higher cost or low quality producers out of business because they can undercut them. A question, therefore, is; what proportion of producers should, in any year, be exiting a product market if efficiency is to be achieved? Clearly, if no companies are going bankrupt or being taken over then there is an insufficient degree of competition. A proper market is thus a brutal place of Darwinian survival and unless some firms are being killed off, then there is necessarily inefficiency and excess profits. Therefore, a necessary condition when considering privatisation is to consider how services will be maintained if a firm fails (Green 2001b).

Secondly, in a more realistic dynamic environment, the advantage is one of diversity; whatever the nature of the change, one or more producers will be better equipped than the others to adapt successfully to that change and so it will survive whilst the other firms collapse. It will survive because it has more appropriate technology or better ideas. These two models are, obviously, in contradiction to each other: in the stable situation, survival of the fittest tends to lead towards uniformity in terms of technologies and approaches. Conversely, in a changing environment, diversity increases the likelihood that one or another producer will be equipped to take advantage of the change whilst others die out. The two concepts are only consistent if there exists more than one combination of technology and output that are equally efficient.

Finally, the purposes of analysis, a perfectly competitive market has a significant advantage: the market price falls out of the market at the point where marginal cost and marginal value are exactly equal and efficiency is automatically achieved (Lipsey 1971). Moreover, it is assumed such markets will be both homeostatic, adjusting to any disturbance, and optimising. It is possible to criticise this model on theoretical grounds since the performance of a market is either a consequence of the decision rules used by individual producers and consumers, or is the result of the interactions between producers and consumers. Since the same people perform other activities, it must be either the approach that they take to making production or consumption decisions in a market, or the interactions between producers that are important. Thus the critical question is how the producers decide by how much to increase or decrease production, whether they can do so, and how long it takes for the change in output to be achieved. Deciding how much to produce in the next time period becomes an even more difficult task if the world is not stable but subject to both external perturbations and trends. In turn, if relatively simple decision rules are used to explain how an individual producer decides how much to produce in the next period (Smith 1990), then the result is chaos rather than homeostasis. The practical problems with water are that where there is a market it is far from perfect and that prices prove to be relatively ineffective inducing optimal responses (Section 15.3).

4

How Do We Choose?

The force of economics lies in the extent to which it provides prescriptions for collective choice, to the degree to which it provides a rational argument for adopting one option rather than another.

4.1 Individual Choice

Neoclassical economic theory has been derived as a theory of how individuals make choices amongst priced goods. This model of choice is then used to provide a basis for arguing how collective choices should be made; it is treated as a general theory of choice so that it can be used to make normative recommendations about the provision of goods through collective action. Thus, two presumptions are made:

- That the individual approaches choices about the provision of goods through collective action as if the choice was about purchase of a priced good; and
- The individual believes that society should base the decision on this premise.

These are two very sweeping presumptions for which we have absolutely no evidence and I will return to them later. But, first it is necessary to examine the economic theory of individual choice between priced goods since there are a number of problems with this approach. Firstly, as a theory built on the demand for priced goods it is a matter of some embarrassment for economics that the very area where economic theory should be the most relevant, the decisions of firms as to what goods to market at what prices, it is least used. If a Sony, for example, has invented a new consumer good then it does not ask an economist how many it can sell at what price. Instead, companies use market research techniques (e.g. Assael 1992) and these are based upon theory from psychology and sociology rather than upon economic theory. When economists (Samuelson 1954) argue that only behaviour is real and asking people what they would do in a hypothetical choice is unreliable, the manufacturer's reply would be that it may be theoretically impossible but that it is necessary to do it. Moreover, if Samuelson's argument is accepted, micro-economics is essentially redefined as a branch of history.

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Secondly, it is essentially a trivial theory; the individual is assumed to made all the really important decisions, those involved in constructing a completely ordered utility function, before they approach any decision. What individual choice theory then covers is simply the mechanical process of applying these pre-existing utility functions to the particular choice.

Thirdly, the third axiom (Robbins 1935) of neoclassical economics is that the individual is rational but rational in a number of specific senses. In particular, it is assumed that the individual never makes mistakes when buying goods in the market. This assumption is simply implausible; there is a wealth of material on the error rate for all kinds of other tasks including car driving (Quimby and Watts 1981) so that we know that we are fallible and prone to make both random and systematic errors when performing tasks. Indeed, an entire science, ergonomics, has developed so as to define the task, and the environment of that task, in order to reduce the risk of human failure. Thus, Watson (1989) reports that human error rates vary from 1 in 1 to 1 in 100 for knowledge-based tasks down to 1 in 10 000 for skill-based tasks. For economists to claim that there is, for example, a small but finite risk of the pilot making an error when flying but that same person never makes an error when buying a toothbrush would simply bring the profession into disrepute. We cannot claim that purchasing decisions are different to other choices without specifying why they are different, nor, equally, without arguing what it is about the individual's performance of such tasks that makes them different. We cannot argue that purchasing choices are more important than other choices; it would be absurd to argue that making the right choice of toothbrush is more important than, for example, deciding when to turn right across traffic or in making the right choice of a partner. If we argue that it is something that the individual brings to the task, then we are necessarily forced to admit that we are more likely to be successful in some purchasing decisions than in others. If it is experience that makes us good at making particular types of choices then, unless it is experience in making purchases in general, we will be better at making some purchases than others; better, for example, at buying toothbrushes than at buying homes or cars. Moreover, if it is experience, then this is to explicitly admit to learning and change; once change is let into the model then it is difficult to claim that once we have learnt how to purchase, we never learn or change any more. Conversely, if it is the attention we give to the decision, where the more important the choice the greater the attention we give to the decision, so that we are good for that reason at buying houses, then it is implied that we will not be so good at routine, habitual choices like buying a cup of coffee. It is further assumed that we make consistent choices; strictly, this rules out learning and learning is a necessary characteristic of a person. In turn, this implies that consistency is a highly undesirable characteristic of choice.

Fourthly, economists have been fond of using the story of Robinson Crusoe as a way of explaining economic theory (Bergmann 1995). The Robinson Crusoe model has been criticised as being both sexist and racist (Grapard 1995). But, the problem with taking Robinson Crusoe as an example is that he would today be expected to have been severely damaged by the experience and to require a long period of therapy and recovery before he was able to re-adapt to normal life. Indeed, living in isolation is usually taken as a particularly severe form of punishment, or as a high form of sacrifice for religious reasons. It is not, therefore, encouraging that the story of a damaged individual living in an alien context is used as a metaphor to explain the basic principles of economics.

Since we grow up in households and spend most of life in some sort of household, I shall argue in Section 4.2 that the logical place to start in constructing a general theory of choice is with choice in households. Thus, in turn, that individual choice constitutes the trivial case of the household choice model. Secondly, it is not possible to simply assume that the individual has already determined their preferences and constructed their utility function before they make any choice. It is necessary instead to consider how this learning may come about since this learning process itself has implications for how we choose.

4.1.1 Learning to choose

The neoclassical economic theory of choice is essentially trivial; it is merely a matter of the individual mechanically applying knowledge that they already have. Before they make a choice, the individual is assumed to be aware of all of the consumption options and to have decided what is the marginal value of each and every consumption option. In turn, neoclassical economics is predominantly a static view of the world. In part this is a result of the assumption of perfect information: in a world of omniscience, we know not only what is but also what could be and can choose between them in perfect certainty. If we know everything, then the future has no surprises and time is dissolved.

Thus, it fails to address either of the two fundamental problems: how do we discover what is available and how do we decide what we want? We begin in the real world as babies with limited knowledge and even more limited preferences. We grow up into a world of rapid change where we are necessarily ignorant about the future. We have to learn to have preferences for goods which we did not know existed, or which have just been invented. Thus, knowing how our preferences are formed is of greater interest than knowing what these may be at any single moment in time.

One fundamental human trait is learning; as we learn more of the world, we also learn what are our preferences. Whilst some preferences may be innate, quite clearly other preferences are learnt or developed. It is, for example, unlikely that we were born with a utility schedule for camcorders or karaoke machines. Neoclassical economics, by assuming perfect information, limits itself to a description of the instantaneous present. Without describing how that state has arisen, it cannot predict the future.

If we have to discover our preferences, then we also have to find out what goods are on offer. Bayesian analysis identifies the value of the potential information gain to a decision (Enis and Broome 1971); essentially, the economic concept of 'quasi-option' value (Henry 1974) is equivalent to this information gain.

Finally, by defining rationality as little more than consistency, rather than as a process of decision making (Arrow 1987; Sen 1987), neoclassical economics made itself better at describing repetitive behaviour than first purchases. But consistency in choice can only occur if we are not learning; consequently, consistency in choices is not necessarily desirable.

4.2 Household Choice

Therefore, it is not unreasonable to argue that we have to learn how to choose as well as learn what we want. Choices in households are then crucial because we grow up in households and it is in this context that most of us learn both what we want and how we should choose. Moreover, in practice, most choices are made in the contexts of households, either the atomistic Western household, or in extended kinship groups. Hence, it is reasonable to take choices by households as the basic model of choice. We might expect, therefore, that the way in which we approach choices in a household influences the way in which we approach choices in other contexts, including formal groups such as at work, informal groups such as friends or clubs, and perhaps even when voting.

In addition, it is necessary to look at exactly what resource and consumption decisions are made by households; in particular, to link the use of unpriced resources to both priced and unpriced consumption. One of the results is that economic value may diverge markedly from willingness to pay and, of course, in an entirely subsistence economy, willingness to pay is a meaningless concept whilst economic value will remain.

There are significant problems in defining a 'household' (Gershuny 1998; Hart 1992; Roberts 1991) because there is such a wide variety around the world, particularly where households are woven into kinship or other linkages. This variety is reflected in the roles within the household, but we might characterise a household as involving some pooling of resources and some sharing or abrogation of decision making amongst its members. Within such households, children have no access to any income of their own; their choices are limited to the allocation of their time and often vociferous attempts to influence the consumption choices made by others in the household.

4.2.1 The household's resources

The basic resources available to the household are the combination of time and energy; the household has to allocate both to the provision and also to the consumption of different goods and services (Figure 4.1). Thus, cash income is purely an intermediary on the way to consumption. In a purely subsistence economy in which each household provides its own household durables (e.g. a

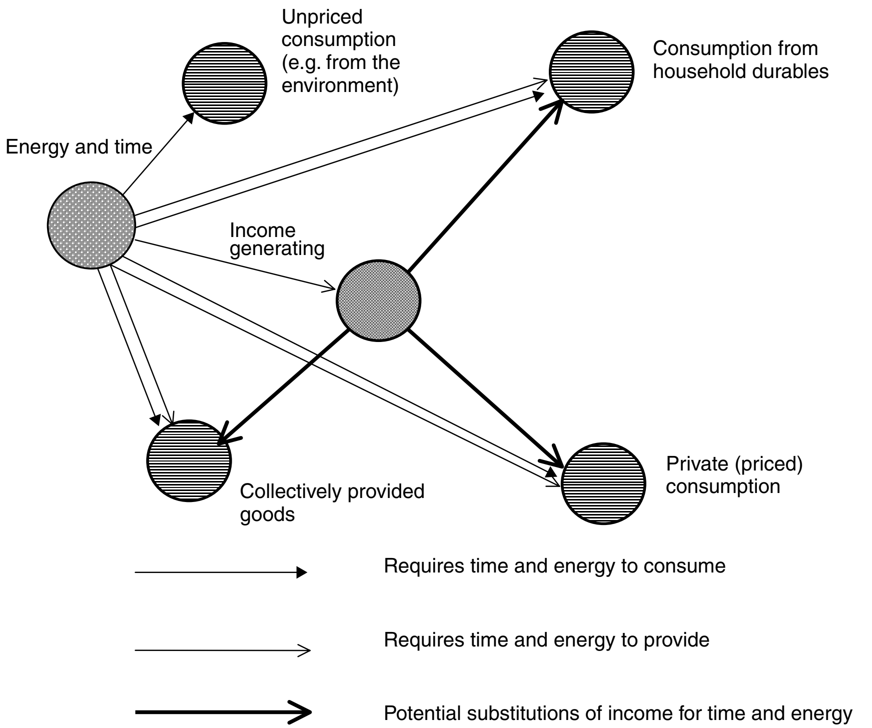

Figure 4.1 *Household decisions*

home, furnishing, cooking utensils) and private consumption (e.g. food, drink, clothing), the only other decision they have to make is as to how much time and energy should be allocated to the provision of collective goods (e.g. hunting large animals, irrigation works). However, once either bartering or a cash economy is introduced, then the household can allocate some time and energy to the generation of bartering goods or a cash income. In a cash economy, the household must decide whether it is better to provide some household durables directly through the investment of their time and energy (e.g. DIY) or indirectly by paying someone else to undertake those works. Similarly, they can either provide some private consumption directly through the use of their own energy and time (e.g. making jam or clothes) or indirectly by buying those goods. Again, collectively provided works (e.g. irrigation schemes) can either be provided directly through the contribution of the time and energy of the household, or indirectly through a cash payment. A critical question is consequently as to the relative rates at which time and energy can be converted directly into the desired consumption versus via the indirect route of first generating income. Which route is more efficient clearly depends critically upon the availability of income producing opportunities; where these are sparse, the direct route will be more efficient.

In turn, many goods require the simultaneous availability of time for their consumption. Indeed, unpriced goods, such as a walk by the river or playing with the children, require only the availability of time for their consumption. Some household durables require time (and energy) for their consumption (e.g. watching television, canoeing) whilst others do not (e.g. a refrigerator, washing machine). A benefit of some durables is then that they reduce the time required for the activity which can then be reallocated to other uses (e.g. electric drills, washing machines, vacuum cleaners).

Whether collective goods require time for consumption depends upon the nature of the good provided; in the case of leisure centres and art galleries, time is required although it is not for other collective goods such as defence or law and order. Private goods usually require the joint availability of income and time. Hence, the household has to allocate time and energy between both production and consumption, with some forms of consumption also being income constrained. We have seen from time budget studies (Table 2.1) that a relatively small proportion of the day is spent on the consumption of immediate consumption priced goods.

On the resource side of the equation, even in households in the UK, a significant proportion of labour inputs are unpriced. Attributing activities to work and necessary support activities is somewhat problematic. Housework is generally regarded as a pure input whose output is consumption in the form of cooked food, clean clothes and so forth. But, like DIY, some forms of housework, such as gourmet cooking, may yield pleasure, consumption as an activity rather than consumption being solely an output of the time expended on the activity. Time expenditure, to some extent, therefore gives a misleading picture of the unpriced inputs to the household. Pahl's (1989) study of households in Sheppey found that nearly 90% of house painting was performed by members of the household, and roughly the same percentage for cake making, vegetable growing and clothing repairs. About 10% of households would undertake major house modifications such as putting in a steel joist or double glazing or a bathroom. Significant proportions of households also made jam, beer, bread and clothes, as well as knitting. Consequently, there are some unpriced resource inputs to the household (e.g. vegetables) but most of the unpriced inputs are in the form of labour. In developing countries, the proportion of unpriced labour inputs in rural communities is often much higher (Table 4.1): the greater labour inputs from women is typical (Brismar 1997). So, too, is a high proportion of resource inputs often unpriced; thus in rural India, some 20% of the resource inputs, such as firewood, water and fodder, have been found to be unpriced (Jodha 1992). In the extreme of subsistence farming, the proportion of inputs to the household and outputs from the household which are priced approaches zero.

Thus, the fundamental problem for the household is the allocation of time and energy between different forms of production, income generation and consumption

Table 4.1 *Time use in the dry zone, Sri Lanka, during the peak season*

	Males		Females	
	Hours/month	%	Hours/month	%
Agricultural production	298	41	299	42
Household tasks	90	13	199	28
Fetching water and firewood	30	4	50	7
Social and religious duties	8	1	12	2
Leisure/sleep	294	41	160	22

Source: Momsen 1991.

whilst at the same time a significant proportion of household consumption is unpriced at the point of consumption.

4.2.2 Decision making by households

If the task of a household is to use its available resources to maximise the consumption of the household, how then does it determine how to allocate its resources? The early economic theory of households (Becker 1991) was essentially that of a benevolent dictator. It has been criticised by development theorists as having little practical relevance in planning interventions with the aim of promoting development (Alderman *et al.* 1995). It also seems to bear little relationship to what has been observed by sociologists and anthropologists (Hart 1992; Jelin 1991).

The second household model is divisive: resources and decisions are shared out between the members of the household. Pahl (1983, 1989), and later Anderson *et al.* (1994), have sought to explore both how decisions are made about the allocation of resources with households and the variations in access to financial resources by gender and income level. There are a wide variety of approaches adopted ranging from the 'female whole wage' system, in which the husband hands over the whole wage packet, minus personal spending money, to the wife through to the 'male whole wage' system in which the male has sole responsibility for managing all of the household finances.

Anderson *et al.* (1994) make the distinction between strategic and executive control over the household's finances, executive control for day-to-day responsibility for organising the household's finances and day-to-day payment of bills. They define strategic control in terms of which allocative system should be used, the proportions of income which should be allocated to personal spending money and who has the final say in big financial decisions. Overall, 70% of their respondents indicated that there was joint strategic decision making; as is logical, this proportion varied with the type of executive decision making, falling to 50% in households in which the executive financial management was via a 'housekeeping allowance'.

Applied consumer theory (market research) has relied on a third model: an interactive model coming out of sociology, particularly on the work of Sprey (1969) who developed a model of household decision making as a system of 'co-operative conflict', a model which was independently proposed by Sen (1990). In this model co-operation, or collusion, can yield a better set of outcomes than individual actions, variously labelled as the 'breakdown position' or the 'status quo'. However, unless there is only one possible collusive outcome which is better than that which results from individual actions then a choice must be made between the two or more collusive actions. The different members of the household may well have entirely different preferences between these outcomes; for example, as to which television programme is to be watched on which television, or where to go on holiday. This choice is, Sen points out, one of pure adversity. Since any of the outcomes is better than the breakdown position, who wins in such choices is dependent upon their bargaining power. Sen argues that 'winners' in one round achieve a better bargaining position in future rounds, particularly as such victories relate to access to household and external resources. There is now quite a large literature that examines the different strategies that the different household members use in order to try to influence household choices (e.g. Kirchler 1993). US market research studies have logically focused upon differences in terms of influence between specific consumer goods (e.g. Munsinger *et al.* 1975) in order to determine the most effective marketing strategy.

The key characteristic of this model of household decision making is thus interaction between the members of the household. Such interactions are completely absent from the neoclassical economic model which Chattoe (1995) describes as consumer theory without people. Tannen (1991) further claimed that: 'Many women feel it is natural to consult with their partners at every turn, while many men automatically make more decisions without consulting their partners. This may reflect a broad difference in conceptions of decision making. Women expect decisions to be discussed first and by consensus.' Thus, she claims that women expected decisions to be discussed and agreed; Wilson (1991) found in a study of women in North London that the dominant ideology of marriage held by a majority of women was 'sharing', although she noted that the reality was less than equal shares. Thus, the two key messages from work on households are:

- There is both interaction between partners and an expectation by many that decisions will be discussed first; and
- A wide variety of strategies are used to influence the outcome of the decision whether or not it is formally discussed.

If people first learn how to make choices in this context and then use this in their everyday life to discuss and negotiate the allocation of household resources then we might anticipate that they will bring the same expectations to group or social choices. If they expect major financial decisions to be made jointly, and a significant proportion pool their household resources, then this form of enculturation might be expected to spill over into the way that they expect larger groups to take resource decisions.

4.2.3 Problems for assessing economic values

The household model shown in Figure 4.1 also illuminates the question of economic value and in particular the extent to which preparedness to pay can be equated to economic value. Economic value is both subjective, measuring how much someone wants something, and is assessed by the sacrifice they are prepared to make to get that something. Hence, economic value exists in a purely subsistence economy where money values do not exist; in such economies, people still both want things and have to make sacrifices in order to obtain them. We cannot, however, in such an economy measure the economic value of something by asking people how much they would be prepared to pay in order to obtain that something. Only if either there is some priced good or some income that they could sacrifice will preparedness to pay be a meaningful measure of economic value.

Since substantial proportions of household inputs and consumption are unpriced, it follows that the prices of priced inputs and consumption are distorted away from those that would prevail if all inputs and consumption were priced. If all housework had to be brought in from, say, a supplier of robotic labour, or we had to pay to see sunsets, then the household would have less money to spend on other things and both the quantities and prices paid for those goods would necessarily fall.

More generally, there are a number of problems for economic evaluation, particularly when undertaking expressed preference studies (Section 12.2.3) either of unpriced consumption or of collective goods. Firstly, the combined rate at which time and energy can be translated first into income and then into priced consumption may be below the rate at which time and energy can be translated into unpriced consumption. In this case, using preparedness to pay will yield a value below the economic value, properly measured as the most valuable sacrifice the household is prepared to make to obtain that which we want to value. Indeed, there may be more efficient ways for the household to translate time and energy into consumption than going through the intermediary step of first generating an income; this is characteristic of poor communities. Thus, importantly, the most successful means of providing water and sanitation in such areas has been through community self-help (Black 1998) where time and energy is directly translated into consumption in the form of water and sanitation services. In turn, this means that preparedness to pay is a poor metric for measuring the value of these services since the compound rate at which time and energy can be translated into income and then into consumption is less than the rate at which time and energy can be directly translated into consumption. In turn, this has implications for the best means of providing those services (Sections 10.2, 14.6.1 and 16.1.1). In particular, for the provision of water and sewerage service by a private company to be viable (Section 10.2.3), it is necessary for the rate at which time and energy can be converted into income to exceed the rate at which they can be converted into the community provision of a water and sewerage service.

Generally, respondents in expressed preference studies are asked how much they are prepared to pay for the good in question rather than what they are prepared to sacrifice. This amount can then only be made available by reducing private consumption, investment in household durables, or by sacrificing further time and energy to produce income. A consequence of this approach is that the proportion of a household's incomes that are committed to the provision of collective goods funded through taxes can only increase as there is no scope with this technique for respondents to either reduce as a whole the proportion of their income taken through taxation, or to reallocate that amount between services. This leaves an asymmetrical approach where individual households can agree to increase taxation to serve a particular purpose but only the political process can decide to reduce tax either as a whole or for the provision of specific goods and services. In general, there is a lacuna in the neoclassical economic approach which argues that the goods supplied should reflect individual preferences but that both the level of taxation and the use of that revenue should be based upon macro-economic theories about the economy and, in particular, as to the appropriate level of public expenditure.

The further problem with a significant fraction of consumption not being priced at the time of use is to evaluate changes in non-priced consumption. The obvious problem is that if we ask for the individual's preparedness to pay then this amount can only be freed up by reducing expenditure on priced goods. The only sacrifice that can be considered is of priced consumption. If the change is nontrivial then the effect will be to reduce demand for priced goods; across demand as a whole, then the effect will be to reduce the demand for different priced goods and in turn, the prices at which those goods can be sold. If we try to value all of the consumption that is not priced, then the new equilibria for priced goods will be at lower levels; in addition, the individual will be at a lower utility level. The change is equivalent to a reduction in real income.

4.3 Societal Choice

Neoclassical economics takes its theory of individual choices for priced goods and treats it as a general theory of choice. So, societal choices are simply individual choices writ large. It is therefore assumed both that individuals approach all choices as if they were about the purchase of a priced good and also that individuals believe that society ought to make choices on that basis although without any evidence for these claims. Nor is the model consistent with how collective choices are made in practice. Both Margolis (1982) and Sagoff (1988) have suggested alternative bases upon which individuals might approach choices involving public goods.

There are six reasons to question whether the assumption that individual choice for priced goods constitutes a general theory of choice:

- It is only a partial theory of choice.
- There are fundamental differences in the nature of different goods which the public might be expected to recognise and take into account in the way in which they approach choices.
- Individuals do not exist in isolation but are subject to social norms and peer pressure which influence their understanding of how they ought to behave in particular circumstances.
- The basis and extent of the provision of goods through a society is intimately connected to our understanding of our relations with each other.
- Moral, ethical and religious issues are typically much sharper in regard to societal decisions.
- It predicts behaviours that are inconsistent with the results of experimental studies.

Any general theory of choice has to encompass all choices and not just some. There are some choices that have no resource implications of any kind such as what colour to paint the front door, what name to give to the baby, or whether to believe in the existence of a deity. A theory of choice about priced goods is not the obvious place to start in providing a theory that can cover all choices.

Secondly, the one distinction that is drawn in neoclassical economics is between 'private goods', those that are readily produced and sold in a market, and 'public goods' (Table 4.2), as well as two other classes of good. Public goods cannot be produced in a market although a charge can be levied for the use or access to them. A public good is distinguished from a private good by reason that:

- once the good is provided for by one individual, it is necessarily available for other individuals; and
- its use by any one individual does not reduce the amount available to other individuals or the value to them of making use of the public good.

Conventionally, the only real implications of the difference are:

- the demand curve is based upon horizon aggregation rather than vertical aggregation of individual preferences; and

Table 4.2 *Public and private goods*

Subtractability	Excludability	
	High	Low
High	Priced goods	Open access
Low	Toll goods	Public goods

Source: Easter, Becker and Tsur 1997.

- to charge for access to a public good can be shown to result in inefficiency so the costs of the provision of public goods are best recovered by a means other than a price or fee for use.

Now, this difference is defined on the demand side of the equation and it may be asked whether there is any similar difference on the supply side of the equation. I have previously argued (Green 1997) that a distinction can be drawn between goods where the individual can make private arrangements, such as purchase, for the provision of the good and those goods that can only be provided by collective action. In addition, that there exist some goods that can be provided by either means but for which economies of scale make their provision cheaper through collective provision (Section 7.2).

This gives a four-way categorisation of goods (Table 4.3). National defence can only be provided collectively: because of the cost of modern weaponry, no individual can afford to construct and maintain a fleet of nuclear submarines or aircraft carriers. Nor, similarly, can any individual afford to send a crew of astronauts on a mission to Mars. Again, no individual can decide to preserve blue whales as it requires agreement of all nations that blue whales will not be hunted.

Conversely, where there is groundwater, the individual can choose to supply himself with water by digging or drilling a well; alternatively, they may buy water from a water vendor. Similarly, they may dispose of sanitary waste by digging a cesspit and paying for the solids to be collected. Again, they can reduce the potential losses from floods by building their home on stilts or flood-proofing it. What is typically true is that it is cheaper to access these services through collective provision but that this will only occur if there is collective agreement that the service shall be provided. A water distribution system cannot be constructed without it crossing some people's land; the construction of a canal irrigation system requires the agreement of the farmers concerned to the construction of the off-take works, the distribution and drainage systems. So, too does the building of a flood embankment require the agreement of the farmers whose land will be taken up by its construction.

The conditions which constrain some provisions to being collective are partly resource constraints; unless individuals club together, insufficient resources are

Table 4.3 *Supply and demand conditions*

Supply	Demand	
	Private	Public
Individual	Cup of coffee, well, cesspit, flood-proofing	Lighthouse, breakwater, wastewater treatment works
Collective	Piped water supply and sanitation, flood warnings, canal irrigation	Conserving blue whales, national defence, flood embankment

Source: Green 1997.

available. In other cases, what is possible depends upon the way in which the relations between individuals are constructed; what system of entitlements and obligations is established. Thus, the individual provision of piped sanitation and water is possible but only if the individual, usually the company, is given rights of eminent domain to enter into private land. In the case of piped sewerage, a purely private solution is only possible if the individual company is either given the right to levy a tax or it is paid through the collective because it is not practical to meter discharges from private properties. In addition, it is usually necessary to establish an obligation on individual households to connect to the sewerage system.

To assume that a theory of choice for the consumption of private, individually supplied goods can be generalised to the other three possibilities is to imply that we cannot tell or there is no real difference between the four categories of good. We assume that for the purposes of economic analysis, blue whales can be treated as being no more than very, very large cups of coffee. This is not a particularly plausible assumption to make.

Thirdly, neoclassical economics takes individuals as the nexus of choice; the opposite extreme is Duesenberry's (1960) remark: 'Economics is all about how people make choices. Sociology is all about why they don't have any choices to make.' That is, that the cultural and social context of the individual will determine the choices made by the individual. Cultural theorists in particular have claimed (Schwartz and Thompson 1990) that different groups have radically different perspectives which will influence, amongst other things, how they believe that goods ought to be provided.

The Duesenberry model treats individuals as little more than ants in an ant nest; the neoclassical economic model simply treats society as being no more than the collective noun for individuals. Clearly, both are gross oversimplifications. Children are socialised, the whole basis for the argument about single-parent families, for example, being about the nature of this socialisation process. Part of this socialisation process is to establish internal norms as to the behaviour to adopt in particular circumstances (e.g. 'let your sister play with your car'), and another part is to inculcate social norms: the behaviour expected of individuals by society (e.g. 'you mustn't steal'). Between cultures, differences should be expected to be greater than the differences between groups within a single culture. If this socialisation process has been successful at all, then we should expect the consequences to be particularly apparent when choices concern the provision of public, collective goods.

Fourthly, the way that decisions are to be taken is clearly associated with expectations about the nature of relations between us. These expectations affect both the way in which a decision is taken and how the individual should respond in the social context of such a decision. Women, Tannen argued, expect decisions to be taken by agreement and after discussion. Moreover, there are a whole series of objectives and values that relate to relations between people

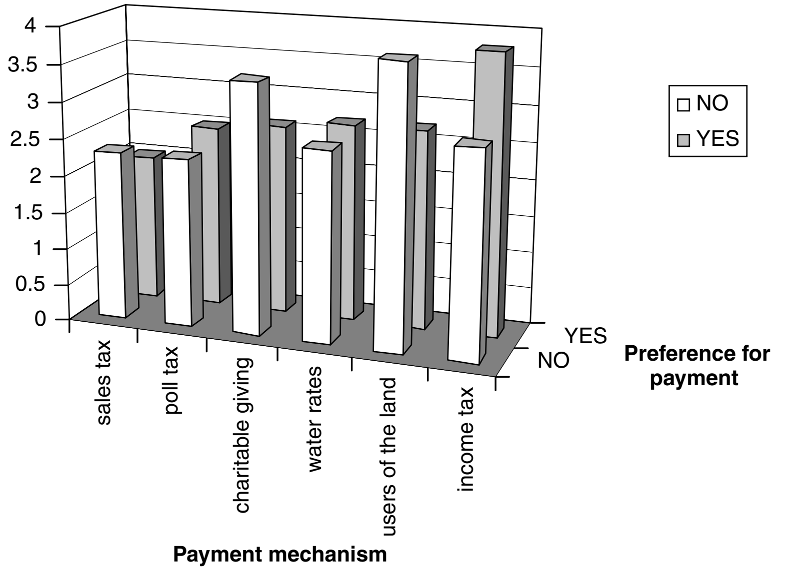

Figure 4.2 *Preferences between cost recovery methods*

(Section 2.1.1.7). However narrowly or widely we define it, equity is about the nature of the relationships between individuals and groups; so too are beliefs in justice and democracy.

Two obvious consequences of this relationship dependence is that, firstly, in social survey studies, such as contingent valuation, people have a clear preference for the means by which the costs of projects are to be recovered and that this preference is associated with whether or not they are prepared to pay (Figure 4.2). Those who are not prepared to pay, in this case for reducing coastal erosion, are more likely to favour payment mechanisms that allow others to pay but do not force the individual respondent to pay towards the cost. Those prepared to pay tend to prefer payment via income tax over the other possible methods of recovering the costs since the tax model forces others to comply with the decision.

The second consequence is in terms of the means of provision that they would prefer. For example, the costs of a wastewater treatment programme may be raised locally, regionally or on a national basis. Respondents may favour one form of programme over another; in a study of river restoration, Tapsell *et al.* (1995) found a slightly higher percentage of local residents were definitely prepared to pay for a project to restore the local river (59%) than for a national programme (52%). Conversely, when asked about programmes to improve river water quality, respondents both in the qualitative studies (Tunstall 1995) and in a contingent valuation method (CVM) study preferred a national programme (80% in the CVM study).

These relationships between us are different to personal moralities. The debate about altruism, its nature (Sen 1977) and whether it can be included in economic analyses (Milgrom 1992), is about personal moralities. I can choose whether to give to beggars; I cannot choose whether or not to pay towards the costs of social security. Moreover, in many countries, a refusal to serve in the armed forces is a punishable offence as it is understood that citizens have a duty to fight to protect their fellow citizens. So, the issue here is not whether I would feel better if I contribute towards the well-being of my fellows but whether I interpret the situation as being that I have duty to contribute, in this instance, to the well-being of my fellow citizens.

Similarly, public involvement in all levels of decision making has been accepted as a necessary condition for sustainable development (ACC/ISGWR 1992). But the whole point of public involvement is to influence each other, to persuade others that our viewpoint should be adopted, or to negotiate a compromise. One of the drivers for adopting public involvement is that the public expect to be involved and such involvement is regarded as a precondition for the legitimisation of the institution with central responsibility for the decision and its implementation (Lawrence *et al.* 1997).

Studies on procedural justice or equity have shown that the perceived legitimacy of the decision-making body is important. This legitimacy is enhanced when people believe that the authorities are honest and competent, people's willingness to voluntarily accept the authority's decisions, and people's feelings of obligation to follow the rules implemented (Tyler and Degoey 1995). Where individuals are personally involved in a dispute, individuals are likely to believe that they were treated fairly if they have an opportunity to have an input to the decision (Thibaut and Walker 1975). It has been suggested (Stroessner and Heuer 1996) that this is less an issue of self-interest than whether group members were treated in a manner implying respect for the group and its rights.

Fifthly, choices about the provision of public goods give more opportunity to express moral values, be these internal or the reflection of understood social norms than do purchases of private goods. In practice, the market research evidence is that understood social norms also influence the purchase of even quite mundane private goods (Ryan and Bonfield 1975).

In psychology, as in everyday speech, an individual's core beliefs are termed their values, Rokeach (1973) defining them as follows: 'A value is an enduring belief that a specific mode of conduct or end-state of existence is personally or socially preferable to an opposite or converse mode of conduct or end-state of existence.'

Rokeach argues that an individual's values function as standards in order to make evaluations and judgements and so as to enable us to heap praise and fix blame on ourselves and others. A second function of values he suggests is motivational; they serve as the objectives which individuals seek to satisfy through their behaviours. Thus, in Rokeach's view, values serve both as Kant's moral values, those which carry a sense of absolute obligation, or 'ought', and those which carry only a sense of desirability, of I 'want' or I 'like'. Furthermore, Rokeach proposes that such values are all or nothing in form; one either believes in freedom or one does not; it cannot be said that an individual believes in a little freedom or a small amount of democracy. Kelly (1955) argued that beliefs are structured hierarchically, lower-level beliefs tending to be narrow in scope or range and specific in form. The highest-level beliefs are more abstract and are, he argued, difficult to change. Again, such high-level abstract beliefs may be labelled as 'values'. Indeed, such beliefs are so central that they may be argued to define the core of the individual's personality.

If the individual uses these abstract values as the basis of making choices, then these moral principles must be turned into criteria for action. Consequently, Rokeach goes on to differentiate between terminal values and instrumental values as parts of this cognitive structure. Kelly (1955) goes further to propose a complete form of cognitive organisation in which simple descriptive beliefs, such as 'sweet–salty', are integrated into a framework which can also include a belief in democracy.

There is a significant body of experimental evidence that social value orientations do significantly influence (e.g. Seligman *et al.* 1994; van Liere and Dunlap 1981) people's beliefs and attitudes. An attempt to explore the nature of the motivations which determined respondents' preparedness to pay for improvements in river water quality (Green *et al.* 1990) found very strong support for the statement 'it is a moral issue; we ought not to pollute'. In subsequent studies, a series of 42 statements were developed to explore the nature of the motivations that motivated people to be prepared to pay for the supply of public, collective goods

Table 4.4 *Optimistic utilitarianism*

Statement	Mean	Standard deviation
If we kept on worrying about the future, nothing would ever get done	2.8	1.9
You learn more about plants and animals from watching them on television than from seeing them yourself	2.9	2.1
I am fascinated by machines and technology	3.4	2.0
Scientists are the only people who know the facts	3.6	1.9
Change is nearly always for the better	3.6	1.6
Life in this country is improving all the time	3.7	1.7
Scientists will always be able to find a solution to a problem	3.7	1.6
Politicians can be trusted to take care of the environment	4.6	1.7
There is nothing to do in the country	4.8	1.6
Cronbach's alpha = 0.63	$n = 542$	
Scale mean	39.3	9.1

Scale: 0 = strongly agree; 6 = strongly disagree.
Source: Green and Tunstall 1996.

Table 4.5 *General environmental value*

Statement	Mean	Standard deviation
I like to be in the open air	0.7	1.2
We owe a duty to our children and grandchildren to take care of the environment	0.8	1.6
I love the peace and quiet of the countryside	0.8	1.4
I want my children and grandchildren to see and enjoy those things I enjoyed as a child	0.8	1.2
We owe a duty to animals and nature, they don't exist just for our enjoyment	0.9	1.4
The Earth and Nature are fragile, and we can easily cause irreversible damage	1.1	1.6
We have a duty to other people as well as to our families	1.1	1.4
We have no choice: we have to protect the environment or we will destroy the human race	1.1	1.5
The countryside is important for recreation	1.2	1.5
It is important to understand the past	1.3	1.5
We should live in harmony with nature even if it means sacrifices on our part	1.4	1.5
Cronbach's alpha = 0.89	$n = 542$	
Scale mean	13.0	11.9

Scale: 0 = strongly agree; 6 = strongly disagree.
Source: Green and Tunstall 1996.

(Green *et al.* 1992). Cluster analysis yielded three groups of statements which were readily identified as:

- optimistic utilitarianism (Table 4.4);
- general environmental value (Table 4.5);
- moral pessimism.

The statements that cluster on the general environmental scale notably include statements that refer to duties and not simply to wants: 'We owe a duty to our children and grandchildren to take care of the environment', 'We owe a duty to animals and nature, they don't exist just for our enjoyment', and 'We have a duty to other people as well as to our families'.

We have found that there are significant associations between scores on these dimensions and the memberships of societies and pressure groups, the features desired of a river corridor and the choice of leisure visits (Green and Tunstall 1996). Table 4.6 illustrates that there are significant differences in the importance given to features of nature reserves when considering whether they should be protected from coastal erosion.

Finally, Hardin's (1968) provocative paper generated two lines of research; the first to establish why a Commons regime did not collapse in the way he appeared

Table 4.6 *Beliefs about the relative importance which should be given to different factors in determining which nature reserves should be protected from loss through coastal erosion (Pearson's product moment)*

	GE	Mean score	OU
It contains wildlife or plants that are disappearing in the UK	+	4.6	
It includes a very rare species of wildlife or plant		4.3	
It includes a natural landscape rather than a manmade landscape	+	4.1	
The wildlife or plants it contains have always been rare in Britain		4.1	
The variety of wildlife and plants it contains		4.0	
The wildlife and plants it contains are typical of the countryside as it used to be	+	3.9	
There are no other sites like it locally		3.8	
The reserve contains a large proportion of the plants and animals of that kind in the UK		3.8	
It contains wildlife or plants that are attractive to look at	+	3.5	
The amount that there is to see when visiting		3.2	+
The number of visitors to the site		2.7	+

Scale: 1 = strongly disagree; 5 = strongly agree.
Key: GE: general environmental scale score;
OU: optimistic utilitarian scale score.

to predict (Cox 1985; Feeny *et al.* 1990), and secondly experimental studies by psychologists. The latter work, social dilemmas theory (Dawes 1980; Kopelman *et al.* 2000), has explored the extent to which people are prepared to cooperate in groups and the allocation rules adopted by individuals in such groups. This work has shown that individuals consistently allocate a substantial proportion of resources to the group rather to themselves as individuals (Batson *et al.* 1995); co-operative action seems to be the expected norm, with individuals contributing 40–60% of their endowment in the game to the common good. This is too much for neoclassical economic theory but it is also too little to maximise the gains to the experimental group as a whole. Sally (1995) found that allowing face-to-face communication increases co-operation by 45% – in the majority of the social dilemmas studies, individuals are only allowed limited written communication with each other. A similar effect has been found when the individuals in the experimental group are told that they have been selected from a wider group with whom they share some identity or interest.

Thus, choices involving the provision of public, collective goods could be expected to involve a rich mixture of:

- What we personally would like.
- What we believe ought to be and what society therefore ought to choose.
- How we believe that a society should choose.

- What we believe should be the relationships between individuals and groups.
- What we believe that other people will expect that we will do.

In turn, we lack a grounded economic theory of collective choice. This can be seen as one aspect of the lack of any economic explanation for the existence of societies, a rather profound omission given the resources that have been committed to the establishment and maintenance of societies.

In carrying out economic analyses, this omission is less disastrous than it might appear. It does mean that in carrying out such analyses the emphasis must be upon exploring how people are approaching the choice, and how they believe it ought to be made, rather than fitting the study into textbook economic theory. Such studies will almost inevitably be based upon the use of expressed preference evaluation techniques, those based on social survey methods (Section 12.2.3), and consequently it is possible to build up the necessary understanding through the use of both qualitative (Krueger 1988) and quantitative methods. Whittington (Lauria *et al.* 1999; MacRae and Whittington 1988; Whittington 1996) has undertaken a number of such studies which illustrate the richness of the material that can be generated if we listen to what people are saying. Similarly, when Burgess (Burgess *et al.* 1997) interviewed people who had recently participated in a CVM study, they reacted with horror when told that the amounts they said that they would be prepared to pay would form the basis of the decision as to whether to preserve the area.

What is necessary to ensure in such studies is that people are prepared to pay real money and put in the context of making a real choice; providing that those conditions are met, it is less important why they are prepared to pay. What I suspect is happening is that people first consider whether they have a responsibility in regard to the issue in question as only then should they be prepared to consider paying at all. Secondly, they consider whether the proposed change is desirable both in social and individual terms. Then, thirdly, if they consider that they have a responsibility and that the change is desirable, then they will decide how much they are prepared to pay. In turn, this means that whether or not someone is prepared to pay is considerably more important than the amount they are prepared to pay, and a refusal to pay is quite different from a preparedness to pay a zero amount. Thus, if a vegan were asked how much s/he would be prepared to pay in order that each school child should receive a free glass of milk each day, the vegan will refuse to pay and object strongly to the proposed programme on principle.

The more difficult problem is that of interaction; if Tannen is right even in part that there are some people of either gender who expect decisions to be taken after discussion, then either discussion needs to be included as part of the process of determining whether or not people are prepared to pay and how much they are prepared to pay, or the results of such discussions need to be used as feedback to those taking part in the expressed preference study.

5

Dimensions of Choice

Although it is said that we cannot compare apples and oranges, choice is the one thing at which we are good. Offered an apple or orange, few people are unable to make the choice between them. Choices necessarily are comparative because we must choose between alternatives. In turn, this means that it always the differences that are important where the differences are between the performance of the different options against the different objectives, or more simply in their consequences, or between the stakeholders in terms of their preferences between the options.

Choices, to a greater or lesser extent, involve comparing alternative options that differ in terms of who experiences what type of consequence and when that consequence is experienced. 'Who', 'what' and 'when' are then the basic dimensions of choices and in choosing between the different courses of action open to us, we have somehow to compare those options across these three dimensions. To make this comparison, we can adopt formal strategies and these have the advantage of being explicit and open to argument. Alternatively, an implicit comparative strategy may be used in making the choice even if that strategy is to ignore the differences.

Not only is choice comparative, it is also relative: differences between the options must be estimated from some baseline. The two basic options are to take the situation now as the baseline or to seek some zero point as a baseline. What is fundamental is that the analysis informs the choice; in turn, this means it must be directed to the nature of conflicts that require the choice to be made.

5.1 How

To compare the perhaps widely different impacts from the different options, some implicit or explicit numeraire or yardstick is necessary. In conventional economic analyses, this yardstick is money. Because money fulfils many roles in economic analysis, there is a danger of confusion. In benefit–cost analysis, money is used solely as a yardstick, by which to compare the value of different things to different people. In using it in this restricted sense, nothing is being

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said or implied about money as a medium of exchange or as capital. In addition, value is conceptually distinct from both cost and price; using some quick intellectual footwork or perhaps sleight of hand, it is possible, as discussed earlier (Section 3.2.3.1), to define conditions under which they will all coincide. But, conceptually, value is not the same as either the cost or the price of something: how much I want something, how it contributes to the achievement of one of my objectives is quite different from how much it costs me or its price. Indeed, it may not even have a price.

Money is used as a numeraire instead of the thing that economists would ideally like to measure, utility, because it is held that the utility that one individual gains from a good cannot be compared to what another individual will gain from the same amount of that good. In addition, money has had the advantage that when economics was effectively limited to the study of exchanges in the market, money transactions could be easily observed whilst estimating utilities would have required doing some work.

Using money as a numeraire has two obvious disadvantages: different people have different amounts of money available to them and it is assumed that the marginal utility of money also decreases. Thus, measuring value using money is rather like measuring length with a spring. To get around the first problem, the assumption is made that the existing income distribution is optimal. Irrespective of the merits of this claim in general, in many parts of the world, women have only limited access to a household's cash resources (Haddad *et al.* 1997). Given that water and sanitation often provide more benefits to women than to men, and women often lack access to the cash resources of the household, the values ascribed by men for water and sanitation are likely to be distorted and the benefits of water and sanitation underestimated.

As a yardstick, money is also limited in its range of application. As a surrogate for utility, difficulties arise when one or more objectives are involved that do not relate to utility. Achieving either personal moral objectives or those objectives relating to interpersonal relationships does not contribute to utility but their achievement does usually require the commitment of resources. Similarly, where the choice is necessary because of a conflict of objectives or because we disagree as to the importance that should be given to different objectives, then money ceases to be useful. In the latter case, we will necessarily need to argue, negotiate and debate our objectives. In these cases, multi-criteria analysis (von Winterfeldt and Edwards 1986) can be used (Chapter 13).

5.1.1 Values

The three critical characteristics of value are:

- It measures the contribution of some proposed action towards the achievement of an objective, or, rarely, the value in itself of some resource or good;

- It is, therefore, necessarily a desirable consequence of undertaking that action; and
- It is measured by the difference from the baseline case.

As we have seen, an action has as many values as there are independent objectives brought to the particular choice. Conventional economic analysis can, however, only compare the alternatives against the single objective of economic efficiency and multi-criteria analysis whenever multiple objectives are involved in a choice. Whilst the above three points also apply to the assessment of values in multi-criteria analysis, the following discussion is specific to economic analyses.

5.1.1.1 Use value

Conventionally, economic value is held to have a number of different possible components. Use value, the value of the action of accessing, consuming or otherwise using a good, is the most obvious component of value. Where a good is priced then the price can be used as the basis for assessing value although almost invariably (Belli *et al.* 1997) the observed prices need some correction before they equal those that would be found in a hypothetical perfectly competitive market.

Where goods are not priced, such as recreation, then things become more difficult and the possible methods of inferring or deriving the value of such goods are summarised in Chapter 12. With all goods, the question that the economist is asking is: what other good would you sacrifice for this good? The essence of economic value is what is the most valuable thing that you would give up in order to get this good? But we have seen that not everything that has a value also has a price and hence the most valuable thing that someone would be prepared to sacrifice for a good may not have a price. For example, in a fire, faced with the choice of whether to save your child or a Rembrandt painting, only the socially deviant will save the Rembrandt. Whilst the Rembrandt has a price as well as a value, the value of the child exceeds that of the Rembrandt although it does not have a price. In this instance, the price of the object that must be sacrificed is irrelevant to the choice since by definition the value of a child exceeds that of any object. We cannot then infer anything about the value of the child from the price of a Rembrandt.

Similarly, we have seen that there are four different streams of consumption contributing to the utility of a household: from consumer durables that are unpriced at the point of consumption, consumption priced at the point of consumption, unpriced consumption from the natural endowment, and from collective services paid for through taxation or other means. It is consequently quite possible that the most valuable form of consumption that the individual would be prepared to sacrifice for one unpriced good is another unpriced good. Secondly, if we were to introduce a charge for a good that is currently unpriced then the utility level of the household would necessarily have to fall; the quantities of priced goods consumed would also have to fall. In turn, if enough households were involved, the consequent fall in demand for priced goods would mean that their prices should also fall (provided that there are diseconomies of scale).

In turn, this means that great care must be taken in seeking to derive monetary values for goods that are currently unpriced. We cannot, for example, derive a value for walks by a river by asking people how much they would be prepared to pay for the walks they take at the moment.

5.1.1.2 Option value

An option value is defined as the value of holding open the opportunity to make use of a good at some future point in time although the individual makes no current use of that good. For example, in developed countries, some agricultural land would almost certainly presently be more valuable in other uses than agriculture, particularly environmental uses. However, given the uncertainties about the impacts of climate change and the future in general, there is likely to be an option value associated with avoiding the conversion of agricultural land to uses that preclude its use as agricultural land in the future, or its reconversion to agricultural land only at high cost. Similarly, I might attach an option value to the maintenance of a specialist cancer unit against the possibility that I may develop cancer at a later date.

5.1.1.3 Quasi-option value

Effectively, quasi-option value (Henry 1974) is the value of the information gained by not taking action now but spending time assessing in more detail the consequences of taking the action.

5.1.1.4 Functional value

The environment provides a number of obvious resources to the environment and other equally obvious forms of consumption, notably recreation. All are unpriced although the acquisition of those resources may incur a resource cost: thus, wild fisheries are free but there are costs attached to catching the fish. Some of the environmental resources are less obvious: common land traditionally provided a wide variety of resources including fuel wood, construction materials, materials for weaving, fish and game as well as water. Equally, some parts of the environment are necessary to support other parts of the environment which produce resources that are directly useful; the areas where fish breed are not necessarily where those fish are caught. Thus, to yield a resource that is useful to humans, a functional ecological web may need to be maintained where the loss of one part of that web results in breakdown of the system as a whole. Thus, Weston (n.d.) argues that the trees of the Canadian forests depend for supplies of trace minerals on the migration of salmon which are then eaten by bears who then excrete the trace minerals.

Table 5.1 *The functional value of saltings*

Width of saltings (metres)	Height of seawall (metres)	Cost of seawall (per kilometre)
80	3	400 000
60	4	500 000
30	5	800 000
6	6	1 500 000
0	12	5 000 000

Source: Dixon, Lagget and Weight 1998.

De Groot (1987) introduced the term 'functional value' to refer particularly to these indirect functional values but more widely to cover the whole range of unpriced support services provided by the environment. The problem for the analyst is then to identify the nature of the support services provided in particular circumstances. For example, Table 5.1 summarises how the cost of providing a seawall to protect the land behind from coastal erosion and flooding varies according to the width of saltmarsh in front of the wall. Similarly, if an aquifer were to be polluted, then alternative means of collecting and storing rainwater for human use would be required. For wetlands in particular, a great deal is now known about the services provided by them (Maltby 1986).

5.1.2 Nonuse value

In Section 4.3, I argued that we have a lack of grounded economic theory as to how we both approach societal choices concerning the provision of collective goods and we lack an understanding as to how people believe that such choices should be made. This problem becomes sharpest when we have to analyse choices involving environmental resources. It is clear that we value the environment for other reasons in addition to any current or future use that we may make of it. This value and the associated preparedness to pay towards the cost of preserving these resources extends to quite remote areas. In the entrance to the Centre of the Forest Park Friendship in eastern Finland, there is a row of transparent collection boxes for visitors' contributions; Figure 5.1 shows the amounts collected over one period. The Saimaa seal is an indigenous species that is under threat, which probably accounts for the greatest amount being donated towards its preservation, but conserving the Amazonian rainforest attracted a nontrivial amount, although Kuhmo is several thousand kilometres away and the centre of an important old growth forest.

This additional value has variously been termed 'passive use', 'existence' or 'nonuse' value. Of these labels, the latter is to be preferred because the only thing that we can be confident about is that it is not use value. From Krutilla (1967) onwards, economists have speculated as to the nature of the motivations that create this value; for example, that we value the environment because we

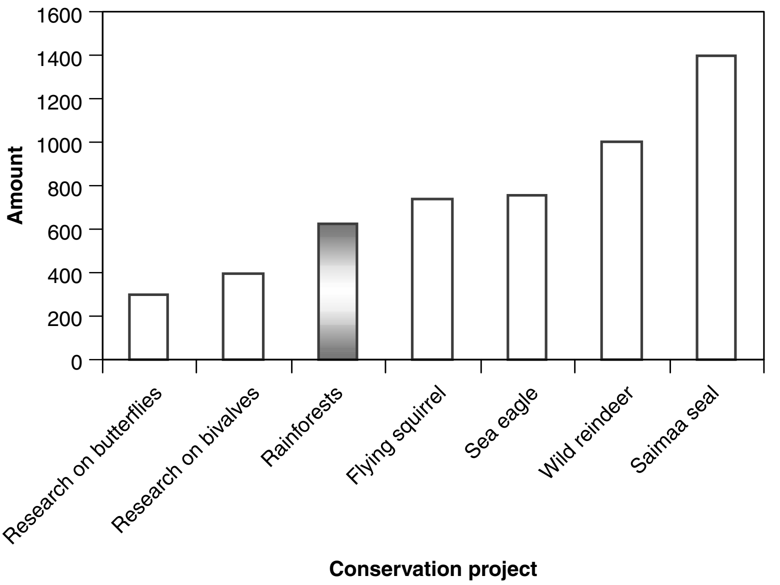

Figure 5.1 *Donations at the Centre of the Forest Park Friendship, Kuhmo. Source: Mantymaa 1996*

want to bequeath it to our descendants. But the motives that have been put forward are strictly speculative and not based upon any empirical evidence. We know that people do value the environment but we do not know why. Although we have a number of hypotheses, there is very little empirical evidence (Croke *et al.* 1994; Green and Tunstall 1996; Spash 1997) as to why people value these environmental resources.

If we do not know why people place such a value on environmental resources, we do not know what it is they value. In turn, if we do not know what and why people value something, it is difficult to claim and more especially to demonstrate that we have derived a valid and reliable measure of that value. This obviously leaves us with a major problem. The practical way forward is then to derive a preparedness to pay for the environmental good, and to assume that this is made up of two components: use plus nonuse value. If we derive preparedness to pay values (Section 12.2.3) for users and nonusers, then the difference in the two values should be the use value, nonusers only offering an amount equal to the nonuse value. This, of course, assumes both that preparedness to pay is given by the sum of use and nonuse value and that those who do not use the resource have the same nonuse value as those who use the resource.

It is, however, more important to try to discover what it is that people value and why they value it. In practice, the values people place upon environmental resources seem to involve three different factors:

- response to public, collective goods is different to that for individual, private goods;
- choices about environmental resources frequently involve moral issues; and
- there are cognitive issues relating to the nature of the good in question.

5.1.2.1 Public, collective goods

I discussed earlier why people might both approach choices about the provision of public, collective goods in a different way to that in which they approach choices about private goods, and also believe that society should make choices in a different way. There is suggestive evidence that they do approach such choices in a different way.

House *et al.* (1994) undertook a contingent valuation study of the value of alleviating low flows in a number of rivers. After being asked whether or not they were prepared to pay to alleviate the existing low flow problem, and then how much they were prepared to pay, respondents were asked which of a number of factors were important in these decisions. Table 5.2 shows the principal components factor analysis of the results. What is significant here is that the statement 'Your household's fair share of the costs' loads on to the affordability dimension and not on the value dimension where neoclassical economic theory would imply that it ought to be: that is, what it is fair for me to pay is its value to me. In turn, the statement about what would be fair was included because when the respondents in the studies by Marwell and Ames (1981) were asked how they decided how much they were prepared to pay, the common response was that they tried to decide what it would be fair to pay. This tends to suggest that people offer what they see as a fair contribution towards the cost of providing such collective goods if they believe that they have both a responsibility to do so and its provision is desirable.

Table 5.2 *Factor analysis of importance of reasons respondents gave as to why and how much they were prepared to pay*

Reason why people were or were not prepared to pay and how much they were prepared to pay	Factor 1 (affordability)	Factor 2 (value)
The other things upon which you would like to spend more money	4.1	
What your household could afford to pay	4.5	
Your household's fair share of the costs	4.3	
The value to you of the improvements to rivers as a place to visit		4.1
The value to wildlife of improvements in water quality		4.6
Explained variance	45.8	24.9

Source: House *et al.* 1994.
Key: 1 = not important; 8 = very important.

5.1.2.2 Moral issues

Choices about environmental conservation and other issues seem not infrequently to be understood in terms of tests of how good we are. How good we are is one aspect of who we are and how we relate to one another. Suppose that a very large oil reserve was discovered in the UK that would increase its GDP by 20% for the next 20 years. Unfortunately, for geological reasons, the only possible location for the oil well head is the area currently occupied by Westminster Abbey. The construction of the Abbey was started some 1000 years ago, and it is the traditional site of the coronation of British monarchs and other similar national occasions. Some 20 monarchs are also buried there along with major writers. So, too, is the Unknown Warrior, who honours those who died fighting for the country in the two World Wars.

It would be quite easy to calculate the use value of the Abbey in terms of tourism (e.g. Willis *et al*. 1993) and many economists would also be prepared to estimate the nonuse value. It would therefore be possible to determine whether, in economic efficiency terms, the Abbey should be demolished and the oil extracted; and, equally, whether it would be worth reconstructing the Abbey on another site.

However, I doubt whether any government or the board of any oil company would wish such an economic analysis to be done because of the way in which the public would then understand the government or oil company. The Abbey symbolises the country's history, culture and identity; how we then treat the Abbey is a message about how much we respect that culture and identity, and by extension, each other. In particular, those who died in war may have had many motivations, from simple patriotism to a desire to protect democracy and freedom; the one motivation that none will have had is to enable future generations to be somewhat richer. To contemplate such an analysis would then convey a clear message that achievement, or to die for one's country, is as nothing to being richer.

The above examples are all apparently quite clear-cut; the complications set in when the choice is as a moral aspect or some people see it in moral terms. The problem is then to recognise when for some people at least the question is one of moral principle and not one of economic efficiency. When this occurs, we are faced with a disagreement about objectives and other techniques, such as multi-criteria analysis, will be more helpful in the debate than applying economic analysis.

5.1.2.3 Cognitive issues

When considering nonuse value, the good in question is frequently very abstract and certainly complicated, involves a complex relationship between the whole and the part, and not infrequently involves a good that has a high symbolic value, most obviously the giant panda and, for the USA, the bald eagle. In the UK, salmon and otters have the same symbolic importance as the Saimaa seal has in Finland. In part, their presence defines the degree to which the environment is unspoilt but their presence or absence also tells us how good we are. In turn, before the question was raised, it may be that we had not heard of the good at all.

We can construct our preferences in one of two ways: working from the part to the whole, or from the whole to the part, from the general to the particular. We can wish to preserve the giant panda because we are in favour of preserving giant pandas and in turn we become in favour of preserving some or all species. Alternatively, we can be in favour of preserving the giant panda because we are in favour of preserving nature. In either case, a critical question is: what is the relationship between the part and the whole? It should not be assumed that we construct our preferences from parts and that the whole is simply the sum of these parts (Green and Tunstall 1997). Indeed, the evidence from studies of cognition suggests that this is not how we work at all (Lakoff 1987; Rosser 1994). Nor would it be a very efficient way of operating in a world of very imperfect information. Finally, the world itself is often complex so that, for example, preserving the giant panda necessarily requires preserving the entire habitat upon which it depends. These issues are then crucial when we ask people to put a value on some good using expressed preference techniques (Section 12.2.3). If we do not understand how people understand the world, how they structure it, there is a risk that we will ask an entirely meaningless question.

5.2 Who

However widely or narrowly across the species the boundary is drawn, any course of action can be expected to result in some gainers and some losers as compared to the present situation. Since neoclassical economics is concerned solely with the net effect on the nation, it has nothing to say about how these gains and losses are shared out. The only issue of concern is whether the total of gains exceeds the total of losses. The basis for the adoption of the benefit–cost ratio and net present value criteria in economic analysis is that those who gain make sufficiently large gains that in theory they could fully compensate those who lose and still make a net gain if the project goes ahead. This is the ‘potential Pareto improvement principle’, or the ‘Hicks–Kaldor compensation principle’.

In turn, this means that an option that results in gains to those are already wealthy and losses to the poor will be preferred to another option where the distribution consequences are the opposite if the net gains of the first option exceed the net gains from the second option. Applying distributional weights has therefore been proposed (Howe 1971); two difficulties are then in deciding what those weights should be and who should determine them. Conversely, economists have routinely argued against using projects to bring about desirable redistributions of income on the grounds that tax and benefit systems are more efficient ways of achieving that end. Equally, in the neoclassical economic model, it does not matter who pays for the project and most projects involve transfers of funds from

Table 5.3 *Possible distributional outcomes*

National net benefits	Local net benefits	
	Positive	Negative
Positive	Win-win situation	Transfer sufficient of national gain to local area to make local net benefits positive
Negative	Project may be justified in terms of social/economic development of the area. Alternatively, the project should be locally funded	

Source: after Green, Parker and Tunstall 2000.

central government to the regional or local area. Those transfers themselves may be negative as, for example, if the revenue from a regressive form of taxation is used to finance a project whose primary beneficiaries are already relatively wealthy by national standards. There is, therefore, a need to examine who gains and loses through a project with attention obviously being given to the effects of the project on those who are already disadvantaged. In turn, there are three possible outcomes of a project (Table 5.3) where 'local' applies to the local area and also to specific groups within the area affected by the project's construction and operation. The obvious proposal for outcomes that fall into the top-right cell is to ensure that local benefits now balance local costs (WCD 2000).

5.3 When

All decisions involve consequences that occur at different points in time and, therefore, implicitly or explicitly some basis for comparison is made. A virtue of benefit–cost analysis is that a formal, explicit approach is adopted. Where there is no such formal approach there is an obvious risk that an inconsistent approach will be adopted; one which involves errors simply as a result of human error. It is difficult to establish such a formal logic in multi-criteria analysis.

5.3.1 Discounting

The rationale for adopting discounting in benefit–cost analysis is two-fold. Firstly, it is assumed that we prefer consumption now rather than later and equally that we would prefer to put off making expenditures. Secondly, since the investment required for the project precludes those resources being invested elsewhere in the economy, it is obviously desirable not to undertake the project if those resources could generate a higher return if invested elsewhere in the economy. Unfortunately, the first argument does not lead to the adoption of discounting and there are major problems in applying the latter approach. Both arguments use money capital and income as a metaphor but with the danger of confusing the metaphor with the reality.

5.3.1.1 Time preference

The first rationale for discounting is the assumption that we have a preference for consumption now rather than later: a time preference. Economists frequently attempt to demonstrate that we have such a time preference by use of a technically incorrect argument; by asking whether someone would prefer £100 today or next year. However, the argument for time preference is about a preference for consumption in time and £100 is both capital, and hence can generate an income, and also potential consumption which can be taken at any time in the future. The concern instead is strictly with consumption. Thus, for example, a technically correct offer is one of £100 of additional consumption to be taken over the next year, or £100 of additional consumption to be taken over the year starting in one year's time. As it is consumption, it is a 'Brewster's millions' offer: it can only be spent on consumption and cannot be used to acquire any durable that would provide consumption after the end of the year, nor held as money capital to provide an income after the end of the year.

The distribution of potential consumption over time is given by plotting the net benefits from the project against time over the life expectancy of the project. Discounting then gives a weighed measure of the area underneath the curve. Moreover, for any one discount rate, there is an infinite number of curves beneath each of which the weighed area will be the same. Therefore, if we assume that we have preferences only for the area beneath the curve and none about the shape of the curve, does discounting provide a basis for preferring one curve to another (CNS 1992)? The arguments concerning intergenerational equity (Goodin 1982) are then simply a specific instance where it is proposed that we ought to have preferences for curves of one shape over other shapes. It follows that if we do have any preferences as to the shape of the curve, then these cannot be taken into account by the adoption of any discount rate.

Thus Figure 5.2 (DEFRA 1999a) shows three project options. If we rely on the discounting rule, the choice between the options is dictated by the discount rate applied (Table 5.4).

Given the discount rate adopted in the UK at the time of writing, then we should adopt option 1. In practice, most people asked prefer option 2 although some engineers have a preference for option 3 on the grounds that the need for substantial further investments at different points in the project's life gives the option of abandoning or at least rethinking the project at those times. Since discounting does not address the issue of our preferences for the distribution of benefits and costs over time, all that can be done is prepare plots of the form shown and then prepare a reasoned argument for the adoption of one option over another where the option preferred may have a lower net present value (NPV) than the other options (DEFRA 1999). Because this is an issue of preferences,

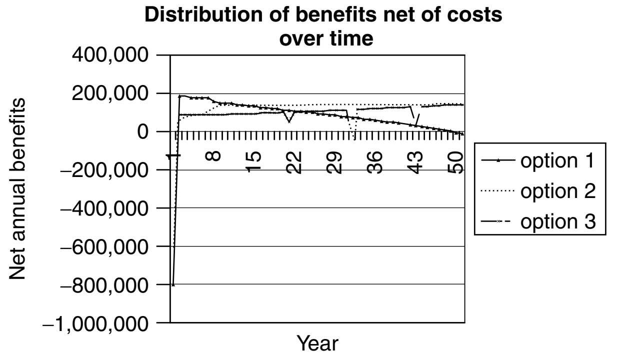

Figure 5.2 Net benefits over time

Table 5.4 Option to be preferred at different discount rates

SUM	Option 1 3 899 505	Option 2 5 990 465	Option 3 5 033 415
NPV (2%)	2 634 504	3 393 392	2 973 244
NPV (6%)	1 319 490	1 237 902	1 308 474
NPV (10%)	694 597	458 903	720 156

or value judgements, there is no technical rule that can be provided to determine what this choice ought to be.

5.3.1.2 Opportunity cost of capital

Using the analogy of money, the argument for applying a discount rate that reflects the opportunity cost of capital is quite straightforward. The two practical problems in applying the opportunity cost of capital approach are:

- What is capital, and
- What is the economic return on capital in other uses?

If we think solely in terms of money, then the logic of the approach is obvious; given two savings accounts offering different interest rates, but otherwise identical in all respects, then we will choose the savings account offering the higher rate of interest. However, money capital and income can be seamlessly substituted for each other; the income from the savings account can be reinvested or spent on consumption, or the capital can be drawn at any time for consumption. What is important is that at the end of the period, we still have the capital.

What is capital? It was argued in Chapter 3 that the only forms of Hicksian capital that exist in physical terms are elements of the natural endowment;

Table 5.5 *Potential substitutions between resources*

	Loss		Gain	
	Now	Future	Now	Future
Priced consumption	•	•	•	•
Nonpriced consumption	•	•	•	•
Production durable	•	•	•	•
Depletable, nonrenewable resource	•	•	•	•
Depletable, renewable resource	•	•	•	•
Nondepletable, nonrenewable resource	By definition, cannot occur			
Nondepletable, renewable resource	By definition, cannot occur			

specifically, that production durables are not capital. Secondly, the advantage of money capital is that it can be converted into income which can be taken as consumption and money income can be converted into capital. No such seamless substitution between capital, income and consumption is possible for all capital resources. Instead, there is a wide range of substitutions that may be implied by an action (Table 5.5). Thus, for instance, we may need to compare a reduction in a depletable, nonrenewable resource now against a gain in non-priced consumption in the future. It is not a self-evident truth that the rate of return on money capital has anything to do with the rate at which we should be prepared to make the trade-off between the capital resource and non-priced consumption, or indeed that the rates of substitution between any pair of gains and losses should be identical with any other.

What is the opportunity cost of money capital? The obvious place to look is at the rates levied on borrowing capital in commercial markets, or at the return on capital that can be earned by legitimate commercial activities. Taxes on profits have to be taken out so that the after-tax return is used. Equally, it has been argued that governments have a large enough investment portfolio that the risk-free rate should be used (Arrow and Lind 1970). Thus, in the USA, the rate at which the government can borrow money is used as a measure of the opportunity cost of capital (US Water Resources Council 1983). However, this rate depends upon what that capital could earn if put to commercial purposes and the financial rates of return in commercial investments require similar adjustments to those that have been proposed for the gross domestic product (Section 3.1). If investments in the commercial sector can export externalities to consumers then the commercial return is above the true economic return. The exact distribution of externalities is, however, unknown but it does not seem unrealistic to conclude that the flow of negative externalities is predominantly to the consumer, or to the consumer in their other role as a tax payer. Therefore, we cannot simply use the after-tax rate of return on commercial investments as the appropriate discount rate.

If those investments can export externalities abroad then from the narrow national perspective, the return on capital need not be adjusted downwards. It may be immoral and may cause international friction but unless the result is to require an increase in defence expenditure, no adjustment need be made to the opportunity cost of capital. It can be argued that externalities imposed upon other commercial sectors will tend to cancel each other out but the rate we require is the marginal cost of capital; the investment that will be displaced by the proposed investment. However, we might expect that the lowest returns on capital are earned in those commercial sectors where other commercial activities have been most successful as treating as a sink for externalities and which are least successful themselves at imposing externalities on other companies.

The next problem is that we have to assume that the current allocation of capital is optimal between public investment and private investment before we can determine what that allocation ought to be. We are seeking, for example, to determine what is the opportunity cost of capital to be employed in constructing a hydroelectric plant by looking at the return from companies manufacturing air-conditioning equipment and televisions. A similar problem arises if we seek to determine the opportunity cost of capital to be used to improve navigation from the return on capital from transport firms. In general, government investment is in the upstream side of the economy: in transport and other infrastructure, R&D, education and skills provision. The returns to the commercial sector depend heavily on the prices charged to them for these provisions.

If the commercial side of the economy is not being charged the full cost of these provisions then the return on capital in the commercial side of the economy is artificially inflated. Similarly, if parts of the commercial economy are subsidised, as is typically the case for agriculture, then the returns on capital in those areas are also artificially inflated. In the case of agriculture, the returns on capital in associated industries such as seed, pesticide and fertiliser producers, as well as by food processors and retailers, will also tend to be artificially inflated.

Finally, the analogy is with money capital; so, at the end of the period assessed, we require either to have the capital intact or to have generated a sufficient excess return to replace the money capital. For example, a dam will eventually fill with sediment and cease to have the capacity to store useful amounts of water. Similarly, a water main will require replacement at some future date. We can approach this issue in one of two ways: we can extend the time horizon so as to include replacements of physical plant, or adopt a time horizon at the end of which all of the capital is recovered and include an annual payment into a sinking fund to accumulate the necessary replacement capital at the end of the project's effective lifetime.

Consequently, estimating the economic opportunity cost of capital is fraught with difficulties. Given that the three drivers of growth, other than drawing down on capital, are reinvestment in production durables, R&D and education, it is not unreasonable to expect the economic opportunity cost of capital to be related to the growth rate in the economy.

In turn, the argument sometimes proposed that since the regional growth rate is higher than that for the nation as a whole, then growth factors should be applied to the streams of benefits is the obverse of the correct argument. Where regional growth rates are higher than for the nation as a whole then the regional opportunity cost of capital is higher than the national average and so a higher discount rate should be used for projects in that region. In general, it is more conservative to assume constant real prices over the lifetime of the project but where a growth factor is used for one stream of benefits or costs, then growth factors must be applied to all streams of benefits and costs. In addition, since an expectation of growth is built into the discount rate, all growth factors are relative to this assumption and it follows that for some streams of benefits or costs, the correct growth factor is negative.

In practice, the discount rate is more realistically set as a capital rationing device and by being set in this way, creates its own truth. If a project is not viable at the designated discount rate, then almost certainly there is some other project that is viable.

6

Choosing What?

Whilst choices must be made between alternatives, the economist is primarily concerned with three areas of choice:

- between different forms of consumption;
- between different patterns of production and resource usage; and
- between consumption and investment.

6.1 Starting or Stopping

There are two quite different potential rules for decision making:

- Where to start; what should we do first?
- Where to stop; what should we do last?

Neoclassical economics is centred on the idea of optimality: a 'stopping' rule. However, in practice, the issue is usually one of where to start: what should we do first? In the case of project prioritisation and policy evaluation; is this the best use of resources this year? It is thus a question of priorities. It is also a question of prioritisation over time since next year there will be another tranche of resources available; whilst we have to make the best use of the labour available this year, next year there will be more labour available. Unfortunately, we cannot, of course, use any of next year's labour this year although our decisions this year may involve resource commitments in future years.

What we decide are the priorities this year equally have no force for next year; our priorities may have changed and we will, in any case, have undertaken the highest priority projects this year so that next year the available resources can be allocated amongst the remaining lower-priority projects.

The economic approach is to determine priorities on the basis of the benefits and costs associated with each of the options being considered. Individual consumers are presumed to choose their consumption by comparing the marginal value and cost of each of the available consumption options. Values and thus willingness to pay determine priorities. Similarly, in benefit–cost analysis, for a single project, the benefits from the options are compared to the costs of those options, and the option with

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the highest ratio or net present value is chosen as is appropriate (Section 13.4.7.1). For a programme of works, that combination of individual projects which yields the highest benefit–cost ratio for the available resources is selected.

Starting and stopping rules converge to the extent to which the overall economy is close to efficiency at present and there is free movement of resources between sectors. In an inefficient economy, and one where resource allocation to public investment is constrained by macroeconomic concerns, then the resources available may restrict the projects which can be undertaken to those high on the priority list. More generally, for the efficient level of public investment to be achieved, the tax taken from private investment and consumption must be equal to the efficient level of public investment. Taxation levels are unlikely to be set either in this manner or with this effect; thus, less or more resources are likely to be available for investment than are appropriate for efficiency to be achieved.

There are a number of problems with the optimality approach and it probably should be dropped altogether. Firstly, where we should stop is a moving target: what we want is liable to change over time, as are the relative costs of the different options. Not only may the value of pollution abatement increase next year but so too might the marginal cost of pollution abatement. Given that programmes of capital expenditure for water management often take 20 years, it is very unlikely that what is optimum now will still be the optimum in 20 years' time.

Secondly, it also requires that we know all values and know them precisely; that we do not is the one thing about which we are certain. We have seen that economic value refers to only one objective and hence is only one value amongst a number. Furthermore, we cannot be precise even about the present and seeking optimality is precisely the wrong approach to making choices when we know that we are uncertain.

Thirdly, the concept of optimality also leads us into problematic concepts such as that of an optimal level of pollution. Douglas (1966) has argued that the label of 'pollution' is one that defines an activity as a moral wrong and consequently we can no more talk of an optimal level of pollution than of child abuse or murder. However, defining an issue in moral terms does not release the resource constraint; we lack sufficient resources to remove all moral ills even if some issues did not involve fundamental conflicts between moral values. But faced with a series of moral wrongs, it is reasonable to ask which should we tackle first. Thus, for example, in assessing the Greater Cairo Wastewater Project rather than seeking to determine what was the optimum level of pollution of the agricultural drains, and hence whether the investment in secondary and tertiary treatment was justified, it was possible to ask whether the pollution of the agricultural drains was the most urgent pollution problem facing the country (Surr *et al.* 1993).

Usually, the fundamental question we face is: how to make a better decision about where to start. At the same time, we need to determine both policies, at a national or regional level as well as at a catchment level, and to determine the best option for implementing that policy in a specific cases.

7

Costs

Costs can be defined in two overlapping but not equivalent ways: as the inputs to an activity and as the undesirable consequences of undertaking that decision. The two definitions are not equivalent because some of the consequences of an activity, the outputs, can be undesirable (e.g. negative externalities).

The four key characteristics of costs are:

- The cost of using a resource for some purpose is given by the value of that resource if used for the best alternative use ('opportunity cost');
- Costs are measured as the difference from the baseline ('marginal costs'), if there is no difference, there is no cost;
- Costs are always in the future; those costs that were incurred in the past and will not be changed by the proposed action are lost and gone ('sunk costs'); and
- Costs are the undesirable consequences of the proposed action, notably the resource costs involved but also any other undesirable consequences including externalities (e.g. the noise generated during construction should be treated as a cost and not as a negative benefit).

Thus, in Figure 7.1, the solid line represents the costs of using the available water for irrigation. To these costs must be added the negative externalities of this use. Water should then be allocated to irrigation if the value of the water to irrigation both exceeds these costs and also the value of that water to alternative uses, such as for industry. In some of the literature on water management (Rogers *et al.* 1998) some confusion has arisen as to the nature of opportunity costs and the question is dealt in more detail in Section 15.5.

The general methods of evaluating costs are discussed in Section 12.2. However, in analysing water-related projects, two convenient assumptions adopted in most economic textbooks do not apply:

- the marginal costs of production can fall as quantities rise as a result of economies of scale or of scope; and
- in a perfectly competitive market, change is costless and instantaneous; in the real world, many costs occur because change is expensive and takes time to happen. So-called transaction costs are often high and information is expensive

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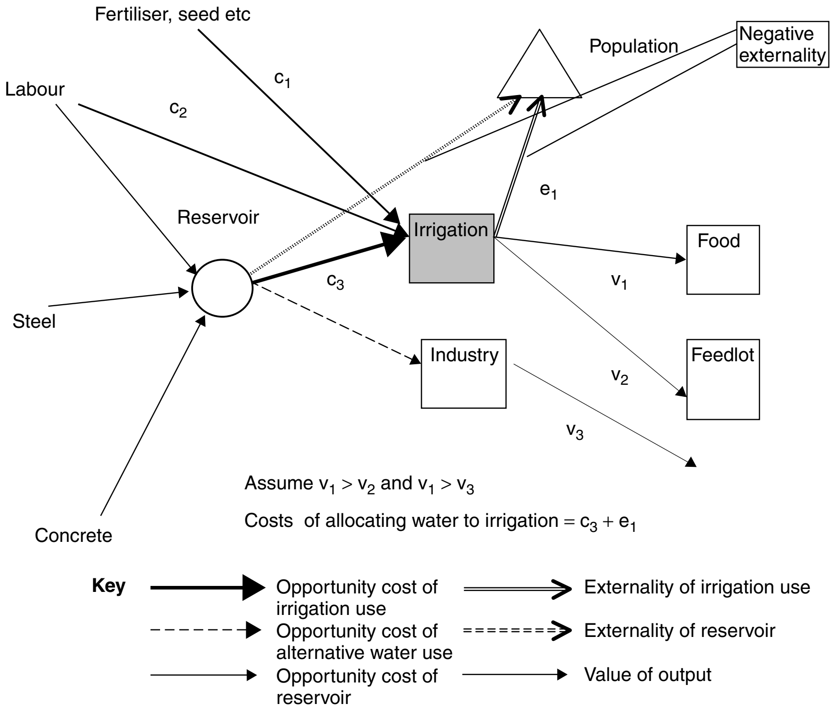

Figure 7.1 *Opportunities costs and values*

to obtain. Similarly, as economies become more concentrated and specialised, so called 'indirect' costs can be significant.

7.1 General Issues of Costs

Costs are apparently much more straightforward than values. Clearly, they include the capital costs such as land acquisition, resettlement, and operational and maintenance (O&M) costs. Often in analyses, construction costs are left as financial costs, those given in the bill of quantities, rather than adjusted to give economic costs. Strictly, it is necessary to correct these costs by taking out so-called transfer payments – notably revenue taxes – where a transfer payment is any transfer of money not accompanied by an equal transfer of resources or goods in the opposite direction. A movement of money alone is purely a financial or fiscal action, in national terms, it is no more than the transfer of money from one pocket to another. It can be necessary to apply shadow pricing (Squire and van der Tak 1975), particularly where there is a high level of structural unemployment or the national currency is artificially pegged to a specified exchange rate. Too much attention is often paid to potential cost overruns: given all the inevitable uncertainties about predicting benefits and costs for perhaps 50 years into the future, an inability to predict construction costs to within plus or minus 20% is a very minor issue.

The costs of the adequate resettlement (WCD 2000) of those displaced by a project are also a necessary part of the capital costs of construction. Care needs to be taken to avoid confusing things (e.g. dams) with resettlement issues whereas the magnitude of the resettlement problem is determined by the spatial extensivity of the project and the population density. When countries have a high population density, then virtually any action involves some displacement of people and this is may be the case for even apparently benign strategies. For example, implementing source control (Balanovski *et al.* 1997) in Buenos Aires as a way of alleviating the major storm water flooding problem would probably involve resettling around 20% of the population. At present, the area responds as if it is 100% impermeable, being very densely developed with very little public or private open space. A significant number of buildings would probably need to be demolished in order to create the space necessary for source control measures. Similarly, on the Yangtze, whilst the Three Gorges Dam is expected to involve the resettlement of around 1 million people, there are 4.2 million already living in the areas designated as emergency flood storage areas on the flood plain, and around 10 times that number living on the flood plain as a whole.

At the same time, population growth creates additional needs for land and work and the Brundtland definition of sustainable development (World Commission on Environment and Development 1987) requires us to take account of these needs of coming generations. When considering the acceptability or otherwise of resettlement then it is appropriate to take account of these future needs unless we are to condemn those future generations to occupy the most marginal and hazardous areas, as these are typically the only land areas left available for new settlement.

Attention should generally be focused upon two other areas rather than uncertainties about capital costs: delays in construction and O&M costs. At high discount rates, the problem with delays in construction is that the benefits are also delayed. For example, in one project, assuming that construction would take four years instead of three resulted in the net present value of the project falling by 22%. In turn, construction delays are commonplace and the risk should be foreseeable; for example, the Greater Cairo Wastewater project (Section 16.5) was expected during the years it was being built to (and it did) require more than the annual Egyptian production of engineering bricks to line the tunnel. In consequence, the project overran by several years as the work was held up by the scarcity of bricks.

Secondly, O&M costs are often not assessed in anything like the same detail as the construction costs where the resources required are usually broken down into fine detail with a unit cost for each. This is frequently not the case for O&M costs and it is not unusual for the organisation who will be responsible for operating and maintaining the works to be different from the organisation responsible for the design and construction of the works. Where the same organisation is responsible for both, the responsibilities frequently lie with different parts of the organisation with often limited communication. But a significant number of projects fail in the long run because they are inadequately maintained, often because the resources are not available to maintain them. Therefore, part of the design process ought to be a priced schedule of O&M activities and a choice may need to be made between a high capital cost, low O&M cost option versus a low first cost, high O&M cost option. Equally, attention must be given to the realism of the funding mechanism assumed to cover O&M costs. These considerations of O&M costs apply equally to projects or programmes that involve institutional changes but perhaps with even more force since concrete tends to stand up to neglect better than institutions.

7.1.1 Critical and constant natural assets

The loss or damage to sites of environmental, heritage or archaeological significance is a particular problem. In countries that have long been densely populated, most of the environment is at least partly a product of human activity; one consequence can be that a project necessarily involves an environment–environment trade-off; doing nothing involving some environmental loss and all of the do-something options also involving damage (Green and Penning-Rowsell 1999). In turn, the different interests of the environment are themselves in conflict: geomorphologists generally would like to preserve change as it is development over time that is their primary concern. Where those habitats of concern have resulted from past human interventions, then it may require considerable human intervention to maintain the current conditions that those habitats require. For example, in a study of the benefits of renovating weir structures on a heavily modified river in the east of England, a considerable part of the benefits was generated by maintaining the water levels in the series of habitats that had developed along the river since it was first modified several hundred years ago (Balfour Maunsell 1995).

Ecologists, however, are usually risk averse; although something of ecological significance may result from geomorphological or other change, the ecologists would typically like to preserve what is there now. Archaeologists clearly do not want any change that damages an unexcavated site and since the process of excavation destroys the archaeological value of a site, they frequently want to leave sites alone until archaeological techniques have improved.

Now, it is usually comparatively easy to determine the use and functional values yielded by a site; the problem lies with the remaining values. Many environmental economists will then go on to derive a nonuse value for the site but for the reasons given in Section 5.1.2, thought needs to be given as to whether this will help make the decision. In particular, given that such a value will reflect what people are prepared to pay to preserve the site, but a decision is necessarily about what we ought to do, it is open to environmental advocates to argue that people say they are prepared to sacrifice to preserve the site but that they have got it wrong.

An alternative approach is then given by the concepts of 'constant natural assets' and 'critical natural capital' (Countryside Commission *et al.* 1993).

Constant natural assets are those where, provided we maintain the current stock at the present level or above, we can lose some sites, with the obvious provision that it is then necessary to replace what is lost by creating new sites. This approach can necessarily only be applied to those habitats and sites which can be recreated in some reasonable period of time. The 'no net loss' policy (Heimlich 1991) and wetland banking policies (Reppert 1992) of the USA are an example of the use of a 'constant natural asset' approach. Three virtues of this approach are firstly that replacement need not be on a one-to-one basis; it would be quite reasonable to require that the loss of one hectare of wetland must be replaced by two elsewhere in order to allow for the risk that recreation will be unsuccessful. Secondly, it is likely to take pressure off sites that are part of critical natural capital, those that must be preserved and are irreplaceable. Given the choice between trying to develop in an area that forms part of critical natural capital and in one that is part of constant natural assets, most developers are likely to choose the latter since they can gain environmental cookie points by exceeding the minimum requirements and they can avoid the legal and political problems of trying to develop in an area of critical natural capital. Thirdly, in developed countries, important habitats are simply the bits left over after past developments, the individual sites may be too small and, in addition, climate change will mean that some will lose the most important species on those sites. Adopting a wetland banking and no net loss approach then gives the resources which could be used to expand some present sites and acquire others that will increase the capacity of the system to adapt to climate change. Clearly, the recreated sites need to be established well in advance of the loss.

The critical natural capital approach is exemplified by the European Union's Birds and Habitats Directives. In the latter, a brilliant piece of drafting requires that governments may only allow damage to, or loss of, sites designated under these directives if there is both no alternative and there are overwhelming socio-economic reasons for allowing this damage or loss. Whilst economic analysis may be a useful support when framing a law, economic analysis cannot be used to determine whether there should be compliance with a law.

In applying this approach, what is then important is to determine what habitats can be treated as part of constant natural assets; unless it is possible to recreate over a reasonable period of time and with a reasonable degree of success such a habitat, it must either be included under the category of critical natural capital or is only of local or regional interest. DEFRA (1999) provides a flow chart for determining how an individual site would appropriately be treated.

7.2 Economies of Scale

Economies of scale are both pervasive and critical in water management. Economies of scale arise as a function of size, a single large plant, at least up to some point, having lower unit costs than many small plants providing the same throughput. For example many construction activities also have a high fixed cost irrespective of the size of the plant which is then installed; this also results in economies of scale in construction. Some economies of scale arise as a function of geometry: a large pipe is cheaper to construct and run than several small pipes of equivalent total capacity because the perimeter increases as a function of the radius but the cross-sectional area increases as a function of the square of the radius. For example, Brown and Schueler (1997) give the costs of stormwater retention basins as US$1 per ft^3 for a 10 000 ft^3 basin, falling to US$0.50 per ft^3 for a 5 million ft^3 basin. Similar economies of scale are reported for wastewater treatment (Bradley and Isaac 1969, Knapp 1978, Water Research Centre 1985).

That there are such economies of scale in regard to so many water management functions has a number of important implications:

- It is one reason why so many services have been collectively provided rather than each individual making his or her arrangements;
- The marginal costs of building to a higher standard of service or ahead of future demand are low; and
- They restrict the degree to which it is possible to introduce competition into the provision of water functions.

As will be described later in more detail, historically irrigation and land drainage in particular have been provided by landowners banding together and forming an organisation to construct and maintain irrigation, land drainage or flood alleviation works. It is generally considerably cheaper to overprovide in the first instance than to go back later and provide additional capacity, hence historically conservative engineers tended to build in a large allowance for future growth in demand. In general, the total cost of individuals making their own provision rises as a linear function of the number of people who make that provision. Conversely, the costs of collective provision are much less dependent upon the number of people served (Figure 7.2). For example, individuals might choose to flood-proof their own homes or build separate flood alleviation works around each small community. Penning-Rowsell *et al.* (1987) examined some local protection options for Maidenhead in the Thames Valley. Updated to 1997 prices, the costs of flood-proofing each individual property were calculated as £15 843. Constructing bunds or walls around each neighbourhood was estimated as resulting in an average cost per property of £2986. Finally, the costs of providing bunds around each of the main built-up areas was estimated to cost £2222 per property. The individual protection option requires the construction of some 140 kilometres of walling; the neighbourhood option, some 42 kilometres of bunding or wall; and the community option, the building of 26 kilometres of bunding. These figures relate to post-development flood protection and the costs of building flood protection into the initial construction of a development might be expected to be lower.

The third implication follows from the first; in urban areas, it is generally cheaper, for example, to provide piped water supply and sewerage than to sell

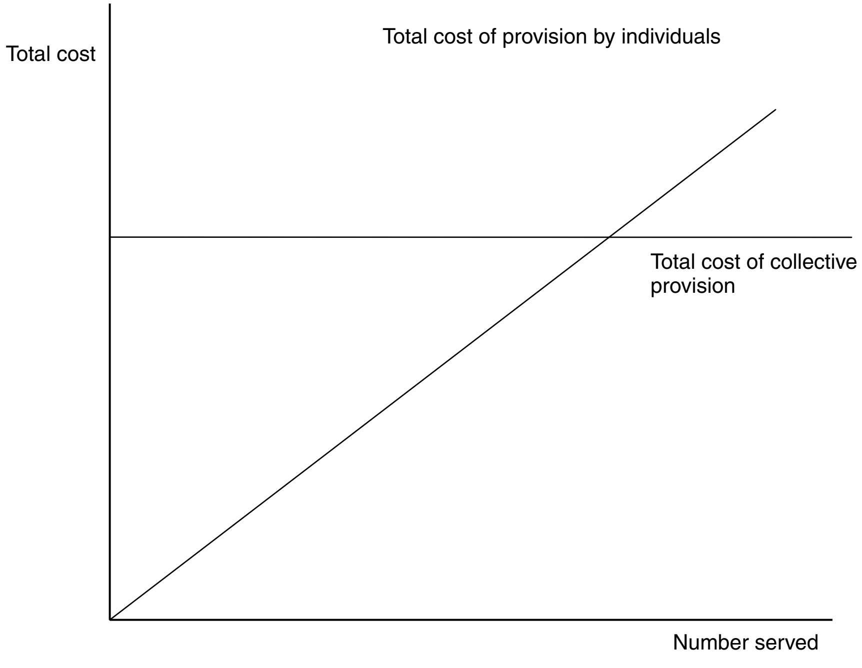

Figure 7.2 *Economies of scale. Source: Green, Parker and Tunstall 2000*

water from trucks (Briscoe 1993) and to remove wastewater from cesspools (Chapter 16) although the latter two solutions are perfect examples of the scope for introducing competition. In principle, the greater the fragmentation of provision in a market, the greater the competition and hence the potential gain in efficiency. Indeed, a key part of the definition of the perfectly competitive market which economic theory asserts will result in efficiency is that there are so many small producers that the entry or exit of any firm will have no effect (Lipsey 1971). So, for the maximum gains from privatisation through competition, we would like to fragment the system as far as possible. If, however, there are significant economies of scale in terms particularly of bulk servicing and treatment then it will not be possible to introduce a significant degree of competition and a local monopoly covering possibly a large geographic area is necessarily the result of privatisation. Economic analyses consequently must explore the extent to which there are, in the particular instance, economies or diseconomies of scale.

7.3 Economies of Scope

The case for integrated catchment management is partly based on the expectation that there are economies of scope associated with water management. That is, managing all aspects of water management will result in a lower cost strategy than trying to manage each separately and in isolation. The second rationale for integrated catchment management is that purely local solutions will be suboptimal from the perspective of the catchment as a whole, so increasing total costs. This is not a claim that there are economies of scale but that local solutions will often simply shift the problem on to another place.

As with economies of scale, the extent to which there are economies of scope has important implications for the institutional form of water management. In particular, the greater these economies of scope then the more likely it is that a monopoly will control a multiplicity of functions. If, for example, there are inherently economies of scope from managing bulk water resources, processing and distribution then even if the three functions are privatised as separate units, the consequence even in the relatively short term is likely to be one company taking over the other two companies. A further economy of scope being explored in the UK in particular is the potential economy of scope of a multi-utility company, one that provides two or more of the major utility services: water, sewerage, electricity, gas and telecommunications.

Taken together, the extent to which there exist economies of scale and of scope will determine whether an integrated organisation covering a large area will have lower costs than single purpose organisations covering small areas where the latter arrangement would make competition possible. In the former case, there is necessarily local or perhaps regional monopoly and introducing efficiency through competition and privatisation is much more problematic.

7.4 Market Imperfections

In the hypothetical perfectly competitive market, everyone has perfect information, there are numerous small and identical producers, and change is instantaneous and costless. None of these assumptions can be expected necessarily to approximate to reality when considering water management.

7.4.1 The costs of data and information

Water is a bulk, low unit-value product and hence it has not generally been considered to be worth spending very much money on collecting very much data since the cost of that data collection, processing and archiving could rapidly approach the value of the water itself. Thus, determining how much data to collect is itself an important economic question in water management (Chapter 22) and when analysing other water management issues, it should be expected that the available data will be sparse and possibly unreliable.

7.4.2 Transaction costs

Again because water is a bulk, low unit-value product, the costs of charging for water or otherwise raising the revenue necessary to pay for the costs of water management can be a significant proportion of the revenue raised. Although economists in principle favour adopting marginal cost pricing, the additional costs of applying this approach can outweigh any efficiency gain that would in theory result from the use of the approach. It may thus be better to find a simple, easy to administer, low cost method of charging than to seek to apply some sophisticated marginal cost pricing approach that is expensive to administer. Indeed, there may be a lower cost means of achieving the same effect than marginal cost pricing is intended to produce. For example, in principle, charging for irrigation water in Egypt by volume should be expected to induce more efficient use of that water. However, in practice, since farmers use human, animal or motor power to lift that water, a simple marginal cost pricing mechanism is already in place. In turn, the cost of metering small fields would be significant and Perry (1996) has shown that other cost recovery methods are more efficient. As Abernethy (n.d.) has pointed out, the ability to pay for irrigation water depends on the farmer producing cash crops rather than being a subsistence farmer. Similarly, the cost of installing meters in dwellings in England and Wales amounts to an increase of around 15%, as compared to the present property-based charge, in the average household (OFWAT 2002). Again, as treatment standards for wastewater increase, so the greater proportion of the domestic water and wastewater bill becomes for wastewater collection and treatment. Logically, therefore, it is outflows rather than inflows that should be metered but such metering is impractical. Hence, the usual practice is simply to multiply the charge for water by some factor to cover the cost of wastewater collection and treatment on the assumption that most of the water that goes in is returned. As households switch to rainwater collection and greywater reuse, this simple relationship will start to break down.

Thus, when considering methods of recovering the costs of water management, it is necessary to consider the practicality of the different methods of recovering these costs and the costs involved. The question of metering water supplies is covered in more detail in Section 15.1.2.

7.4.3 Indirect costs

In a perfectly competitive market, all changes are costless: if one plant ceases to produce, the consumers can immediately buy the same good from another factory at exactly the same cost. However, real economies are becoming increasingly concentrated and specialised; instead of many plants producing near identical goods, there are often only one or two plants in a country or even in the world that can produce a particular product. Thus, for example, the Kobe earthquake stopped production at the one plant in the world that produced a particular component for personal computers. Similarly, one plant in the UK produces 60% of bakers' yeast for the country (Parker *et al.* 1987). Consequently, the effects of a water shortage or flood can disrupt an entire economy rather than the lost production being seamlessly and costlessly taken up elsewhere in that economy.

8

Social Relations

An economy is made up of a system of exchanges of goods and services, each of which exchanges consists of two parties who are linked through the exchange. In turn, the nature of the exchange defines and is defined by the relationship between the two parties making the exchange. In part, those relationships are formalised into law which also defines what exchanges are permitted. Neoclassical economics, however, focuses exclusively on the content of the exchange to the exclusion of the nature of the relationship and assumes that the nature of the relationship is irrelevant to the content of the exchange. But, in Section 2.1.1.7, I argued that some objectives or values derive specifically from relations between people. In consequence, when we believe that we are asking about the value of something, it may be that the respondents understand the question in terms of relationships defined by the nature of the exchange. Equally, the way in which costs are recovered may then define the nature of the relationship that is understood to exist. Therefore, when considering possible institutional structures, such as privatisation, to manage water, or possible means of cost recovery, it is reasonable to consider what such arrangements say about our relationships with each other and the consequences that flow from those understood relationships.

Secondly, neoclassical economics is largely based upon the assumption that the system of entitlements and obligations derives from Anglo-Saxon law, with its stress on private entitlements and derivation of those entitlements from land. In turn, this is to assume either that Anglo-Saxon law is superior to all other systems of law in terms of its performance, or that Anglo-Saxon law represents 'natural law' (Beyleveld and Brownsword 1994). Notably, it is also usual to talk about 'property rights' as defining individual rights and obligations. This links property and a right, and conjoins the questions of 'what is right' with 'who has a right' and associates both with the possession of property. The term 'entitlement' will be used here as being a less confused and confusing term. Thus Bohannan (1960) points out that tenure is a relationship between people and 'rights' are attributes of people against other people; in Anglo-Saxon law, some of these rights then become attributes of the land. But, as Wood *et al.* (1990) note, there are many rights that are created from other bases than the ownership of land.

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Two questions then arise from the presumption in neoclassical economics of Anglo-Saxon law:

- Does neoclassical economics then have anything of value to contribute in countries where there is a different legal structure, notably in those countries where the legal system is based upon Islamic law (Caponera 1992)?
- If we derive a set of criteria by which to define the most effective system of water law, is Anglo-Saxon law the best?

To answer these questions means considering the nature of entitlements and obligations, and how they are derived.

8.1 Entitlements and Obligations

Schlager and Ostrom (1992) defined a series of hierarchy of entitlements (Table 8.1) that give progressively wider entitlements in terms of the actions to which the holder of the entitlement is empowered. In turn, these entitlements translate into management regimes. Usufructory entitlements are entitlements to withdrawal, whilst alienation entitlements are the classic Anglo-Saxon property ownership entitlements. The two categories in between, management and exclusion entitlements, are then those associated with common property management (Section 10.2.1). There is no natural or universal tendency to ascribe alienation entitlements to land or to water. Thus, famously it was remarked: 'Our land is more valuable than your money. It will last forever. It will not even perish by the flames of fire. As long as the sun shines and the waters flow, this land will be here to give life to men and animals. We cannot sell the lives of men and animals; therefore, we cannot sell this land. It was put here for us by the Great Spirit and we cannot sell it because it does not belong to us. ... As a present to you, we will give you anything we have that you can take with you; but the land, never' (quoted in McLuhan (ed.) 1971).

It is also possible to categorise possible entitlements as shown in Figure 8.1. Some entitlements are associated to the individual; of these, some are tradable, notably the use of labour, and others are not: such as the pursuit of life, liberty

Table 8.1 *Hierarchy of entitlements*

Entitlement	Power
Access	To enter a defined physical property
Withdrawal	To gain benefits from that property
Management	To define withdrawal entitlements
Exclusion	To define who will have an entitlement to access
Alienation	To sell or lease withdrawal entitlements

Source: Schlager and Ostrom 1992.

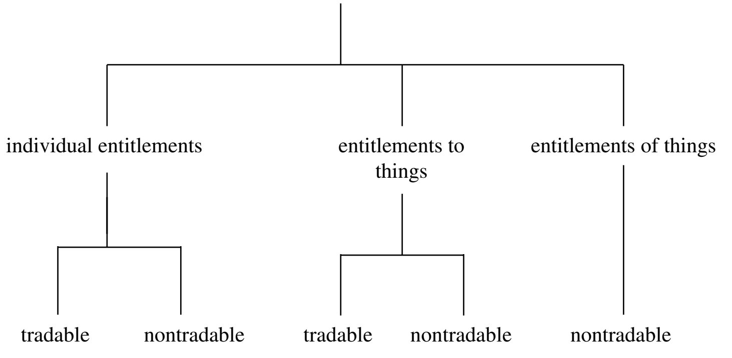

Figure 8.1 *Categories of entitlement*

and happiness. Surrogate motherhood, wherein women rent out their bodies for pregnancy, arouses concern because it is on the fringes of what is a tradable entitlement and what is not. The abortion debate is fought out entirely in the framework of nontradable entitlements; of the right of women to choose versus the right to life. It is unlikely that any suggestion that any woman who was prepared to pay enough could buy a right to choose would be felt to enrich the moral debate. Equally, whilst the problem of partner bashing could be cast in efficiency terms so as to determine the frequency and severity of battering where the gain to the batterer just equals the suffering to the battered, such an approach would be unlikely to be seen to reflect any understanding as to what the choice is about. What has been described above as ‘individual’ entitlements is a reductionist view; organisations, institutions and groups all have entitlements and can hold entitlements. Limited companies have entitlements, and recognised churches in many countries have an entitlement to tax exemption.

Other entitlements are associated with things; where an entitlement is tradable, then an individual can acquire entitlements to that thing, and those entitlements can be bought and sold in a market. As Common (1934) pointed out, what is bought and sold in a market is not the thing but some defined entitlements to that thing. Thus, an entitlement to buy a gun does not now carry with it the entitlement to kill someone with that gun. In any particular culture, there are entitlements associated with things which are not tradable: for example, it is not possible in the United Kingdom to acquire an entitlement to mistreat an animal, indeed, entitlements to kill animals are tightly controlled. The pattern or distribution of entitlements varies between cultures; for example, there are wide differences in the extent to which it is possible for an individual to have any tradable entitlement to land rather than, for example, some specified rights to use that land for a particular purpose. Where such entitlements to a tradable entitlement exist, there are wide differences in the limits of such entitlements. For example, whilst land has tradable entitlements in Scandinavia, this does not restrict others from having coterminous entitlements to the use of that land. Anyone may, for example, pick berries or camp on that land, subject to some understood but incompletely formalised practices: thus, for instance, one should not pick berries within 200 metres of someone's house or camp on that land for more than a day (Swedish Environmental Protection Agency 1996).

In particular, there are wide differences between countries and cultures with regard to entitlements with respect to water and especially in whether an entitlement to land defines the entitlements to the use of water on or about that land. Similarly, the pattern is dynamic over time within a culture; thus, until comparatively recently, there were many societies in which it was possible to hold a tradable entitlement over another human being: in addition to slavery, wives or children could be sold. Traditionally, in most cultures, women have been treated as having fewer entitlements than men both in terms of individual entitlements and in their ability to claim 'things' entitlements, or to those things over which it was possible for them to have entitlements. Such an arbitrary distinction in entitlements is now becoming increasingly untenable. The emphasis both upon countries and dynamic change indicates that entitlements are derived as the outcome of a social process rather than being in any sense 'natural'. Consequently, what is a tradable entitlement and what is an untradable entitlement are in the longer term socially negotiable, and attempts are being made to introduce into Western society a new category of entitlements: entitlements which things have to themselves. Hence, the fifth branch in Figure 8.1; some cultural traditions have long recognised that some things have their own entitlements as opposed to individuals having entitlements in relation to those things. Thus, under Islam, other species have entitlements; indeed, since the universe is part of God's creation, people have obligations towards all parts of that creation and it is within this context that humans have subsidiary entitlements to those things which are part of God's creation.

There are those who object to the application of economics to environmental issues, arguing that this results in the 'commodisation' of the environment. In part, what they are arguing is that what they regard as nontradable entitlements in the environmental good, or what cannot in practical terms be tradable entitlements, are being treated as if they were tradable entitlements. Libertarians indeed commonly argue that what are now in practical terms nontradable entitlements should be converted to tradable entitlements, and argue that such a conversion is the best way of safeguarding those resources. Such an argument embodies what are effectively ideological claims both as to the superiority of one form of allocation of entitlements over all others, and as to the process by which entitlements may be reallocated. Thus, those who argue against the 'commodisation' of environmental goods may fear a slippery slope where once the concept of applying monetary evaluation to environmental goods is accepted, the slide follows as this necessarily then implies that entitlements in such goods are or should be tradable.

The most important societal decisions may be those about conflicts in entitlements; for example, that over abortion. Those who object to the commodisation of the environment may argue that a debate over entitlements is being trivialised to one about the allocation of resources. Thus, the story is told that George Bernard Shaw, at a dinner party, asked the woman next to him whether she would sleep with him for £100 000. When she answered yes, he then asked whether she would do so for £5. Her reply was: 'What do you take me for?'; Shaw's response was: 'We have established what you are; now we are negotiating a price.' The more money involved, the greater the temptation but the issue may not be changed. Conversely; the neoclassical economist can sometimes give the impression that Judas's only failing was that he did not hold out for the market rate, that there would have been some qualitative difference if he had obtained 300 or 3000 pieces of silver instead of 30.

The linkage between technology and institutions is also close (Kohler 2000); unless something is technologically possible, there is no need to have any law that covers the issue. Thus, in many if not most countries, the invention of tube-well technology coupled to relatively cheap diesel or electric pumps has created a groundwater crisis with overabstraction rapidly and drastically lowering levels in the aquifer. The Ogallala aquifer (Postel 1993) is perhaps the best known instance of such a crisis but similar problems have occurred in many other countries, including the Yemen (Kohler 2000). In the absence of any effective means of making use of underground water, it was been unnecessary to have any law controlling abstraction of groundwater and groundwater has typically been left as an open access resource or it has been assumed that the landowner has a right to the waters beneath their land. Law has been left to try to catch up with the technology.

This example illustrates a second issue; to be real, an entitlement has to define some actions in regard to something that is also specific; an abstract principle must be translated into some concrete and relevant entitlements and obligations. Conversely, only when action is possible is it necessary to define the principle that will define the relevant entitlements and obligations.

The different legal frameworks vary in the relationship which is defined between individual rights and the rights of the community, which may be formalised as those of the State. There are two main conceptual pathways that have commonly been argued by which a property right can emerge: all land is originally held by the Crown or the State or the community; alternatively, property rights are initially created by individual use or annexation out of waste land. In the former case, any private property right is granted by and held at the pleasure of the State; the latter approach, at least, in part was adopted by some philosophers (e.g. Locke 1960) in order to avoid formally resting ultimate ownership in the State. Interestingly, these are two extreme versions of an individualistic model; the pole extremes of the divine 'I' and individual 'I'. Depending upon how property rights are defined to originate, then the nature of the entitlements and obligations of individuals versus the community are then argued to largely follow from that initial allocation. Thus, Locke (1960) argued that once individuals combined together to form a commonwealth governed by consent, entitlements and obligations derive from that commonwealth: 'Whosoever, therefore, out of a state of nature unite into a community, must be understood to give up all the power necessary to the ends for which they unite into society to the majority of the community ...'.

Again, the neoclassical model rests centrally upon the assumption of an inherent individual property right as justification for the individual behaving so as to maximise his/her self-interest. If property rights flow in the opposite direction, the appropriate question would instead be how to allocate labour and other resources so as to maximise some State or community objective.

Within Europe and the countries formerly colonised by European traditions, there are two legal traditions: Anglo-Saxon law and Roman law. The Roman law tradition articulated the conflict between the individual and the community, seeking to define the relationship between each. The third great legal tradition is that of Islam (Bagader *et al.* 1994). This is the only one of the three traditions which has an explicitly ethical or religious basis and it is one in which individuals, through duties to their god, have duties to other people and other species.

In turn, there continues to be a debate in jurisprudence between those who argue that there is natural law and the legal positivists (Beyleveld and Brownsword 1994; Dworkin 1971; Hart 1961; Lloyd 1991; Lyons 1984; Morawetz 1980).

8.1.1 Criteria for a legal framework for water

Given the variety of alternative systems of water law which exist around the world, it is appropriate to look for some criteria with which to assess the relative advantages of these different systems. South Africa, for example, has determined that the predemocracy system of a combination of Anglo-Saxon and Romano–Dutch law needs to be replaced because it institutionalises the inequitable distribution of resources of the apartheid era (DWAF 1996).

Since the supply of the resource is exogeneously and dynamically determined, a necessary criterion is that:

- the system can adjust to changes in the availability of the quantity and quality of water over time as a result of climatic or other factors; that it is resilient.

This also means that it should be able to recover relatively easily and quickly from what are discovered in hindsight to have been errors; if yesterday's allocations bind us for ever, then the scope for adjusting to future changes is progressively diminished.

The principles of sustainable development require that:

- the environmental consequences of the use of the resource are factored into the decisions that are taken as to its use;
- the use of the resource does not exceed supply; thus that use equals the sustainable yield of the resource; and
- the efficient use of water both by the individual user and in terms of the allocation of water between users is promoted.

The economist will further argue that:

- the available resource should be allocated to the highest and best use;
- the externalities of those uses are internalised into the users' decisions;
- the system can adjust readily to changes in the patterns of demand, and to changes over time in the relative values of the different possible uses;
- the system does not encourage the creation of monopolies; and
- it does not give undue weight to mere geography or time – for example, that the use of land above an unconstrained aquifer does not give unnecessary entitlements.

The process of adjusting the claims to the available resource must also satisfy some criteria:

- it must be transparent and promote accountability;
- it must be seen to be fair both in outcome and in process;
- all interested parties must have equal access to the decision process in real terms;
- it must be cheap and simple to administer, and decisions must not take an undue length of time;
- where time and costs reflect any bureaucracy involved and also any legal proceedings.

Beyond this common base, a society will want to take account of its own cultural, religious or moral traditions as these reflect its beliefs about the common character of water resources; beliefs about the rights and entitlements associated with ownership or use of some resources; and those of the individual *qua* individual; the duties and obligations of individuals to both other individuals and to society; and those of society to its citizens.

In developing a system of water law to match these criteria, it is also logical to start with systems of law (Caponera 1992) that have performed well over several hundred years in the context of an arid climate where irrigation is required. The Anglo-Saxon model, whilst ideal in a colonial system of apparently infinite resources and empty spaces, or at least of lands in which the interests of the indigenous peoples could be ignored, would seem now almost universally to create problems in those countries which have adopted it of overabstraction, inflexibility and inequity. Again, the principle of *sic utere tuo alienum non laedas* – one must so use his own as not to do injury to others – depends both on a relatively large supply relative to demand and nonconsumptive uses. If water is scarce, and water is required for irrigation, it is not a practical rule to apply. Consequently, when human interventions became large compared to natural variations, they had to be replaced by administrative law (e.g. Brubaker 1995; Gustard *et al.* 1987).

Whilst the eastern United States was able to continue with English riparian law, in the western states, irrigation was a requirement for effective farming. Since the use by one person of water from a river necessarily reduces its availability for those downstream, the riparian doctrine could not be applied. The prior appropriation doctrine developed instead (Wright 1990). If the presence and interests of the indigenous populations were ignored, then the west could be treated as empty. If there is nobody living there and using water, then the principle of 'first in time, first in right' has obvious advantages in a process of colonisation where government and law follow after the settlement of the land. In turn, this doctrine has run into trouble when the available water has been fully appropriated and is used inefficiently for low-value uses, leaving no available water for incoming and higher-valued uses. This is a general problem in countries with an Anglo-Saxon legal philosophy: more resources have been converted into private property than actually exist so that rights to abstract water may exceed the drought flows.

Conversely, in arid climates, viable systems of law had to be developed and both Islamic (Caponera 1992) and Spanish colonial law (Stevens 1988) have been successful in managing surface water for several hundred years. Hence, when seeking to reform water law, these two models are the logical place to start. But, as noted earlier, law has generally yet to catch up with the technological advances that opened groundwater to exploitation.

8.1.2 Different systems and categories of resource management

The pattern of entitlements and obligations translates into systems of resource management; these are two sides of the same coin. It is possible to distinguish between five main classes of entitlements in relation to land (Table 8.2). Of these approaches, common property management is particularly important because it has both been historically important in the management of water and because it is a model that is being rediscovered.

In 1968, Hardin wrote an important and influential paper in which he effectively argued that the only way that common property resources, such as environmental resources, could be preserved was if they were converted into private property. A self-evident problem with his paper was he explicitly referred to the English Commons, a system that had survived for several hundred years without the consequences he predicted occurring (Clapham 1963). Rather than demonstrating that a Commons inevitably resulted in disaster, he indirectly drew attention to what was a neglected but apparently rather successful way of sustainable management.

Hardin's paper provoked two forms of response. Ciriacy-Wantrup and Bishop (1973) made the distinction between 'common property' (*res communes*) and 'open access' (*res nullius*) resources and pointed out that Hardin confused the two. Whereas his analysis holds true for open access resources, those to which there is no control over who may use them and for what purposes, common property resources, like the English Commons itself, has historically proved to be an effective and sustainable form of resource management. Some common property resource systems have survived successfully over centuries. The best known of these is Netting's (1981) analysis of common property management in

Table 8.2 *Categories of entitlements*

Category of entitlement	Description
Open access	Open to all uses by anyone without control; for example, wasteland or wilderness in a society where there is an excess of land over demand
Common property	Management by a group who controls the uses which may be made of the resource and who make such uses. Those who, by membership of the group, acquire such entitlements are not able to trade these entitlements
State property	Resources which are owned by the state and which are 'farmed' either by state bodies or by individuals under usufructory entitlements
Limited individual ownership entitlements	Entitlements which are granted by the state but within the boundaries of those entitlements, and the obligations to others, the individual may do what so ever s/he pleases. The owner of such an entitlement can pass this entitlement on to their children or to whomsoever they think fit. The United Kingdom model of Anglo-Saxon property rights
Unrestricted individual entitlements	Derived from the assertion that entitlements to land in particular are the 'natural law' and the highest form of liberty. Claimed that any restriction or limitation of the use that may be made by the individual of that which s/he has an entitlement is an infringement of their rights and liberty. The US libertarian view of property rights

the Swiss Alps, where common property management dates from the thirteenth century. Historical analyses of the English Commons were also available (see Cox 1985 for sources), which refuted Hardin's claim that private property ownership was the only way of preserving environmental resources.

There is then an expanding body of research covering the extent of common property resource management. These studies have shown that common property resources form a large part of available resources and contribute a significant fraction of household income in less developed societies (e.g. Jodha 1992). Common property is markedly different from an open access resource; there are typically strong controls over who may use it and for what purposes, as, indeed, there were with the traditional English Commons. The difference compared to private property is that it is owned and managed collectively by those who use it. The rights to the use of the property are often inheritable and may or may not be saleable.

In agrarian societies, resources such as forests and woods, lands providing fodder or grazing, game for hunting, fisheries and sources of running water, along with 'rights of way', were all often managed as common property. Whilst some writers have argued that it is low intensity and somewhat marginal resources that are usually managed as common property, many irrigation works (and land drainage schemes (Wagret 1967)) have been constructed as common property resources. Therefore, the explanation does not appear to be wholly adequate.

The characteristics of other successful common property resource management bodies such as the Watershappen in the Netherlands (Wagret 1967) are similar: a highly democratic decision-making process; both law and tax-making power; and a means of enforcing those laws and of collecting those taxes. Effectively, they are a state in miniature. What is particularly notable is the democratic structure; the Watershappen have been said to be the oldest democratic institutions in the Netherlands and to date back to the first polders. Similarly, the Huerta system in Valencia dates back to the fourteenth century (Glick 1970). But it appears that some common property resource management bodies were democratic well before the host country as a whole was democratic.

Most recently, given that the evidence is that common property resource management has proved historically to be a highly effective means of managing some resources over centuries, the question has turned to defining under what conditions is common property resource management successful. The World Bank (1993) is now promoting the use of the strategy, in terms of Water User Associations, to manage irrigation, water supply and local sanitation.

8.2 Social Exchanges

Neoclassical economics entirely excludes the relationships between people and treats these as being wholly irrelevant to the relations of an individual to things. Indeed, it seeks to construe the relationships between individuals and between groups in terms of the relationship between an individual and objects and services. However, in reality, our relations to things are set in social contexts and decisions are commonly taken as part of a social group, be this a household, community or a company. Even when we take decisions as individuals, socialisation is likely to affect the way we take decisions. In turn, relationships between individuals and things need to be understood and interpreted in terms of the relationships between individuals and individuals to groups. For example, the roles of 'consumer' and 'owner' are both social constructs. Similarly, a 'price', a 'charge' and a 'tax' all define different forms of social relations. Again, as both Marx and Common (1934) pointed out, the economists' 'property rights' are actually not relations between people and property but about relations between people.

The gender role of women is also intimately linked to the relationships and roles that constitute households. A number of irrigation projects in West Africa, for example, have failed because it was assumed that women's labour would be available for working on cash crops; something which has traditionally been a male's task (Zwarteveen 1997).

One specific articulation of a relationship is exchange; this is of particular interest to economics since a focus of economics is the exchange of resources for consumption. Many societies have complex systems of exchange (Davis 1992) of goods which are completely different to, and outside of, the concept of market exchange. As Davis notes, even in Western societies, a significant proportion of exchange is semi-ritualistic exchange outside of the money economy (e.g. Christmas and birthday presents, lift giving, buying rounds of drinks etc.). Davis (1992) described a partial repertoire of exchanges in British society and showed that these varied highly.

If we look at this repertory, it is found (Green 2000b) that each exchange can be characterised in terms of the roles of the two sides involved and the social legitimacy of the transaction. The difference between a 'tip' and a 'bribe' is largely socially defined: some inferiors may be tipped (e.g. taxi drivers, waiters) but equals and superiors may not be (e.g. doctors), nor may other classes of inferiors (e.g. water meter readers). In addition, a 'tip' is given after a service whereas a bribe is given in order to induce a service. Similarly, a 'gift' may only be given to socially appropriate others and be of limited forms; small children are, for example, warned never to accept gifts from strangers. Other gifts, such as the exchange of Christmas cards, are socially expected. This table also excludes all purely personal exchanges such as handshakes, kissing, hugging and embracing.

There is an equally high variety of labels given to transfers of money in British society (Table 8.3), and the labels again distinguish between the roles of the giver

Table 8.3 *Different forms of monetary transfer*

Definition	Definition
Alimony	Housekeeping
Bequest	Incentive
Blackmail payment	Inheritance
Bonus	Loan
Bribe	Pay
Capital gains	Payment
Charge	Payoff
Child support	Pension
Christmas box	Performance pay
Compensation	Pocket money
Covenant	Profit share
Damages	Prize
Donation	Repayment
Embezzlement	Salary
Extortion	Smuggling
Fee	Surcharge
Fine	Tax
Fringe benefit	Theft
Gift/present	Tithe
Golden handshake	Tip
Holdup	Winnings

Source: Green 2000.

and recipient, the nature of the transfer, and the moral/legal basis of the transfer. There seem to be rather fewer labels applied to the giver and recipient, illustrating that between two people in the same relationship, transfers can differ both in their nature and basis.

These labels very clearly define both the relationship between the two parties, and its legitimacy, as well as the roles of the two parties; the same transfer can then have different labels depending on the relationship and roles. Payment transforms the nature of a relationship; for example, payment for sex transforms the nature of the exchange: what was potentially an exchange of pleasure becomes merely a transaction wherein pleasure is exchanged for money. What was of mutual benefit now becomes a one-way transfer that can only be brought back into balance by a cash transfer. The introduction of a transfer of money in this instance at least signifies the nature of the relationship and perhaps even transforms it.

Thus, the form of payment for water and sewage denotes the relationship involved; attempts to change the form of payment imply an attempt to change the nature of the relationship and the roles of the parties involved. Were a water company to demand a tithe of my income, then I would find this a very strange and wholly illegitimate demand because a tithe is a religious duty and the water company is not a religious organisation to which I have chosen to belong. In the long run, water metering is therefore almost a prerequisite for a privatised water supply system because a charge per property is effectively a tax. Prices are set by suppliers and the consumer can choose whether or not to buy at that price. However, taxes are set by accountable forms of government; a private company accountable only to its shareholders cannot be allowed to set a tax. Therefore, if costs are to be recovered through charges, rather than metered prices, then price regulation is almost inevitable.

Against this richness of forms of relationship and roles, the standard economic approach seems trite and barren. Thus, the problem with standard economics is not that it introduces money but that it treats all of the variety of exchanges as equivalent to that of buying and selling, and all roles as being those solely of a consumer and producer. Therefore, when considering how to recover the costs of water and the management strategies to be adopted, we need to consider the nature of the relationship, the behaviours consequently appropriate to that relationship, and the desirability of those behaviours. For example, in the 1976 drought in England, when water supply was run through public institutions, the government appointed a minister to be responsible for managing responses to the drought. In 1993, after the water industry had been privatised, in another drought, the minister called in the chief executives of the water companies in order to issue a press statement announcing that he found their performance unacceptable. Finally, whereas in 1976, some water suppliers that had no water resource problems called for voluntary cuts and banned some uses out of solidarity with neighbouring water suppliers who had real problems; this did not happen in 1993.

9

What is a Better Decision?

The entire force of economics lies in the extent to which it enables us to make 'better' societal decisions: what we mean by 'better' is therefore critical. By 'better' we certainly mean that today's decisions should be an improvement on past decisions and we also want to perform consistently better in making the 'right' decisions. By 'right', we are concerned to make decisions that are right in both senses of the word: they are correct and they are equitable or just. At a minimum, we want to get closer to achieving these two aims than we have in the past.

In turn, a decision is to make a choice and a decision thus has three elements: objectives, alternative means to achieving those objectives, and a procedure for making the choice. Whilst the objectives are abstract, the means is concrete, literally so in many cases, and it is the means selected that determines who therefore bears the costs of the decision: who pays and who bears the adverse consequences of the choice.

9.1 Making Correct Decisions

By 'correct', we mean that if we could look back at today's decisions with the advantage of, say, 200 years' hindsight of each of the possible alternative futures that would result from adopting each of the possible options open to us, then it would prove that we had adopted the best course of action, that which came closest to achieving our objectives. Since it is impossible to carry out this test, we have to use the characteristics of the decision process as a test of the likelihood that we have made the correct decision. How rigorous and complete was the framework of analysis that was used to inform the decision, and was the decision based upon this analysis?

In other words, as a species, we take it as an article of faith that using reason will result in making better decisions than the use of other methods of informing decisions. A simple and cheap method of determining which option to adopt would instead be to toss a coin; as argued above, it is difficult to determine whether using reason is more likely to result in the right choice being made. In short, we cannot prove conclusively that using reason results in better decisions than any other process but the use of reasoning has a number of advantages:

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- It promotes transparency and accountability because the chain of logic can be seen and tested.
- It provides a basis for argument, debate and discussion, because we can identify where we disagree.
- It reduces the risk of errors being made in the analysis and increases the likelihood that they will be identified during the course of the decision.
- It promotes consistency of approach between different projects and hence equality of treatment to the gainers and losers from different projects.

9.2 What is the Equitable or Just Decision?

Dictionary definitions of equity include: 'that which is fair or right; impartiality; the recourse to the principles of justice; the quality of being equal or fair' (*Shorter OED* 3rd edition). Again, in early English law, 'equity' was that part of the legal system built around the principles of natural justice and fair conduct and it was specifically designed to deal with those cases where formal law would result in an unfair outcome in the case in question (Lloyd 1991). Thus, equity has two components: a moral principle as what ought to happen coupled with the fair or equal application of that principle to different decisions. Notably, equity is a far richer and more diverse and complex subject than its treatment in neoclassical economics as equality of income. In particular, equity relates both to the outcome of the decision and the procedure by which that decision is reached. Thus, we seek to make the right choice by the right procedure, and distinctions can thus be drawn between outcome and procedural equity (Mitchell *et al.* 1993).

If equity is composed of a moral principle plus its fair application, then a distinction must be drawn between economic efficiency as technical efficiency and economic efficiency as an objective in its own right (Section 3.1). As soon as economic efficiency is treated as an objective in its own right, it becomes merely one possible interpretation of equity, one moral claim as to what ought to be an objective of collective decisions. Hence, to claim that there is a conflict between equity and economic efficiency is false, the argument is between moral claims as to what is equitable. Therefore, a distinction must be drawn between 'technical efficiency', the maximisation of the achievement of some set of objectives within some set of constraints, and 'economic efficiency', the maximisation of some aggregation of consumption within some set of the constraints. The former is a technical question; the latter relies upon a moral claim.

However, there is a distinction between law and decision making; legal decisions are zero-sum games: what one party gains from the decision, the other party loses. Conversely, societal decisions are multi-party and the objective is generally to achieve an outcome where the gains outweigh the losses except where the intention is deliberately only redistributive.

What objectives should be pursued is a moral, ethical, religious and political question. Different countries place different emphasis on different objectives or make different trade-offs between them. Thus, over much of western Europe, 'national solidarity' or 'communal solidarity' is given as a basis for taking decisions. For example, the French constitution asserts that there will be national solidarity in the face of natural disasters. Traditionally, in Britain, the basis for societal decisions was taken to be the 'national interest'; something that both existed over and above individual interests and which could be objectively identified. Other countries place an emphasis on following the laws of the deity or seeking to maintain social stability. Libertarians assert that individual rights must have primacy and that individual property is the highest form of liberty; in turn, this implies that libertarians should neither contribute towards nor gain from collectively provided goods. In some other countries, such as the Netherlands, the objective is primarily about the process by which decisions should be taken; that decisions should ideally be made through a process of establishing a consensus. Most countries now also include sustainable development amongst the objectives brought to a decision.

9.2.1 Outcome equity

Depending upon the nature of the choice, the outcome may result in some surplus that is to be allocated across the collective; there will certainly be some costs, monetary and/or otherwise, to be shared. These costs need not always be monetary; for example, if there is inadequate water available to meet existing demand, for which and to whose demands should supply be cut back?

In terms of distributional equity, Pettit (1980) categorises the various bases of theories of justice into three, in order of historical development:

- Proprietary; the natural law model (e.g. Noznick 1974).
- Utilitarian; welfare models following from Bentham (1948).
- Contractual; distributions which the individual would choose if s/he did not know their initial starting position (Rawls 1971).

Pettit (1980) also notes that what is equitable can be defined either as a principle that can be used to determine the appropriate outcome or as being a characteristic, or property, of the individual. Sen (1992) shows that these models can further be defined as models of equality of one form or another; all embody some belief in equality, but they differ widely in what is to be allocated equally. Whilst the debate on equality is often defined in terms of income, Sen shows that the libertarian claims about the primacy of individual rights and liberties and utilitarian theory are essentially arguments about equality. Thus, although Bentham described the natural right model as 'nonsense on stilts' and sought instead to derive a principle to select the outcome of a choice, rather than basing choice upon the basis of some property of the individual, the maximisation of welfare assumes that the utilities of all individuals are to be treated equally. Consequently, Sen (1992) points out that the central question in discussing equality is 'equality of what?' whilst almost all approaches to the ethics of societal arrangements are based upon some assertion of the requirement of equality of something. There is, however, wide debate and conflict as to in what respect individuals are to be treated or regarded equally. Moreover, Sen (1992) argues that ascribing one characteristic as the centre of a claim to equality typically implies that consequentially individuals cannot be treated equally in terms of another property.

The problems for economic appraisal of considering equality as an objective are then two-fold: firstly, equality is relative rather than absolute, and, secondly, which equality is appropriate? The advantage of restricting the analysis to economic efficiency is that more economic efficiency is always better and in consequence different decisions can be made entirely independently of each other. But equality is by definition a balancing act; often then the appropriate outcome depends upon what other actions are also being taken that will in turn impact on equity. If, for example, eight decisions are taking place simultaneously, and in each case the benefits are distributed according to the relative need of individuals or groups then the result may be to radically alter their standing, and hence need, so that now another group of individuals stand out as being in need. Thus, Mitchell *et al.* (1993) similarly remark that: 'Justice is not a stable, well-defined ideal end-state toward which people purposefully move; rather it is a dynamic, ever-shifting equilibrium between the excesses of too little regulation on the one hand and too much on the other.'

The moral principles that have been proposed as the basis of decisions regarding the provision and allocation of goods, and the allocation of the costs of provision, include:

- The benefits should be distributed on the basis of the contribution of the individual to the provision of the good or of their wider contribution or importance to the group;
- The benefits should be distributed according to the relative need of the individual or group (Farmer and Tiefenthaler 1995);
- The benefits should be shared equally between individuals;
- The costs should be borne according to the value of the resource to the individual or group ('user-pays principle');
- The costs should be borne according to ability of the individual or group to pay; or
- That the polluter ought to pay according to their contribution to the problem ('polluter-pays principle').

These principles in turn may and often do conflict, with quite different outcomes. In the case of flood alleviation, the application of the user-pays principle may be argued to require that those who are protected against flooding should bear the costs of providing that protection. However, flooding may equally be treated as an externality of other people's land use in so far as the way in which they have developed that land has changed the pattern of runoff. In this case, the polluter-pays principle should be applied and those upstream land users should bear the costs of the downstream flood alleviation scheme. We have in short to argue and determine the moral principle, or principles since one principle may not result in a unique outcome, to be applied in a societal decision before we can take that decision. Moreover, of the above six principles, only the first and fourth result in the same distribution of benefits and costs.

In addition, projects often involve significant transfers from national or provincial funds towards a local area or groups within that area. In many cases, the reason for these transfers is an objective other than economic efficiency: for example, national solidarity or to promote socio-economic regeneration, or development, in a relatively poor region. To then apply the user-pays principle would be to vitiate the entire purpose of the project. Thus, the EU's Water Framework Directive excludes projects intended for these purposes from the general requirement that there should not be subsidies towards water management activities. In general, other than a concern for 'pork barrelling', the tendency to promote projects for local political reasons where those projects are subsidised from national funds, transfers from the nation to particular groups are not very problematic. That people should agree to give to others is clearly their right although if the gainers were relatively wealthy and the tax system is regressive, then there are obvious questions.

Conversely, projects where a small group lose a lot but a much larger group gains, usually a relatively small amount, are much more problematic. Historically, the displacement of the population to make way for a large-scale project has been the most extreme example of such redistributions. In particular, those lacking power are most likely to be displaced, and, in turn, those with least power are usually minority groups. Nor can any nation claim an unblemished reputation with regard to its treatment of minority groups. More than adequate compensation and resettlement, the primary concern should be to involve the groups affected in the decision (WCD 2000). Where the area concerned holds graves or religious sites, then compensation for those losses is impossible in principle; the issue is one of whether the overall good generated by the project, and the lack of good alternatives, is sufficient to outweigh the losses.

Absent from the list of principles that might be used to determine the distribution of benefits and costs from a project is the potential Pareto improvement principle applied in benefit–cost analysis. In turn, this does not seem to be commonly used in practice: for example, the Huerta in Spain use different principles to determine how water should be allocated when water is scarce (Maas and Anderson 1978).

9.2.2 Procedural equity

One aspect of procedural equity is equality of treatment: 'all those in the same category shall be treated as equal' (Lloyd 1991); that is, in accordance with the categories laid down by law and not in either an arbitrary or biased manner.

Lloyd also differentiates between formal and substantial or concrete justice where formal justice involves treating in a like way so that:

- there are rules setting out how people are to be treated in given cases;
- these rules shall be general in character; and
- these rules are impartially applied.

Conversely, substantial justice then refers back to outcome equity so that each shall be treated according to their just deserts.

A rather limited amount of research has been undertaken on aspects of procedural equity in regard to water management. That work which has been done (Tyler and Degoey 1995; Syme and Nancarrow 1997) suggests that principles similar to those given by Lloyd are important to promote compliance with the decision that has been reached (Lawrence *et al.* 1997).

Possible tests for the adequacy of the decision process are then:

- Were all key stakeholders engaged in the decision process?
- Were the key objectives that the different stakeholders bring to the choice considered?
- Was an adequate range of options considered, including those favoured by particular stakeholders?
- Were all the most probable and most important consequences of adopting each option considered?
- Was the process of analysis rigorous and logical?
- Was the best available data (not incurring excessive cost) used in the analysis?

Two quite specific requirements for procedural equity are then the consideration of gender and other issues of power, and stakeholder involvement. In the case of gender and parallel issues, these are necessarily also an issue in outcome equity.

9.2.2.1 Gender/power issues

One of the Dublin Principles (ACC/ISGWR 1992) for the sustainable management of water is to recognise the importance of the role of women in the management of water. It is now more common to speak of the need to recognise gender issues where gender is: 'a social construct through which all human beings organise their work, rights, responsibilities and relationships' (Thomas-Slayter and Rocheleau 1995). Equally, a gender approach looks at women and men, and not women in isolation (Maharaj *et al.* 1999). The gender approach is further extended to cover the wider issues of inequalities of access to resources, to power, to education and to money within communities as a result of caste, ethnicity, religion and other factors (Mehta n.d.). Thus, Maharaj *et al.* (1999) point out that: 'A community is not a collection of equal people living in a particular geographic region. It is usually made up of individuals and groups who command different levels of power, wealth, influence and ability to express their needs, concerns and rights.'

Within this wider framework of inequalities, there continues to be a wide range of gender differences and these differences are not limited to the developing countries. For example:

- A significant proportion of households in many countries are female headed as a result of death, divorce, or the migration of the male partner to find work in urban areas. In Sri Lanka, for example, one in five households is now female headed (Maharaj *et al.* 1999).
- In many countries, women have traditionally had responsibility for finding and collecting water (Table 9.1) and carrying water may consume one-third of a woman's daily calorific intake (Tahseen n.d.). In Nepal, 94% of women alone are solely responsible for fetching water (84 litres/day).
- Collecting and carrying water exposes women to more risks than men – and not just from water-related disease vectors (White *et al.* 1972).
- At the same time, collecting water and washing may be an important opportunity for women to socialise with other women and so water collection and use plays a social role as well as having a utilitarian purpose (Brismar 1997; van Wijk-Sijbesma 1985).
- Because finding and collecting water is women's work, water management may consequently be regarded as of no importance (Katko 1992).
- Because of their greater workload than men, women may have no time to attend meetings or participate in organisations. Again, girls are often too busy with household work to go to school. For example, one respondent in an Egyptian village is quoted by El-Katsha *et al.* (1989): 'By nightfall I feel as if somebody is banging at my head as a result of carrying water back and forth during the day. I have no energy to do anything but sleep. Do you expect me to worry about bad conditions in the village?'
- Women are typically the main producers of staple crops, producing 60–80% of the food in developing countries (FAO 1997); in Tanzania they produce 60–70% of all food consumed whilst they provide 90% of the labour for rice cultivation in southeast Asia and 53% of agricultural labour in Egypt (FAO 1997). As men have to move to the cities to find work, agriculture is being

Table 9.1 *Time spent collecting and carrying water*

Place	Hours per week spent drawing and carrying water
Botswana	5.5
Mozambique – dry season	15.3
Mozambique – wet season	2.9
India, Baroda	4.0

Source: Brismar 1997.

feminised. It is usually men who plough fields and drive draught animals (and similarly grow cash crops) but women who sow, weed, apply fertiliser and pesticides, harvest and thresh. In turn, irrigation schemes can result in an increase in women's workload (Hart 1992).

- Women have the primary responsibility for childcare and dealing with illness in the household and hence the burden of water-related diseases falls on them. Sen (1990) points out that if a rural woman were to be asked about her personal welfare, she would find this a meaningless question, being only able to conceptualise welfare in terms of her family.
- Women are often responsible for re-establishing a household after a disaster such as a flood.
- Women commonly have less access to cash than men, and also other household resources, including food. They also have less time available to earn income; in developing countries, men spend 76% of the time earning income, women 34% (UNDP 1995).
- Whilst women generally have less entitlements to land and other property than men, it cannot be assumed that the household holds such rights in common and that the male members of the household control such rights (Meinzen-Dick *et al.* 1997). In parts of Africa in particular, women have traditionally held separate and distinct rights to land to men. But when projects have involved redistributing land or resettlement, women's rights have been ignored in the past (Zwarteveen 1997).

In turn, the implications for the design and appraisal of projects are:

- To take account of the differences between genders and other groups in their work, experience and behaviour with participatory studies being essential to discover these differences and the interactions between the groups (Mehta n.d.). If these differences are ignored then projects often fail or are only partially successful.
- Equity: it is clearly necessary to avoid exacerbating existing inequalities, whilst it is desirable to achieve a reduction in inequalities.
- Finally, since more than 50% of a country's population is female, no country can afford not to make the best use of this resource.

9.2.2.2 Stakeholder involvement

The maximum involvement of the public in all levels of decision making is one of the Dublin Principles (ACC/ISGWR 1992) and one of the clear requirements for procedural equity. There is a wide range of arguments in support of increasing stakeholder involvement:

- 'It is also a moral duty. Public authorities work for the public' (DETR 2000a).
- The experience of projects is that they do not succeed unless the different stakeholders are committed to them. For this to happen, they have to be involved

in the decisions that resulted in the particular option being adopted (Garn 1997). In rural areas, the doctrine is that community involvement is essential if rural water supply systems are to be sustainable (Black 1998) in the long run, particularly with respect to the operations and maintenance of the system, and perhaps especially with regard to funding the latter function (Breslin 1999). Indeed, it is currently argued that demand responsive service provision is essential (Cernea 1992).
- The local population will have more knowledge about some aspects of local conditions than any outside specialists.
- One or more of the options may only work if the community changes its behaviour; the community therefore first has to decide that such a change in behaviour is desirable.
- To strength democracy and the community.
- Participation increases the perceived legitimacy of the decision that is the outcome of the process.
- The constitutional structures are such that the only way to make the system work is by bringing together the different stakeholders; there is no way of creating an institutional structure that can otherwise implement the plan.
- It is in any case inevitable as a result of an ageing population: retirement now leaves a large number of physical and mentally active people with high levels of skills, knowledge and experience – often more in total than that of the design team who are developing the project.

There is now a very large literature on stakeholder involvement in decision making (e.g. Creighton *et al.* 1991; World Bank 1996a); what it is understood to mean varies almost as much as do definitions of sustainable development. Birkeland (1999) set out a useful comparative analysis (Table 9.2) which emphasises that its meaning derives from the wider paradigm that is adopted. This table is perhaps more useful for defining the first three paradigmatic approaches than that which is labelled as ecofeminist and bioregional, not least because others, such as green ecologists, would lay claim to some or all of that conceptualisation.

Stakeholder involvement is necessarily about the degree of power transferred to those engaged in the process; at one extreme, power is wholly vested in the stakeholders involved. In terms of single-function organisations, relatively common examples are farmer-managed irrigation schemes (e.g. Sutawan 1989) and the provision and management of water supply systems by the local community (e.g. Garn 1997). The most developed example of such multi-functional, stakeholder-based organisations is probably the Watershed Councils that are being established in Australia (Comino 2001).

At the other extreme, the views of the different stakeholders are simply sought in order to inform the decision process. In between lie different forms of dialogue with more or less control over the final decision being reserved. Goss (1999) (Table 9.3) has provided a useful structure of the different levels of involvement and the tools that may be used to support this involvement.

Table 9.2 *Participatory planning models*

	Technocratic/ comprehensive	Liberal/ incremental	Radical/ advocacy	Ecofeminist/ bioregional
Objective	Public or national interest	Reconcile the conflicting individual interests	Redistribution to the marginalised communities	Sustainable development
Concept of community	Public interest as determined by experts	Individual interests and preferences	Under-represented groups threatened by development	Interdependence; systems model of society and ecosystems
Form of participation	Public consultation by experts	Consumer choice	Development of counter-plans and offers	Discourse based
Planner's role	Determine optimal solutions	Determine public preferences	Ensure equal access to decision making	Facilitate bioregional/ global perspective
Concept of planning	Comprehensive	Incremental	Advocacy	Debate and negotiation
Process	Scientific evaluation	Democratic representation	Law-based, adversarial	Self-help and empowerment
Favoured methods	Benefit–cost analysis, SEA, social impact analysis	Voting analogies e.g. surveys, participation	Educational and adversarial strategies	Self-help and empowerment
Ethical basis	Utilitarianism	Liberalism	Critical theory	Ethic of care
Key role of community	Input into the scientific process	Input into pluralist process	Counter-plans, protest, obstruction	Self-determination
Government's ideal role	Weigh expertise and other policies	Balance competing interests	Distribute wealth, arbitrate	Meet basic needs, facilitate
Project initiator	Private or public developer	Private or public developer	Private or public developer	Community self-reliance
Philosophical aim	Rationality	Procedural justice	Distributive justice	Justice, well-being
Competing values	Majority wins	Balance of interests, trade-offs	Equal opportunity, fair game rules	Consensus
Preferred reforms	Transparency of decision making	Deregulation and less government	More community power and autonomy	Systems change

Based on Birkeland 1999. SEA = Strategic Environmental Assessment.

Table 9.3 *Local authorities and public involvement*

Giving information	Consultation/ listening	Exploring/innovating/ visioning	Judging/deciding together	Delegating/supporting/ decision making
Sign-posting	Surveys	Consultative workshops	Deliberative polls	Neighbourhood committees
Leaflets/newsletters	Focus groups, priority search	Visioning workshops	Citizens' juries	Town/estates
Community profiles	Interactive community profiles	Simulations, open-space events	Negotiation workshops	Tenant-managed organisations
Feedback on surveys and consultation	Public meetings, forums		Community issue workshops	
Annual performance reports			Community workshops	Community development
Support/advice	Panels	Planning for real community discovery	Consensus conferences	Partnership with communities
Video/internet communication	Video boxes	Use of theatre, arts/media		Referendum tele-voting

Source: Goss 1999.

However, stakeholder involvement does not change the nature of the choice; it only changes who makes the choice. In terms of the choice that must be made, it changes nothing; its virtue lies in procedural equity rather than there being any necessary improvement in the quality of the decision that will emerge from the process. As Birkeland (1999) noted, there is an assumption that if the process is right, then the outcomes will take care of themselves. Indeed, there is a danger that elected representatives will shift the most difficult and contentious decisions onto a stakeholder involvement process simply because they are difficult and contentious. Thus, those who are presumably best prepared and are being paid to make such decisions will shift the burden onto the public without necessarily providing the time and resources that we need to take those decisions.

Similarly, a fully participatory approach cannot be assumed to inevitably result in the best choice being made and equally there are likely to be more or less successful approaches to participation. In practice, the literature about the performance of small groups is not particularly encouraging (Brown 1965); a great deal of care is necessary if the outcome is not simply to be the result of the original composition of the group and the dynamics within the group (Sunstein 1999). Simply creating a deliberative group neither necessarily results in a consensus nor in a decision that is better than the decisions the individuals would have taken on their own. Sackman (1975) has stressed the dangers of the pressure within the group towards compliance with apparent social norms.

Trial juries are the direct inspiration for one participatory technique, variously known either as 'citizen juries' or *plannungszelle* (Dienel 1978; Dienel and Renn 1995). Examining how well trial juries perform and the conditions that either promote or inhibit the success of trial juries should therefore be expected to provide useful lessons for citizen juries and other forms of stakeholder involvement. Trial juries do have a relatively simple task to perform in that there are generally only two possible verdicts on each charge in a criminal trial, although the task in a civil trial may be more complicated. In the UK, research into juries has been forbidden, in part perhaps to protect the mystique of the jury. What research is available provides mixed messages; juries do take their duty very seriously (Young *et al.* 1999) and will seek to uphold the interests of justice when the law seems to them to violate justice (Krivoshey 1994).

However, the jury foreperson is, as might be expected, likely to be a white, male professional (Wrightsman 1978) and the procedure adopted by the foreperson influences the final verdict – those who bring a coherent structure to the deliberations increase the likelihood that the verdict will be based on the evidence. Whether the jurors are asked, immediately after they have retired to consider their verdict, by the foreperson to give an initial verdict, or, alternatively, to outline what they see as the critical issues, influences the final verdict (Young *et al.* 1999). Moreover, in a majority of trials in the New Zealand study, the jury misunderstood the law in fairly fundamental ways (Young *et al.* 1999). The overall lessons from the New Zealand study are:

- Oral evidence is poorly assimilated.
- A route map, such as a flow chart, helps the jury to make sense of the evidence.
- Evidence is best presented in the form of a story line; juries can then set up a narrative story and fit the evidence they hear into this picture.
- Juries find it difficult to assess credibility.
- Transcripts of evidence should be provided.
- Jury members should be encouraged to take notes.
- Expert witnesses are needed who can communicate.

Whether the majority pressures a minority to accept the majority decision or whether the minority can persuade the majority or whether the jury seeks a compromise (Young *et al.* 1999), such as a finding of guilt on a lesser charge, is also a function of the personal dynamics of the particular jury (Law Commission 1999).

So, it is necessary to provide support so as to enable stakeholder groups to reach better decisions. Goodin (1999) points out that 'deliberative' is defined as studied rather than rash or hasty, as reasoned (Pettit 1980), and as involving a consideration of the reasons for and against the alternatives whilst 'governance' is taken to mean equal respect for all deliberators. The first part of this definition is precisely what has been found to be so difficult in taking any complex decision. Expanding and opening out the group who have to make the decision, with limited time, increases the need for supportive project appraisal techniques and ones that meet the needs of these users.

There are three developing strands in terms of decision aids; the first supports the definition of the problem, supporting debate on the nature of the problem and dialogue on the key issues. Much of this work derives from Checkland's (Checkland and Scholes 1990) 'soft systems theory'. One example of this approach being applied to catchment management is the 'IdeaMap' (Gill and Wolfenden 1998). A second strand is information support; effective stakeholder involvement requires the democratisation of information and a means whereby participants can extract useful information from what may be an overwhelming mass of data. GIS systems are starting to be employed for this purpose (Correia *et al.* 1994). The third strand is of tools to support the discovery and arguing of preferences between the options. This strand is typically composed of variants of multi-criteria analysis (Section 13.3).

Since shifting to stakeholder-based decision processes does not change the nature of the choice that must be made, it does not eliminate the conflicts that are at the heart of the choice. There are three possible outcomes from each round of participation: consensus on one option being the best option; a compromise to adopt one option; or out and out disagreement as to which is the best option. It cannot be expected that either of the first two outcomes will necessarily occur: indeed, it is possible that the process will simply make the nature of the disagreement sharper. In both the USA (Priscoli 1996) and Australia (Handmer *et al.* 1991), techniques of conflict mediation have been quite widely used. But, equally, it is necessary to have a formal structure through which conflicts are finally resolved. In this sense, it is not necessarily a failure if a conflict has finally to be resolved in the courts; in some cases, there may be no middle ground for a compromise.

Increasing public involvement creates a series of new problems or perhaps exposes issues that have not previously been considered:

- Who has a right to participate?
- How to include the excluded?
- How to include the interests of outsiders?
- How representative are those involved?
- Groups will frequently be spending other people's money; how can these others be confident that their money is wisely spent?

Do I have a right to participate in decisions as to the future management of the Mississippi and on what grounds can I claim this right? Or, equivalently, by what right can, say, a developed country-based NGO claim a right to participate in decisions about the Mekong or Ganga, or the population of Vietnam to participate in decisions about US or European energy policy? We each may claim that we have an interest in the best management strategy being adopted for each of the three rivers but does that establish a right to be involved? In particular, it is obviously easier for those in the developed world to involve ourselves in decisions in the developing world: we are richer, and we have more time and greater access to information and to influence. There is consequently a risk of a new form of neocolonialism where we deny people in these other countries the right to take their own decisions simply because we don't like the decisions they take. When it is someone from a country with an average per capita annual income of US$25 000 who claims the right to overrule the decisions of people in a country with an average income of US$500, the moral legitimacy of such a claim is not self-evident.

We can define three possible levels of involvement:

- the right to inform, to advise;
- the right to argue or advocate; and
- the right to decide.

It is only the third and highest level where the question of the legitimacy of the interest becomes evident. Maximum involvement in informing and in advocacy can only enrich the debate but the extent of the right to decide is more restrictive. Two possible basic conditions for a legitimate claim to have a right to involvement in deciding are then a willingness to negotiate and to compromise, and to be bound by the conclusions of the group. Refusal to accept these conditions is to claim a right to determine the decision unilaterally. In turn, it is not necessarily the case that all groups should seek involvement in decision making. I would prefer that, for example, Greenpeace stays outside of decisions and acts as an advocate for the environment. If they formally take part in decisions and become involved in reaching decisions that balance environmental and other considerations, then they will inevitably have to make compromises. A further condition for a right to involvement in the decision is that the individual or group must either commit resources to the decision or potentially experience a material benefit or loss as a result of the decision. Van Koppen (n.d.) therefore defines a stakeholder as someone who links resources and people. Neither that I don't think a decision is right, nor that I don't like the decision that has been made, are sufficient reasons to claim a right to override the decisions of those directly affected.

There are obvious risks that those who have power and influence at present will use the involvement process to reinforce their power and influence, and those who are currently excluded will be further excluded. Women, as already noted, often do not have the time to participate and in general participation costs time and also money. Since both are differentially distributed across society, some people are more likely to participate than others. Pastoralists may be excluded by neglect so that land owners, particularly arable farmers, use the process against the interests of the pastoralists. Hence, it is necessary to identify all those who have an interest and then to seek to ensure that all those interests are represented.

One risk is that public involvement is then simply a way of reinforcing NIMBY ('not in my back yard'); that a local community puts its own interests over all others. It has been argued, for example, that environmental impact assessments provide a useful weapon for local communities to keep out low-income groups by raising the cost of development and hence thereby excluding low-cost housing. At the same time, resources are often passed to local areas from central or regional government. Thus, stakeholders will often be spending other people's money and with that goes a responsibility to ensure that money is spent wisely. There thus needs to be some formal mechanism to justify the spending of that money. Equally, integrated catchment management, by definition, involves a coherent strategy rather than piecemeal local plans.

Stakeholder involvement raises questions of how representative are the participants of any wide group, and of the legitimacy of the process versus the legitimacy given by election, and hence of the views of elected politicians. The latter concern is raised whenever those involved and those elected reach different conclusions. Again, with decisions shifted to local stakeholders, those stakeholders may reach conclusions that are inconsistent with wider policies; the EU Water Framework Directive both sets mandatory standards for rivers and promotes public involvement. The two principles are contradictory in that the decisions are already mandated.

9.2.3 Means and ends

If we can have concerns both about the outcome of a decision and the process by which that decision was reached, it is also true that there need be no clean

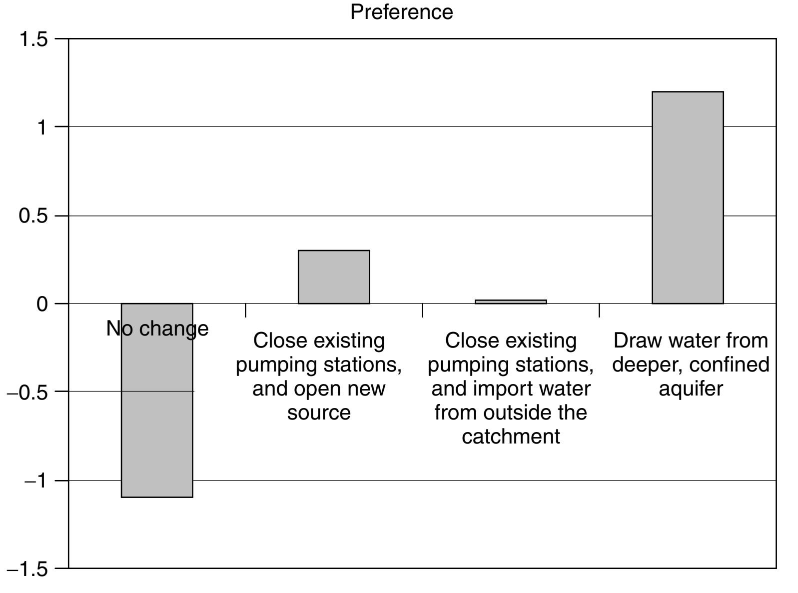

Figure 9.1 *Preferences between options for alleviating low flows. Source: House et al. 1994*

separation of ends and means. Actions are made by coupling means and ends, and earlier I argued that it is actions that have values and not things, that, by definition, instrumental value is associated with an action. However, it is relatively easy to fall into the trap of presuming that people are only concerned with the ends and not at all with the means. Thus, for example, it would be a mistake to assume that whilst people may want river pollution to be reduced, they are entirely indifferent either to the means to be adopted to achieve that reduction or the means by which the costs will be recovered from them.

Not surprisingly, not only do people have preferences between alternative methods of cost recovery (Figure 4.2), they can have strong preferences between the three different options that could be adopted in order to alleviate the low flows in the river (Figure 9.1). Such preferences ought not to be surprising and must be taken into account.

9.3 Better Options

The decision can be no better than the quality of the options considered; if only a poor set of options are considered, then the choice will be poor. Therefore, we need better sets of options to be considered but unfortunately there can be no set of rules that will necessarily result in the 'best' option being amongst those considered. This is because options need to be invented so the quality of the options is ultimately down to the quality of the imagination, creativity and expertise of the team responsible for developing possible options. What we can do is to adopt rules that reduce the risk that the solution space will not be narrowed prematurely. DEFRA (1999) includes a set of such rules for flood and coastal defence projects and a wider set of such possible rules are to:

- adopt an appraisal-led design process;
- use the public participation process;
- look at variations in the standard of service offered by the project;
- consider whether now is the best time to do this project;
- look at what approaches have been adopted or proposed elsewhere;
- consider the options that others will expect to be considered;
- assess what courses of action would be best for the environment and for the local communities.

Adopting an appraisal-led design process can contribute to the identification of the best options both by creating an understanding of what the decision involves and by keeping attention focused on what we are trying to achieve. In two of the case studies, those for Cairo and for Grootvlei, I shall claim that one outcome of the appraisal process was a suggestion of some additional options that could be examined. Moreover, inventing a new option can be a way of resolving conflicts between objectives and between people.

Small variations in the standard of service offered by the project are obvious options to consider; a small reduction could make possible either a drastic reduction in cost or be achieved by a radically different alternative. Conversely, a small increase in the standard of service may offer a larger increase in the benefits of the project in comparison to the increase in costs.

Equally, an obvious question is whether now is the best time to undertake the project; delay may enable additional information to be collected. Again, where there is some existing provision, it may be more efficient to continue to use that provision until rising costs and/or the increased risk of failure of that existing system show that replacement would be more efficient.

It clearly makes sense to look at the options that have been adopted elsewhere. However, merely because an option was adopted elsewhere does not mean that it is the best option to be adopted in the country or region in question. What is the best option for charging for water is likely to be different in a city where current domestic consumption is nearly 1000 litres per person per day (Winnipeg, Canada) than in a city where supply is both intermittent and averages 70 litres per person per day (Taiyuan, China). Similarly, the appropriate water management strategy for food production is likely to be different in a country where there is 0.10 hectares of arable land per capita (China) to that in a country where there is nearly 0.90 hectares of arable land (USA). The appropriate water resource strategy in an arid climate (e.g. Australia) is likely to be different to that in a temperate climate (e.g. Germany). There has probably been far too much export of the solutions appropriate to one country to another in the past and there is a danger that this will continue in the future only in a different form. In the past, the export was of capital-intensive, technologically complex solutions; the risk is now that these will be replaced by the export of the environmental needs of the developed countries.

Similarly, it should be self-evident that those options that stakeholders propose ought to be considered both as potential options and to show respect for those stakeholders. Not to consider such an option or to dismiss it summarily sends a very clear message that those stakeholders are not going to be heard, let alone their concerns become incorporated into the appraisal.

Looking for the best options for the environment and the local community serve to bring these issues into focus. There may not be a clear-cut environmental best option; this is often true in coastal erosion projects where continued erosion may result in the loss of an important freshwater wetland whilst preventing erosion results in coastal squeeze and the loss of mudflats (Green and Penning-Rowsell 1999). As the World Commission on Dams (2000) has reported, as have many others before, the interests of the local communities most affected by a project are often the least considered. In each case, even if the best environmental and community options are not finally adopted, their consideration will make it clearer what are the concerns.

9.4 Criteria for Project Appraisal Tools

Decision aids, methods of helping us make choices, have themselves to be chosen. Several sets of criteria have, therefore, been proposed as the basis upon which to make this selection (Green, Tunstall and House 1989; Lichfield 1964; Nash, Pearce and Stanley 1975). One possible set of criteria (Penning-Rowsell *et al.* 1992) is:

- **Elucidation of the issues.** As a result of the analysis, all those interested in the decision should be left with a clearer understanding of the issues and the trade-offs involved than they had before the analysis was undertaken. This is the most basic criterion. As the emphasis in decision making shifts to stakeholder involvement, it becomes increasingly critical that project appraisal performs in a communications role, enabling the different stakeholders to understand the nature of the choice that must be made, including the differences between stakeholders in their definition and interpretation of the choice.
- **To simplify the issues.** Decisions are difficult not least because of their complexity; the project appraisal method must structure and organise the data and issues so that the decision is comprehensible.
- **Value basis.** The values and trade-offs in the analysis should be those of the public rather than those of some expert or specialist.

- **Completeness.** The method should be able to encompass all of the significant differences in the consequences of the different options and thus to cover all those objectives which should be considered in making the choice.
- **Rigour.** The analysis should be transparent and logical; the results should not depend upon who undertakes the analysis. In particular, rigour is essential to accountability, to the establishment of a clear audit trail.
- **Feasibility.** The methodology must be capable of application both within the time and resources which are available and within those which are appropriate to the importance of the decision.
- **Reliability.** Since decisions are about the future, a project appraisal method involves predicting the future. A method is reliable to the extent that the predictions embodied in it and consequently the prediction made as to the best option subsequently are borne out in the future.

If those interested in the decision are not left with a better understanding as to what the decision involves, then there are no advantages over tossing a coin. Thus, the most important test of a project appraisal is: do we have a better understanding of what the choice involves than we did before? Glyde (1992), reflecting on the lessons of probably the most important contingent valuation study yet undertaken (Imber *et al.* 1991), points out that when the results of a study are rejected, then it must be held to have failed.

Equally, decisions increasingly involve more data, in increasingly specialised forms, than can be assimilated and we bring more objectives and constraints to choices. It has been found that we cannot, on average, juggle more than seven considerations at once (Miller 1956), and a function of an appraisal method is thus to reduce complexity to a manageable level. However, it should not oversimplify reducing the problem below the level of complexity that we can handle since simplification can only be achieved by imposing a structure on the problem. So, elucidation and simplification are themselves conflicting criteria.

At the same time, there are too many decisions to make in a developed society; I neither wish nor have the time to participate in every collective decision that must be made. Hence, most decisions are left to institutions and I want those institutions to take those decisions that I would take had I the time and energy to be involved. Essentially, an important role of project appraisal is thus to routinise the trivial decisions so as to leave time for the important decisions. For those routine decisions, rigour, feasibility and their value basis of the project appraisal technique adopted are important considerations, with rigour being particularly important in that it promotes transparency and the establishment of an audit trail. Whilst the secrecy of a jury deliberation may be important in a trial, in other decisions, transparency is critical.

None of the available project appraisal techniques are clearly superior to all others against all of these criteria. The choice of the appraisal technique, or techniques, therefore needs to be made by considering the nature of the conflicts that make the choice necessary in the first place. Where it is conflicting objectives or differences between groups that are the central concerns, multi-criteria analysis is likely to be most appropriate. Conversely, the greater rigour of benefit–cost analysis (Section 13.2) is more appropriate to routine decisions which are left to different institutions to take.

10

Institutions for Managing Resources

Institutions matter: it is institutions, and the interaction between institutions, that largely both take decisions and implement those decisions as to water policy and water projects. Secondly, the form of the institutions makes a difference to the effectiveness of catchment management. In terms of improving the efficiency with which we use water, there are two concerns:

- Delivering integrated catchment management; and
- Delivering specific functional services within the context of that overall management strategy.

If we want integrated catchment management then there needs to be some mechanism to provide the coordination between the different functions. This mechanism can then be separate from the institutions that deliver the services and provide the functions. Even if we use market mechanisms to provide the services, the market must be structured so that it acts to achieve the wider objectives as well as controlled so that competitive pressures are maintained.

There are then two alternative mechanisms for service delivery: cooperation or competition. In turn, competition is necessary when cooperation would be against the public interest, but traditionally water services have been provided through cooperative structures in the form of common property management or through government, notably local government, or special-purpose bodies such as the levee districts (Harrison and Mooney 1993) or special-purpose water districts (California Department of Water Resources 1998) in the USA.

10.1 Catchment Management

Mostert *et al.* (1999) identify three possible models for catchment management:

- The administrative model, where water management is the responsibility of the provinces and municipalities whose boundaries are not based on hydrological boundaries.

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- The hydrological model, an organisational structure based on hydrological boundaries.
- The coordination model of a river basin commission which is charged with coordinating the activities of the provinces, municipalities and other bodies.

The differences in these models lie in their boundaries and in the mechanisms used to promote coordinated service delivery. The available mechanisms are: coercion, where the catchment administration orders other groups to adopt particular courses of action; narrow self-interest, where the catchment administration offers incentives to other groups to adopt particular courses of action; and cooperation, where the different bodies agree a plan and then take action to implement it. Money is the obvious example of a mechanism that uses narrow self-interest to promote the adoption of particular courses of action. In the first two cases, the catchment administration decides on a plan and then seeks to ensure that others act according to that plan. But in the last case, the plan is essentially a widely shared vision of the future.

All three models have been tried, the most famous example of the hydrological model being the Tennessee Valley Authority (Miller and Reidinger 1998) which has, with varying degrees of success, been exported to China and Africa (Adams 1992; Barrow 1998). However, the coordination model will often be the forced solution when constitutionally the powers necessary to achieve integrated catchment management are reserved to provincial or municipal government but the catchment crosses several or many administrative areas. The Ruhrverband (Kneese and Bower 1968), although limited both functionally and geographically, is the best known example of administrative areas recognising that they had to coordinate their activities within an agreed plan if water management was to be successful. ORSANCO in the USA (Vicory 2001) and the Murray–Darling Basin Commission (Pigram 1999) in Australia are notable examples of this approach, both in countries with weak federal systems and constitutionally reserved powers to the provincial governments. Only through the provinces agreeing to form a compact to coordinate their activities could a catchment-based approach be implemented. On the other hand, in another weak federal system, that of Germany where water management is constitutionally reserved to the provincial governments, achieving catchment management is a problem. Again, in the USA, for smaller scale catchments, the cooperative approach is necessarily being developed (e.g. Center for Watershed Protection 1996; Personett 2001). In the case of international rivers, a cooperative approach is the only option; of these, the International Rhine Commission (Academie de l'eau 1998) appears to be the most successful. In turn, the best place to learn lessons about the cooperative model is then in those situations where there is no other possible option.

On the other hand, France chose a cooperative approach in the form of the Agence Bassin (Barraque *et al.* 1994; Barraque 1999). In many ways, this has resulted in one of the most successful catchment management systems but one that has had to fight off political challenges from other branches of government, notably the Finance Ministry (Commissariat General du Plan 1997). Similar approaches are being adopted elsewhere, notably in Mexico (Wester *et al.* n.d.) and Chile (Academie de l'eau n.d.). Again, as part of the COAG water reforms, the states in Australia are developing innovative forms of stakeholder-driven cooperative catchment management (Comino 2001; New South Wales Government 1986), as they are in, for example, India (Turton and Farrington 1998) and elsewhere by NGOs in particular, although Marshall (2000) argues that our desire for stakeholder-driven integrated catchment management has outrun our ability to deliver it.

Because of the necessary boundary problem in institutions, the number of policy and management areas that overlap with catchment management, and the number of different policy tools and instruments necessary to implement integrated catchment management, the cooperative model looks like the best approach. In this model, the involvement of the stakeholders should then result in a plan that is a widely shared vision of the future, one to which the stakeholders commit themselves. How that plan is then implemented, and how the behaviour of individuals and organisations is to be changed so that they act in accordance with the plan, is discussed in Chapter 11. What is, however, certain is that they need some power to raise the monies necessary to implement those actions; who provides the money, has the power. A strength of the Agence Bassin is that they have powers to levy charges on abstraction and wastewater discharges which revenue can then be used in the form of grants and soft loans to finance works that are agreed in accordance with the plan (Barraque *et al.* 1994).

Ostrom's (1990) eight rules for effective common property management provide a core for the delivery for integrated, participative catchment management but the reviews of such systems in the USA argue that it is too soon to tell what works and what does not (Adler and Straube 2000; Imperial and Hennessey 2000).

10.2 Service Delivery

The choice is between cooperatives or competition whilst the issue is which will provide the greatest efficiency in the particular circumstances. To the economist, privatisation is no more than a means to create, if possible, competition, since a monopoly is expected to be inefficient whether it is a private or public monopoly. The only difference between a private and a public monopoly is that they are expected to be inefficient in different ways: the first, to extract an excessive profit and the latter to provide a poor service to the consumers. There are then three basic models for service delivery:

- in the form of special-purpose common property bodies;
- various forms of privatisation; and
- municipal companies.

The first is sometimes misleadingly included within the privatisation category but it is quite distinct from a private company in that the owners are the consumers so that there is an identity of interest. Conversely, under the private company model, there is usually little or no, and only an incidental, overlap between the owners, the shareholders and the consumers. The interest of the owners is then to maximise long-term profits and the latter to maximise the ratio of service quality to cost, and the only ways to bring the two sets of interest into alignment are competition or regulation.

The third approach is a specialised company wholly owned by one or more municipalities or other elected local governments. This was the traditional form of delivery of water and sewerage services and continues to be particularly strong in the Netherlands (Blokland *et al.* 1999) and in other parts of Europe, notably Germany and Austria.

10.2.1 Common property management

The model was developed in societies that were labour rich and cash poor and, in the past, this was probably the predominant form of water management, especially for agriculture (Wagret 1967). The benefits of economies of scale promoted collective action in irrigation (e.g. Tardieu n.d.), land drainage (e.g. Huisman 2000) and flood control (e.g. Zorkoczy 1993). Amongst the advantages of the model is that the owner and consumers are the same people and consequently there is pressure both to maximise performance and to reduce costs whether these costs be in the form of contributed labour or cash. That the system belongs to all and is managed by all creates strong normative social pressures on individuals, although those who are already powerful maintain their power to influence the group decisions (Mehta n.d.). Finally, it is clearly this approach which achieves the maximum of public involvement.

As an approach, it has been rediscovered in recent years; irrigation schemes are increasingly being turned over to the farmers who serve the system with Water User Associations being established to operate the schemes (e.g. Bruns and Atmanto 1992). There are, however, a whole range of other forms of service in which a common property management approach has been tried including condominial sewerage systems (Otis and Mara 1985), rural water supplies (Evans and Appleton 1993) and projects such as that in Orangi (Zaidi 2000). In developed countries, there are an increasing number of community-based projects (e.g. Pinkham *et al.* 1999) that approximate to a common property management approach.

However, the common property management approach presupposes that either there is an existing community or that one can be created. Thus, White (1997) argues that the success of farmer-managed irrigation services in Haiti are a consequence of the strong tradition of collective action, the strong role of social norms favouring collective action, and the recognition within the society of the importance of banking favours. Agarwal (n.d.) argues that when seeking to establish communal water harvesting systems, the first two years of any programme must be spent on social mobilisation. Moreover, this presupposes that there is at least a latent community to which an appropriate project form can be mapped, it being important to map the project to the community rather than attempting to create a community than matches the project (Schoeffel 1995).

Ostrom (1990) proposes eight principles as being necessary for common property resource management to be a success:

- the user group and the resource both have well-defined boundaries;
- the use rules are appropriate to local conditions;
- the users can participate in rule modification;
- the users themselves monitor compliance;
- the users themselves enforce compliance through graduated sanctions;
- there are low-cost methods of conflict resolution;
- user groups have quasi-independence from higher forms of government; and
- in complex cases, the regime is organised in a federal, hierarchical form.

The problem for catchment management is then one of seeking to coordinate the actions of an almost feudal system of geographical small-scale, single-purpose organisations into one holistic approach to the management of the catchment. That the organisations are usually single functional also tends to mean that their locus of concern may exclude wider concerns; thus, the waterschappen in the Netherlands have been called ‘farmer republics’ because they were elected largely by farmers and tended to exclude any other interest other than that of the farmers when they made decisions.

10.2.2 Municipal management

In urban areas, the development of water supply and sanitation in the nineteenth and twentieth centuries was almost exclusively undertaken by the municipalities (Hassan 1998; Hietala 1987). Particularly in those countries where local governments have constitutionally protected powers and entitlements to tax revenues, notably Germany and France, the municipal model continues to be important. In particular, it continues to be the primary mode of provision in the Netherlands (Blokland *et al.* 1999) and also Sweden (Gustafsson 2001), and one which after the initial somewhat dogmatic enthusiasm for privatisation is being considered more closely (Hall 2001).

There appear to have been many reasons for the importance of municipal provision. The first is externalities of provision: water and sanitation works were partly undertaken as a response to the outbreaks of cholera and typhoid which spread to those who had their own drinking water and sanitation from those who had not. The second is philosophical; John Stuart Mill (1848) was in favour of provision of services by voluntary associations and municipalities, and was almost as acerbic about the capabilities of joint stock companies as he was about central government. He was opposed to the provision of water services through private companies (Schwartz 1966), and indeed the granting of a monopoly to any private company (Mill 1848); and he was caustic about their performance: '... the gas and water companies, among which, though perfect freedom is allowed to competition, none really takes place, and practically they are found to be even more irresponsible, and unapproachable by individual complaints, than the government' (Mill 1848). But, perhaps surprisingly in this period of liberal economics there was a strong reluctance to allow private companies to profit from the supply of water and *laissez-faire* principles were seen as limited in their application (Taylor 1972). In turn, as Mill concluded, it proved extremely difficult to introduce competition into water supply and sanitation and where it occurred, the result was inefficiencies (e.g. two companies' pipes down the same street) rather than efficiency (Hassan 1998).

Thirdly, the only practical means of charging for sanitation is effectively through a tax whether this tax is levied on a per property basis or as an addition to a charge for water supply. It has been commonly asserted that only governments have the right to levy a tax, with the public demanding accountability of that government. Fourthly, municipalities had access to cheap money in the form of long-term loans at much better rates of interest and periods than any private company could obtain and certainly lower than the rates of return demanded on share capital (Alexander and Mayer 1997; NERA 1999).

Most of these advantages remain true and the municipal model is still the default model for water and sewerage provision because they can be very efficient (Shirley *et al.* 2000); they provide accountability to the consumer; they avoid the problems of trying to introduce competition in what is generally a natural monopoly; and municipal companies can generally borrow money at better rates than can private companies. In turn, because water and sewerage services are so capital intensive, the cost of capital either borrowed or equity effectively determines the cost of provision.

Conversely, these comparative advantages can be offset by other problems that may suggest instead that privatisation of the services is the only way to improve the standards of service. These problems tend to be macro-economic and political rather than concerned with service provision per se. If the country has a poor credit rating then it may no longer be true that the cost of public borrowing is less than the cost of private capital. Again, corruption may be so endemic that only a radical change is seen as a way to reduce if not eliminate it; there are a number of well-known water supply systems where as soon as chlorine goes in the front door, it is sold out of the back door, or where your water bill depends upon how much you bribe the meter reader. Equally, since each contract requires a pay-off, the costs of constructing works may be higher in the public sector than in the private sector. Public services may also be largely politically controlled as a way of rewarding voters or other client groups. Again, the public sector is often a way of soaking up graduate employment so that public agencies are overstaffed, although pay levels will also be low. A consequent problem may then be that any attempt to provide training and institutional support simply serves to enable those trained to find higher paid jobs in the private sector or abroad. It may consequently be reasonable to consider public agencies as a training agency as well as a service provider.

10.2.3 Competition

The economist's mantra of 'why are you doing this, what is the problem and what are the alternatives?' is perhaps particularly important in this context because it is often not clear exactly why privatisation is on the agenda. From a purely economic standpoint, the critical issue is the extent to which it is possible to introduce competition: in turn, this depends upon the extent to which there are economies of scale and/or scope. The greater these are then the more quickly will the market collapse into monopoly if it does not start as one.

Secondly, there is an apparent conflict between the Dublin criterion of increasing public involvement in water management and the introduction of privatisation which reduces citizens to consumers. From the Dublin principles it necessarily follows that any change in the institutional structure of water and sanitation must be undertaken through a process of discussion and negotiation with all of the principal stakeholders, most notably the consumers. This is particularly true in developing countries where the consumers and communities have commonly already invested in some form of water supply and sanitation and where the most effective means of extending water and wastewater services is likely to involve working with those communities (Sections 14.6.1 and 16.1.1). The most dramatic failures of attempts to introduce privatisation have been those where it was attempted to introduce privatisation by fiat (Hasan 2001; Lobina 2000) and where it was forgotten that privatisation is no more than a potential means of improving the quality of service and cost of that service to the consumer.

From a wider perspective, there are a variety of reasons why privatisation may be an appropriate option (Green 2001b). Of these, the institutional problems of the existing utility are often an important driver. In some cases, the levels of corruption or sclerosis within the existing organisation may be such that only the most radical change has a chance of introducing efficiency to the organisation. Or, it may simply seem easier to pass the problems off to someone else rather than to try to solve them. For politicians, this has the great advantage of giving them someone else to blame for any subsequent problems and failures.

A second reason is that the requirements for capital investment to expand and upgrade services may be very high. This inevitably means that prices will have to rise. The dominant school of macro-economists has held that who is responsible for the debt, whether this is a governmental or quasi-governmental organisation or a private firm, is more important than the cost of raising and servicing that debt. In this case, privatisation has the virtue of shifting debt out of the public sector and into the private sector.

In addition to the institutional issues, there is typically a range of service problems as well. In the developed world, the problem facing a wastewater or water supplier is likely to be the requirement for heavy investment to improve treatment standards. In less developed countries, the problems facing the suppliers are likely to be:

- expanding connections to all urban customers; and
- expanding supply to customers (e.g. to c. 100 litres/person/day).

There are also likely to be all sorts of operational and other problems including high levels of leakage. There are some general rules concerning privatisation that seem to emerge from world experience (Green 2001b):

- Don't sell the infrastructure with the aim of raising money for the government.
- Don't follow the model of England and Wales: adopt the concession approach.
- In so far as there are not significant economies of scale and scope, let the concession be in separate parts and functions.
- The contract must be let on a competitive tender basis.
- True competition must be promoted and certainly not discouraged.
- The contract must be a public document.
- The relations between the concessionaire and the parent company must be clearly defined.
- There must be a sophisticated system of regulation in place to ensure that the supplier complies with the contract in terms of service standards and to control prices.
- In developing countries, a major problem is often that the coverage of the services is well below 100% of the population and expanding the service to reach 100% will involve major capital expenditure. It is necessary to decide how this expansion will be funded.
- There must be an exit strategy in place so that wastewater and water services will continue if the supplier goes bankrupt, the contract is terminated because of a failure in compliance by the company, or the company decides that the contract is no longer profitable.
- There must be a requirement that the supplier shall let all major engineering and construction works through competitive tender.
- The structure of the contract and the pricing mechanisms must be such as to promote sustainable water management; options such as rainwater harvesting, source control, demand management and reuse/recycling are to be encouraged rather than forbidden.
- The contract must specify how particular risks are to be shared between the concessionaire and the government.
- Finally, privatisation is only one option amongst several with regard to the institutional arrangements for supplying wastewater and water services. A comparative assessment needs to be made as to the advantages and disadvantages

of each before one form of privatisation is adopted; in turn, such a comparison implies that a privatisation option will not always be the best option.

10.2.4 Comparative advantages

It is difficult to compare the relative efficiency of different service providers, particularly between countries, since efficiency is the ratio of output to inputs. It is particularly difficult to do so between countries where the relative costs of labour and capital can be very different, especially where some services are contracted out. Contracting out services to private companies can then give a superficial appearance that, for example, the ratio of supply points to employees is higher in one area than another. Equally, lower charges for water may simply reflect lower qualities of service, or economies of scale, or simply different conditions (e.g. ample groundwater may be available in one area whereas another must rely on long-distance transfer and pumping), or that the capital costs were incurred many years ago so that loan repayments have been much reduced through inflation. The different systems of performance indicators (OFWAT 2000a; VEWIN 2001; World Bank 1999a) should therefore be used with care. For example, Hall and Lanz (2001) report that in France, charges are 14% higher where the service is provided by private water and sewerage companies than when it is provided by a public body. This is interesting rather than decisive evidence. More generally, it is not unreasonable to expect that the communes let a concession when the capital costs of provision will be high. For example, the extent of municipal provision of water services in Germany is probably associated with the reliance on groundwater for water supply in Germany.

Table 10.1 gives a number of criteria that might be used to make this comparison between different strategies of provision. There are arguments that private companies are inherently more efficient than public bodies (Shirley and Walsh 2000). This is an ‘on average’ argument: it clearly cannot be claimed that all private companies are always more efficient than all public bodies, not least because we all have had experience of some incompetent private companies. At times, where private companies have performed badly, the blame at least partly lies with the structure in which they operate. Bakker and Hemson (2000) partly blame the structure in which ‘build–operate–train and transfer’ was introduced in South Africa, as well as the structure of the concessionaire, for the poor performance of the system.

But, at the same time, equity finance is generally more expensive than debt finance (Alexander and Mayer 1997; Haarmeyer and Mody 1998; NERA 1999) where the cost of debt depends upon the creditworthiness of the country where the debt is incurred rather than of the particular company (Haarmeyer and Mody 1998).

Finally, two sets of social relationships will change through privatisation. Firstly, a primary benefit for politicians of privatisation is that they will have someone to blame; and they will blame the concessionaire for all problems of

Table 10.1 *Performance of privatisation compared to some form of ownership by the public*

Criterion	Relative performance of privatisation
Cost of capital	Higher: equity capital is more expensive than debt financing
Efficiency	Higher ? – the workforce will be reduced but reductions in labour costs do not necessarily result in a reduction in total costs, nor does a reduction in cost necessarily translate into lower prices
Technological transfer	Higher: multinational companies will usually be involved and they will be more aware of technological advances
Government bad	Essentially an ideological argument
Accountability	Lower: to shareholders rather than to the public
Public involvement	Lower
Regulatory burden	Higher and expensive: this is probably desirable in itself but the country may have a scarcity of expertise in precisely those areas required for effective regulation
Environmental performance	Higher but because of forced separation of gamekeeper and poacher roles; this separation is desirable in itself but does not require privatisation to be achieved
Reduction in public debt	There is a dangerous tendency for privatisations being undertaken in a form that maximises the price the government gets for the utility rather than the long-term least cost solution
Reduction in government expenditure	Yes, but since the public will now pay as consumers instead of as tax payers, the economic question is whether this cost will be lower or more equitably distributed?

whatever form. Secondly, the consumer–company relationship is quite different from those of voter–government and citizen–society. Consumers expect to get what they have paid for; any problems are then ones for the supplier and not for the consumer. This change has particularly important implications for drought management plans as calls for voluntary reductions in demand are likely to be much less effective in a privatised regime than when water supply is owned directly or indirectly by the consumers. Since calls for voluntary reductions typically result in a 25% cut in demand (USACE 1994), this is potentially a significant problem. On the same basis, it might also be expected that compliance with mandatory demand cuts will also be lower under privatisation.

In the longer term, it may be questioned whether models of privatisation other than the concessionaire approach have a future. There are two reasons why it is not self-evident that approaches to privatisation on the English and Welsh model are sustainable in the long run. Firstly, mutuals owned by their customers or municipalities can be financed through debt at a lower cost than through equity capital. The 'Glas' model in Wales is a possible model of this development where the operation of the facilities has been let out on a competitive tender basis (OFWAT 2000c). Potentially, this gives the advantages of competition without creating a monopoly.

Secondly, the expertise of the multinational companies is in designing, building and operating plants. It does not make very good sense for them to tie up very large amounts of capital in then owning that plant when inevitably the return on capital will be driven down to realistic rates. Nor is an industry where demand will eventually fall whilst the costs of quality increase one that looks a particularly good industry in which to invest. One model for the development of the companies is then to increasingly act as operators of public facilities, owned by mutuals, and to sell package services to large consumers (Ernst & Young 1999).

11

Implementing Decisions: Inducing Change

A policy or plan without a means of implementing that policy or plan is an empty gesture; it may make the originators feel good, which may be the main purpose of the policy or plan, but it will have no practical effect. Equally, part of the review of options that went into the decision process should have included a comparison of alternative strategies for implementing that policy or plan. This is obviously particularly important when it is the actions of other stakeholders that will need to change. However, the plan itself should have been developed with the stakeholders as a widely shared vision of the future so that the stakeholders take ownership of the plan.

The actions that it is desired that the different actors adopt may be to use water more efficiently, reduce demand, reduce abstraction, adopt source control, treat wastewater before discharging it, and so forth. The two options are to use a carrot and/or a stick; to encourage change or force change. At the same time, it is also necessary to identify the barriers to adopting the actions we hope to promote and specifically to address those barriers either by removing them or by providing a sufficient incentive to overcome them. However, conventionally, economics assumes that only economic incentives have any real effect and that they are always effective. In practice, prices do not seem a very effective way of inducing change in the behaviour of the different actors. In consequence, a wider range of possible carrots and sticks needs to be considered.

11.1 Barriers

A lack of knowledge is one obvious barrier to change; people cannot change their behaviour until they are aware that an alternative behaviour is possible. One of the roles of waste minimisation clubs (Johnston 1994) is to reduce the 'costs' of access to information and to provide the individual actor with a comparative assessment of his or her performance. Unless it is possible to change, then no change is possible; in the absence of a suitable technology, we cannot expect

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change to occur. For example, permeable pavements as means of source control are only considered to be suitable for lightly trafficked roads (Office of Water 1999) otherwise they would be a convenient strategy for handling the increases in rainfall intensity that appear to be occurring in some areas as a result of climate change (Hurd *et al.* 1996). However, the very purpose of signalling that the change is desirable may be to promote the development of the technologies that will make the change possible. Similarly, it is concluded in Section 14.5.1 that domestic water demand is to a large extent determined by technological factors so that unless low flow shower heads, low flush toilet cisterns and front-loading washing machines are available, there is comparatively little scope for the consumer to make significant reductions in internal water use.

If people do not have the resources, defined in the widest sense of skills, time and money, to make the change then no change can be expected. The poor will typically have limited access to capital and that at a very high cost; changes which involve the investment of capital will then be particularly difficult to promote. Reducing the cost of capital through micro-credit facilities (Saywell 1999) may then be necessary if the change is to be encouraged. The success of systems like condominial sewerage systems (Otis and Mara 1985) thus are the result of redirecting the burden away from a resource that is scarce: capital, to a resource that it is relatively plentiful: voluntary labour.

A weakness of the use of charges to change behaviour is that it reduces the money resources available to the actor to make that change. A way around this problem is to hypothecate the income from the charge to provide soft loans and grants for the purposes of undertaking works that will result in the change that is desired. The comparative success of the charging systems for wastewater adopted in the Netherlands and France is ascribed to the hypothecation of the revenue in this way (Andersen 1994).

Legal barriers are relatively commonplace; government agencies and departments cannot act except in regard to the powers that they have, including the restrictions upon the purposes for which they can spend money. It may, therefore, be necessary to change the boundaries of the relevant institution and one of the unanswered questions concerning catchment management is whether it is possible to have multifunctional management whilst having functional budgets (Green, Johnson and Penning-Rowsell *et al.* 2001).

Tenants may be expected to be reluctant to make investments where they cannot recover the costs when and if they leave that property. The legal definition of a 'sewer' has also been argued to have a chilling effect on the willingness of developers to construct source control measures in new developments (Howarth 1992).

Social/cultural barriers may restrict the adoption of a particular technology; for example, treadle pumps for irrigation can greatly increase agricultural productivity but women may feel too exposed when using them (IPTRID 2000). Making unrealistic assumptions about gender roles or assuming that women would be prepared to sacrifice their resources for the gain of male members of the household have been common problems in projects in the past (Zwarteveen 1997).

Given the obsessive concern with the cleanliness of WCs in the UK and the USA, and the related heavy proportion of products that claim to kill all known germs, there may be problems of cultural adaptation to low flush toilet cisterns or waterless toilets. A number of religions require washing at particular times or occasions and those behaviours will be particularly resistant to change.

There are in addition purely practical barriers; source control tends to take up significant amounts of land and this limits the possible density of development. In turn, high density development may be desirable for planning or community reasons, or simply be the consequence of high land prices.

11.2 Prices/Charges/Subsidies

Economists usually assume that prices always work but that nothing else does. This leaves us with a very restricted range of policy tools. In practice, prices do not seem to work particularly well in water management as a means of changing behaviour, and other tools can be more effective. It needs also to be noted that prices themselves do not change behaviour, they only provide an incentive and a signal for people to change their behaviour. Thus, water metering does not reduce demand for water but people may respond to the signal provided by metering and incentive given by charging by volume to change their behaviours in ways that result in a reduction in water demand. In turn, prices can only work to the extent to which there are the means to change behaviour, and people know what these means are, or can find out at a relatively low cost.

Although conventionally economists believe that only prices, or market-like instruments, are effective in changing behaviour, in practice prices often seem relatively ineffective at changing behaviour. The results from waste minimisation studies around the world consistently show that industrial firms are using 15–25% more water than the amount that would maximise their profitability (e.g. ETBPP 1997; Porter and van der Linde 1995). In part, such reductions are possible because reducing water intake can often save money in four ways: through the reduction in the consumption of water, reduced wastewater charges, reduction in energy usage and a reduction in the raw materials lost.

Secondly, short-term price elasticities are typically low, in the order of −0.1 to −0.2 (Herrington 1987), so that doubling water prices is necessary in order to induce, respectively, a 10% or 20% reduction in demand. There are obvious political problems with doubling prices to achieve a relatively small change in demand. Equally, for the water supplier, metering is a high risk strategy as it means that revenue falls if demand falls (Section 15.1.2). That companies who pay for water on a metered basis still use more water than would maximise their profitability suggests that price elasticities may measure no more than the extent of market failure; that technical elasticity is considerably higher than revealed elasticities. This increases the revenue risks to the water supplier as the response to a price rise may be a considerably greater fall in demand and hence revenue than was predicted. On the other hand, a somewhat cynical view is that farmers perform very closely to the hypothetical economic person: provided that they are given a large enough subsidy, they will produce whatever you want, be this wheat or butterflies.

In addition, in water management, there are:

- strong economies of scale; and
- a high degree of interdependencies between the actions of individuals.

So, we often should seek to promote cooperative, collective action rather than action by the individual if we are to achieve the efficient solution. For example, it will often result in an inefficient outcome if individuals all construct their own cesspits, or flood-proof their properties, or construct on-site detention basins. In each case, economies of scale will often, and especially in urban areas, make collective provision a more efficient solution.

Secondly, a catchment is a system and one with pronounced spatial differentiation. As a result, the consequences of the action of one individual depend upon what actions other individuals undertake. Externalities are simple interdependencies, with the effect flowing in one direction, but in a catchment the interactions can be two-way with actions of one individual affecting another whose actions in turn affect the first (Falkenmark and Lundqvist 1999). In some cases, the result can be positive feedback making things worse rather than better. For example, suppose that everyone on a catchment installs source control to hold the 10-year return period rainfall event, after which storage is released. When, say, the 20-year return period rainstorm occurs, not only will the storage capacity be full so that the peak rainfall intensity is unattenuated, but the storage from the earlier part of the rainstorm may also be released. The result may be flooding that is more severe than if nobody had installed source control. To create a pricing system that reflects these differences adequately is likely to be expensive and imposing a low variety system through regulations may be much simpler to manage.

Next, we are seldom so lucky as to be in a 'second-best' situation (Lipsey and Lancaster 1956–7); if we impose a charge on a negative externality, the effect may be to make things worse if it shifts actions towards those that impose larger but different externalities. When land use imposes multiple externalities, the logic is to examine the relative importance of the different externalities and decide where to begin to introduce charges in a way that reduces the total magnitude of the externalities from all sources.

The other risk with introducing charges on externalities is that they will be captured by the finance ministry. Finance ministries operate on only two principles: to maximise revenue and to stop government spending any of that revenue. Introducing charges on environmental externalities have two great advantages to a finance ministry. Firstly, they are taxes on sin and hence difficult for anyone to object to; secondly, they are relatively invisible as compared to taxes on income, sales or property. In turn, rather than be set at the level which will change behaviours, the likelihood is that the finance ministry will seek to ensure that they are set at a level that maximises tax revenue. Hypothetication of the revenue, reserving it to a specific purpose, as is the case with charges on water pollution in France and the Netherlands (Andersen 1994) avoids this problem. However, it does introduce other risks notably that the revenue will be spent simply because it exists and the creation of a very complex system of hypothecated charges, which is resistant to reform.

Finally, as discussed in Section 8.2, exchanges define or are defined by social relations. A complaint that has been made by industry about charges on pollution is that it creates a right to pollute; legally it does not, socially it does as a price buys a right to consume. Similarly, Thomas and Syme (1988), in a contingent valuation study of the price elasticity of domestic water demand found that high income groups were quite prepared to pay large sums to use water for external purposes. The way they framed the issue was in terms of buying a right to use water for these purposes in all circumstances rather than as a payment for the water they used.

11.3 Motivations and Changing Behaviour

That people are motivated wholly by narrow self-interest does not seem to be true; the evidence concerning behaviour related to sustainable behaviours suggests that life is more complicated and that social or environmental value orientations are a determinant of such behaviours (e.g. Aragon-Correa and Llorens-Montes 1997).

11.4 Social Norms

Social norms are a significant influence on very mundane consumer behaviour (Ryan and Bonfield 1975). Hence, mobilising social norms to change behaviours with regard to collective goods is quite effective; people do what they think other people do and groups also impose sanctions on deviants. Thus, the USACE (1994) report that calls for voluntary reductions in water use can result in falls of 25% in demand. In Indonesia, the government has established a system of rating the pollution performance of industrial concerns from world leaders down to very poor; the rate of improvement in the worst performers is impressive (Wheeler *et al*. 2000). Again, voluntary approaches to pollution control in Japan are reported to have been successful (Imura 1999). More generally, if there is not a social norm that consumers will pay for a good or service, or that social norm breaks down, then the market model will collapse.

For this to work, it is necessary to have a community and some clear social norms that are established by that community (Cleaver 2000). Creating stakeholder organisations then creates a forum in which strong social pressures can be put upon deviant members to comply with group decisions. At a crude level, one reason for the success of the Agence Bassin (Barraque 1999) is that executives of companies that resist complying with the plan suspect that they will be black-balled from the golf club they want to join. Thus, Alan Vicory (2001), the Executive Director of Ohio River Valley Water Sanitation Commission (ORSANCO), has argued that the critical issue in catchment management is to resolve the relationships between the stakeholders and that for this to occur, there needs to be a forum for the stakeholders. A governor of an upper stream state comes under considerable pressure from the members of other states, including those not directly effected, to change the policies of that state. Again, Crichton (2001) reports that in flood management groups in Scotland, similar pressures are exerted on members to comply with the group's policy. Equally, the literature on juries shows that jurors feel under strong pressure to either agree with the majority verdict or to reach a compromise (Young *et al.* 1999). Indeed, sometimes the force of the social norms established are quite scary; in Switzerland, one group of spies were caught because they were making a noise after 10 p.m. on a Sunday and a neighbour reported them to the police.

This example illustrates one advantage of the social norms approach; it multiplies the number of enforcers. Equally, it can be argued that social norms underlie all of the approaches; unless there is a social norm to comply with regulations or to pay charges, then compliance will be so low as to cause the regulatory or charge approach to be ineffective. If the majority of water connections are illegal then introducing metering is meaningless, as it is if the consumer can simply bribe the meter reader to record whatever amount of water the consumer chooses to pay for.

11.5 Regulations

Two very desirable characteristics of any system of control are that there is predictability and transparency; that it is immediately obvious what it is desired that people should do. The great virtue of regulations can then be that they are simple, transparent and clearly define the behaviour that is desired. The disadvantage of economic instruments is that those whose behaviour it is sought to influence have to decide what they should do. It costs them time and money to determine what to do. Regulations can then offer economies of scale to those whose behaviour it is intended to influence; it is likely to be considerably cheaper to require that toilet cisterns have a maximum flush capacity than for several million households to each determine the relative economics of installing cisterns of different sizes.

The transaction costs of regulation can also be low and will usually be lower than for economic instruments. A regulation that no chimney shall emit visible black smoke is easy to apply and to check, including by neighbours. Conversely, if a charge is applied based upon the weight of particles emitted above a certain size, then measuring equipment has to be installed on all relevant chimneys. This equipment then has to be checked and the records audited. If tradable permits for emissions are issued then, in addition, public available records have to be maintained and a system for trading permits also has to be established.

This is an example of the advantages of reducing variety; the virtue of pricing and competition is that it will generate innovations. But some of those innovations will simply be ways of avoiding the charges without satisfying the intent of the charging mechanism in the same way that taxation generates tax specialists who seek ways of avoiding taxation by finding loopholes in the tax law. In turn, governments then spend time seeking to close those loopholes. Neither activity contributes anything to economic efficiency. In principle, therefore, any pricing mechanism needs to cover all possible ways of responding to those price incentives. Conversely, regulation can either restrict allowable responses to a given range or exclude some behaviours altogether. A combination of regulations to define the boundaries of permissible behaviour and prices within that range is then the traditional model of a market – laws covering weights and measures were introduced very early into markets.

Where behaviour is determined by technology then it will be considerably cheaper to mandate the use of a particular standard of performance that can be achieved by that technology than to start by instituting a pricing mechanism with incentives such that people will then adopt that technology. For example, domestic water demand is markedly determined by technological factors (Section 14.4.1); therefore, establishing regulations that define the maximum water usage of a washing machine can save everyone a great deal of time and effort. Conversely, a virtue of adopting a price mechanism is then that it may spur the development of a new technology that will achieve the desired end at a lower cost than existing technologies. In addition, it will tend to increase demand for such technologies which may in turn drive down costs.

Regulation is more efficient in practice when it defines the ends rather than the means; when it mandates the maximum flush volume of a toilet cistern than when it specifies the technology to be used to achieve that flush volume (e.g. flapper valve or siphonic action). If we define the ends then we can hope that competitive pressures will result in innovations that can deliver these ends at lower costs. The weakness of regulation is when it freezes technology at a particular state rather than promoting change.

11.6 Comparative Advantages and Disadvantages

The economist's perpetual cry is: what are the alternatives? It should not then be assumed that there is only one way of changing people's behaviour and the whole range of possible ways of both signalling a change is desired and of providing an incentive to that change need to be examined on a case-by-case basis. In this comparison, the transaction costs and the costs of information to all parties need to be considered and may indeed form a large part of the total costs. One way of reducing those costs is then to reduce the variety of possible actions that each individual must consider.

Equally, since the purpose is to change the world, the actions should promote further change where that change will further the intent of the intervention. We want to encourage better and cheaper means of achieving our ends; the ends therefore need to be clearly signalled.

There will also be some behaviours that are not economically practical to change, or are not feasible to change. For example, in the UK, gardens are being converted to hard standings for car parking; the effect is to increase the proportion of rainfall that is converted to runoff and to increase urban flood problems. It is unlikely that either regulations or charges for runoff would be effective means of controlling this problem; the regulatory approach would require that households knew that there is a restriction and the costs of instituting a charge could well exceed the revenue generated.

Some general criteria that might then be used to appraise alternative means of inducing changes in behaviour:

- *Theoretical efficiency*: performance compared to the theoretical position where the required or optimal reduction in pollution is achieved at the lowest possible cost.
- *Administrative cost*: the costs to regulators of monitoring pollution, maintaining records, undertaking inspections and, in the case of tradable permits, creating and maintaining a market.
- *Science base required*: the level of knowledge required as to the physical, chemical and biological processes involved together with the data on the particular media in the specific location. This has a cost but there is also a limit at any point in time; for example, new pesticides may be introduced ahead of any technical means of detecting residues of those pesticides in water, food or animals. The requirement is that the intervention strategy can work successfully with very imperfect information.
- *Adaptability to changes in supply and demand*: adaptability to both exogenously determined changes in the receiving media (e.g. as a result of climate change) and to new entrants who will pollute.
- *Compliance cost to the polluter*: the costs to polluters of monitoring, maintaining records, applying for necessary licences or permits tradable or otherwise.
- *Probability of effect*: how certain it is possible to be in advance that the expected change in pollution will actually be achieved.
- *Transparency to the polluter*: the certainty which the polluter has as to how to respond to the stimulus in the best manner and, indeed, what change in behaviour is required.
- *Risk of regulatory capture*: the likelihood that the regulator will only require what the polluters claim that they can afford to deliver.

- *Revenue raised*: the 'tax' revenue raised; finance ministries are attracted to new ways of raising tax revenue and 'green taxes' are particularly attractive as they are hidden and have a moral connotation.
- *Dependency upon the approximation to a perfect, competitive market*: the extent to which the intervention to work in the predicted way and to achieve what is expected the strategy relies upon the assumption of a perfect competitive market. Conversely, the extent to which imperfections in the market will result in either failure to achieve the desired end, undesirable effects or unexpected effects.
- *Incentive effect to technological innovation*: the extent to which the measure induces technological innovation or otherwise drives down costs, or, conversely, tends to freeze technology in its current state.
- *Maintains res commune*: it should not require the creation of new private entitlements at the expense of common property rights (or those of other individuals) unless the ideological argument for such a shift has been first accepted.
- *Degree to which short-run efficiency promotes long-run efficiency*: if the demand for pollution abatement is income elastic then in the long run the optimum level of pollution is likely to shift downwards. Any such effect will be amplified by technological innovations which drive down the marginal cost of pollution abatement. If pollution abatement is capital intensive, then these changes should not necessarily require the complete replacement of existing capital stocks. For example, the UK was in the process of building long sea outfalls to discharge raw sewage, relying upon dispersal and dilution, when a policy shift to a requiring treatment before discharge occurred. In effect, something like £800 million was wasted on constructing such long sea outfalls.
- *Dependency upon other externalities being taken into account*: it is unlikely that the externalities of any individual or company are limited to a single form of externality. That there may be multiple externalities is, for example, recognised by the multimedia approach which the Environment Agency was set up to achieve. In such circumstances, a reduction in one form of externality may simply result in an increase in other externalities; the result might then be a decrease in economic efficiency.

Absent from this list is the effect on international competitiveness. This is because there are no clear-cut answers. There is usually a concern that Pigovian taxes will affect international competitiveness, particularly on imports since taxes on goods going for export could be rebated. This is more generally an argument that requiring tougher environmental standards will affect the home country's industry competitiveness as compared to industry based in countries with lower environmental standards. For a given environmental standard, Pigovian taxes or tradable permits ought, theoretically, to have less effect upon international competitiveness than the other two alternatives. Very high Pigovian taxes are calculated from studies of price elasticity needed in order to have a required effect and these would damage competitiveness. But, as I have argued earlier, price inelasticity is often no more than a sign of market failure, firms failing to respond in the optimum manner to market signals.

Also missing from this list is public accountability, an essential requirement of any regulatory system. The test of public accountability is taken to be that the regulatory agency is achieving what the public requires that agency to achieve and is doing so fairly. It is assumed that the criteria defined above, together with the avoidance of arbitrary or wholly subjective judgements and fair and equal treatment of all parties, constitute the overriding criterion of public accountability.

Comparison across these criteria suggests that there is no clear-cut winner (Table 11.1). Performance-based regulation is generally preferable to technology-based regulation except when the science base is thin and administrative costs

Table 11.1 *Comparative performance of different intervention strategies*

Criteria	Command and control		Tradable permit	Pigovian tax
	Emission standards or receiving media standard	Technology standards		
Theoretical efficiency	••	•	•••	•••
Administrative cost	••	•••	•	•
Science base required	••	•••	•	•
Adaptability to changes in supply/demand	•••	•	••	•••
Compliance cost to polluter	••	•	•••	•••
Probability of effect	•••	•••	very uncertain	uncertain
Transparency to polluter	••	•••	•	••
Risk of regulator capture by polluter	•	•	•••	••
Revenue raised	•	•	•	•••
Dependency upon approximation to perfect market	•••	•••	•	••
Incentive effect to technological innovation	•	•	••	•••
Maintains res commune	•••	•••	•	•••
Degree to which short-run efficiency promotes long-run efficiency	•	•	••	•••
Independence of extent to which other externalities are being taken into account	•••	•••	••	•

Scores: • = poor; •• = moderate; ••• = good.

must be minimised. Pigovian taxes are similarly generally preferable to tradable permits when the externalities problem is marked or there is a high risk of regulatory capture. More generally, a society which is highly developed and so has an advanced science base, for a good where the situation approximates to a perfect competitive market with clearly established private property rights, is likely to favour Pigovian taxes or tradable permits. Conversely, a developing country with a thin scientific base, few administrative resources and thin markets, is likely to start by favouring command and control mechanisms. Unfortunately, those are precisely the situations in which the risk of regulatory capture is greatest, in some cases by corrupt means.

12

Turning Theory into Practice

Achieving the sustainable management of water is accepted as requiring the integrated management of land and water across the catchment as a whole (Global Water Partnership Technical Advisory Committee 2000). Figure 12.1 outlines a simple model of the intentional and accidental interactions between the economy and the water environment.

Water management is concerned with managing both the natural (e.g. seasonal variations in flows) and unnatural (e.g. climate change) perturbations in water quantity, water quality and the erosion and deposition of sediment. These three systems are themselves quite closely coupled. Moreover, for human uses, we seek stability from systems that are naturally dynamic. So, in the case of water resource management, we seek to bring variations in the supply of water into line with the variations in the demand for water where the variations in demand over time are typically less than the variations in supply. In particular, a main reason for intervention is to manage the perturbations in the perturbations, floods and droughts being extreme cases of normal variations in the flows over the year. At the same time, human activities induce shifts in the water quantity, quality and the processes of erosion and deposition where these changes both directly impact on other human activities and on ecosystems. Indirectly, human activities are further impacted by the latter effects. It is these changes, both intentional and consequential, in the dynamics of the different systems that determine the benefits and costs of any project or policy.

Thus, abstracting water for irrigation and potable water use have direct benefits to the socio-economic system; similarly, so does the collection of wastewater and surface water runoff, not least because a significant benefit of collecting wastewater is that it enables people to use more water. Similarly, drainage is often a necessary part of irrigation if salinisation of the soil is to be avoided. But both abstraction and the discharge of drainage water will typically have negative effects upon the flow regime and quality of the riparian environment.

Some economic products such as recreation and fisheries are a function of the state of the watercourse, defined by its water quality and flow regime (and hence also its geomorphology); others such as hydropower and navigation require

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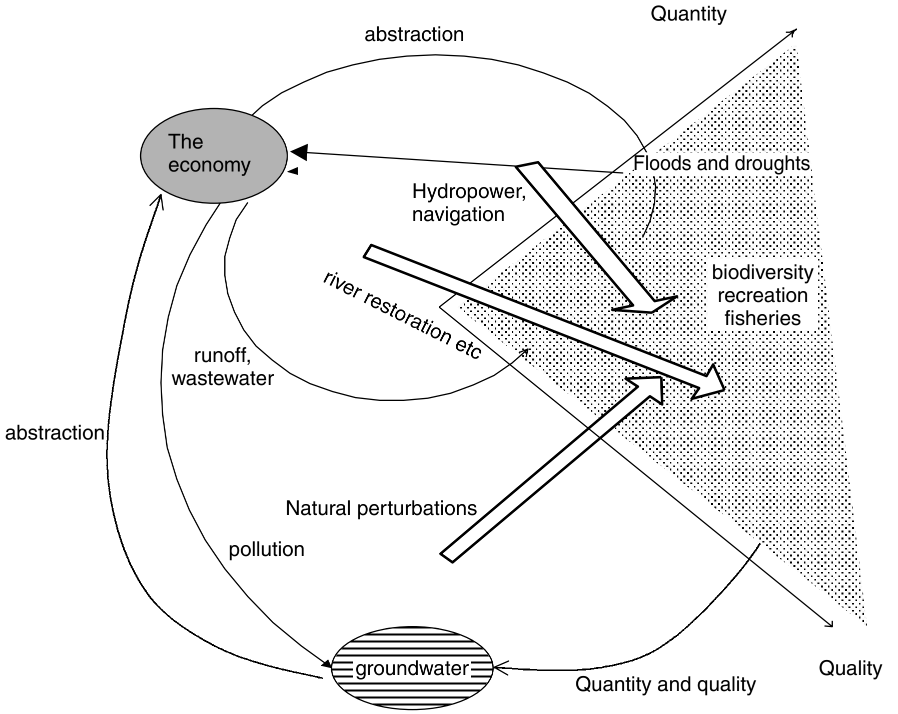

Figure 12.1 *Interactions between the economy and the water environment*

changing the flow regime, and consequently have a series of knock-on effects on the riparian environment. The magnitude and value of changes in these products depend upon the extent of the change in water quality or quantity and not upon the reason why such a change has occurred. The economic justification for constructing a wastewater treatment works, undertaking low flow alleviation works, or river restoration works all arise from these benefits. Conversely, navigation works, dams, water abstractions and improvements in land drainage are all likely to negatively impact on these economic products. Some forms of flood alleviation works, such as channel deepening, are also likely to impact negatively upon these economic products but other forms of works, such as engineered wetlands, are likely to have positive effects.

Integrated catchment requires that the economic analyses undertaken must be based upon the analysis of the impacts of the proposed scheme upon the catchment as a whole and in terms of each of the three systems. However, historically, projects have been developed on a functional approach and one that treats specific perceived problems. For example, the objective will have been to provide an irrigation system, a wastewater treatment works or a flood alleviation scheme and economic analyses have been undertaken in these primarily functional terms.

Such a simple functional approach would have made it possible for the reader to identify a single section of this text as being relevant to the project although with considerable overlaps between sections. Conversely, an integrated approach is likely to result in more projects being undertaken that are multifunctional; an engineered wetland, for instance, that provides wastewater treatment, flood storage, groundwater recharge and recreational benefits. Or, similarly, methods of source control that also provide water for flushing toilets or providing amenities (Pinkham 2000). Therefore, the sections that are relevant depend in part on the options being considered in a particular project.

Moreover, a key stage in an economic analysis is to identify each of the different positive and negative consequences, both those intended and also those that are side-effects, of the proposed project. We seek therefore to undertake a holistic analysis through a piecemeal approach and adopt this approach precisely in order to reduce the complexity to a manageable and comprehensible level. In turn, each of these separate impacts is generally evaluated in terms of a unit value multiplied by the size of the population, be this households or fields, that is affected. In this way, we reduce the risks of missing out specific impacts but at the cost of increasing the risk that we will miss out synergistic effects of the different consequences (SACTRA 2000).

Furthermore, the economy is itself a system and needs to be treated as such. For example, the locus of concern in development is 'sustainable rural livelihoods' (Ashley and Carney 1999). One aspect of the failure to consider the economy as a system has been the failure to differentiate between gender roles (Hart 1992), to omit the inputs of unpriced resources (Jodha 1992), and the failure of many irrigation schemes to take account of the complex farming patterns in parts of Africa have been well documented (Adams 1992; Marchand 1987).

12.1 Evaluating Impacts

The basic approach to the economic evaluation of the consequences of some action is:

- Identify all the disparate consequences of that action.

This is easy to say but difficult to do: significant consequences have been omitted in the past because we did not notice them and because it is difficult to predict the behaviour of complex systems of which we have incomplete knowledge. Seeking advice from as wide a range as possible of specialists and particularly the people who live in the area offers the best chance of identifying the significant consequences of the alternative courses of action being considered.

Then, for each consequence, it is necessary to:

- Quantify the nature of the change.
- Specify the change in terms which can be related to a value.

- Relate this change to parameters that can be predicted.
- Estimate size of the population of people, households, or others who will gain or lose by that change.
- Estimate the unit value of a change.
- Estimate the benefit or cost of that change by multiplying the unit value by the number within the affected population.

This does not involve a simple linear process of analysis because there are a number of interdependencies between the components. In particular, the nature of the population who benefit from a given change depends upon what it is that people value about the river and whether that will be changed by the proposed project.

12.1.1 Quantifying impacts

The second stage is usually undertaken by water quality scientists, epidemiologists or other appropriate specialists. For example, the estimation of the change in the nitrates or suspended solids (SS) in a river as a result of works on a combined sewer overflow (CSO) and the distance downstream that these works will have an impact is a task to be carried out by water quality specialists. Similarly, estimates of the response of crops to changes in the availability of water is a task for agronomists rather than economists. In general, developing such 'dose response' models (Hanley and Spash 1993) requires expertise that economists lack. However, the economist does need to understand what the specialist is saying and jointly they must build the bridge so that the change is defined in way that is related to the value of the good.

12.1.2 Determine what it is that people value

Since value is no more than a reflection of what people want, we must first determine what it is that people want. If economic value is subjective, so necessarily are the characteristics of the good that determine that value. In turn, knowledge of who wants what determines the population who will benefit or lose by a specified change. A valued change in river water quality is one that people will want for the particular purpose they have in view. If we seek to value the benefits for informal recreation of an improvement in river water quality, then it is necessary to start by understanding what makes a river desirable and valuable as a place to visit. In turn, the critical parameters that define river water quality are then those that affect the desirability of the river as a place to visit. Fortunately, in this instance, quite a lot is now known about the characteristics of a river that make it valuable and hence what changes would increase or decrease this value (e.g. Ditton and Goodale 1973; Tunstall *et al.* 1997).

Again, if consumers are to be asked how much they would be prepared to pay for an improvement in the taste of tapwater, then it is first necessary to determine the characteristics of tapwater that are important to the consumer (Guirkinger 1988). Similarly, in evaluating a potential improvement in a recreational fishery, it is first necessary to determine what it is about the fishing venue that anglers value (Section 21.2.2.1).

Therefore, it is necessary to start by discovering what is that people value. Where there is a distinction between what it is that people value currently and what would maximise their best interests, then the two need to be brought into line. If they cannot, then there is no point in providing what would be in their best interests if they knew what those were. Hygiene, sanitation and water supplies can all be instances where there is a distinction between traditional practices and behaviours (Water and Sanitation Program n.d.), and consequently the characteristics that are used to define the value of a water source, for example, and best practices as based on current health science.

In many cases, what determines economic value depends upon perceptual evidence but it is what people understand the relevant concept, such as river water quality, to mean and imply that determines which perceptual cues they seek. Simultaneously, perceptual data is being interpreted in cognitive terms. In turn, people may then either have different cognitions of the good of issue or use the wrong signals: for example, turbid water is commonly interpreted as meaning that the water is polluted (Burrows and House 1989; Green *et al.* 1989b).

The 'market' for a particular activity may be segmented; in turn, the preferences of different groups, and more particularly those seeking different activities can conflict (Daubert and Young 1981).

12.1.3 Relate change to parameters that can be predicted

Whilst economic value is subjective, since what people want is subjective, we need to be able to predict how much of a change will result from the alternative actions being considered. These predictions will be based in turn on mathematical or physical models whose outputs will be given in physical, chemical or biological units. It is therefore necessary to establish a link between that which can be predicted and what people want.

For example, part of a methodology to evaluate the benefits of river water quality improvements (WRc/OXERA/FHRC 1996) involved angling benefits. In turn, it was necessary to determine what different types of anglers wanted from a fishing visit. The necessary next step was then to tie these classes to both the water classes used for reporting river water quality (WRc/OXERA/FHRC 1996) and the parameters that can be predicted by water quality models (Russell *et al.* 2001). This is a critical step since that which can predicted may be meaningless in cognitive and perceptual terms. Equally, the signs that people use to determine the state of some good may be extremely difficult to relate to some biological, physical or chemical parameters than can be measured and predicted. Moreover, people may only distinguish between quite wide classes.

12.1.4 Estimating the number of beneficiaries

Typically, the benefits of a change are estimated by multiplying the estimate of the number of people or others who will benefit by a unit value. The former number is often very large and the latter number can be very small. Consequently the effect on the estimate of the project benefits of errors in the definition of the population who benefit can be larger than from errors in the estimates of the unit value. In consequence, it is at least as important to define the population who benefit as to estimate the unit value accurately. It is, however, a question which is often neglected in economic analyses or dealt with by making quite arbitrary assumptions.

The questions of what someone wants and the definition of the population who benefit are clearly linked: if someone wants the change then they benefit from that change. It may be obvious who benefits from a change; for example, all those who live or have property within an area protected by a flood defence scheme, or anglers who will benefit from improvements in the ecological status of a stretch of river. In the former case, the current population who benefit is already enumerated by the action of definition. More often, as is the case for the anglers, we can define the class who will potentially benefit but then need to calculate the number of people in that population. It is rare for there to be data available on the number of visits made by anglers to the site at present, or indeed for any class of visitor to a river. Moreover, an improvement to the river should be expected to attract more visits to that river either as a result of those who already visit the river visiting more often or because people are attracted away from other sites. In either case, those visits will be made at the cost of sacrificing some other activity, in the latter case by making fewer visits to a comparable site.

In practice, even in those cases where the population who benefit is well defined, the estimates of the size of the population who are affected are frequently very imprecise. For example, in the Grootvlei case study (Section 21.7), three different estimates of the water withdrawn for irrigation were obtained and these varied by a factor of five. Similarly, whilst flood extent maps have an appearance of precision, both the flood outline itself and the estimates of the number of properties within the flood plain are often subject to large margins of error.

Nor should such changes in behaviour be expected to occur instantaneously; the rate of take-up will be important to the accurate estimation of the present value of benefits. Thus, following the completion of an irrigation scheme, it should not be expected that all farmers will immediately change their existing pattern of cropping.

If the rather nebulous concept of ‘nonuse’ value (Section 5.1.2) is considered, then the definition of the population who benefit becomes even more ill-defined. The conventional assumption is that to hold a nonuse value for a resource does not depend upon the individual currently using that resource. Consequently, who should be expected to have a nonuse value for a river improvement? Those who live near to it, those who know of it, those people who live in the administrative unit which will bear the costs of the improvement, those people who in principle would wish to see such an improvement made? There is no logical way of predetermining what are the boundaries of the population who benefit and, as was shown in Section 5.1.2, in some cases people very remote from an environmental resource are prepared to pay towards the cost of its conservation or enhancement. The conventional approach assumes that people hold nonuse values that are specific to particular cases so that, in principle, to determine what is the nonuse value of improving the one million or so kilometres of river in the USA (US EPA 2000), it is necessary to ask some populations about each kilometre of river or to generalise from questions about some specific lengths of river to all rivers (Section 5.1.2.3).

12.1.4.1 Counting visitors

For recreational activities, the number of adult visitors to a site at present is seldom known but may be very large. A number of different techniques (Scottish Natural Heritage 1993; Tourism and Recreation Research Unit 1983) can be used to estimate the number of visits made to that site. Ideally, a reliable count is made of those visits using infra-red or similar people counters. However, those counters require calibration since a bicycle may register as several passages past the counter and some visitors will pass several counters. In addition, some counters will fail to record on some days so that estimates of the number of people who passed the counter on those days must be estimated on the basis of regression equations using the measured numbers on other counters. Consequently, estimating the number of visitors on the basis of recorded counts can be both complex and time consuming (Garner *et al.* 1994).

Often, inferential methods will have to be used; counts of visits made to one area of the site, such as a visitor centre or car park, being used to estimate the total number of visits made to the site. Frequently, such data or infra-red counter data will only be available for part of the year and it will be necessary to use a growth curve, similar to those used to convert short period traffic counts to estimates of annual traffic flows, to generate an estimate of the total number of visits made by adults over the whole year. However, the pattern of visitors to different types of sites shows significant variations (Table 12.1) and so it is necessary to decide to which kind of site the one under study is most similar.

Moreover, even apparently similar sites, such as the selection of forests shown in Figure 12.2, can show very marked differences between sites with those that attract predominantly local visitors showing the least variation in numbers over the year. Moreover, even given a year's data of visit numbers, it is possible that it could be an abnormal year; the weather in particular may have been unusually good or bad. In principle, it is possible to go further and adjust the estimate of visit numbers for these abnormal conditions.

If we can determine how many visits are made to a site at present, then the next problem is to predict how that number will change in consequence to some

Table 12.1 *Variations in visitor numbers over the year*

	January	February	March	April	May	June	July	August	September	October	November	December
Total tourism trips by UK residents to England	0.46	0.54	0.66	0.80	0.79	0.73	0.85	1.00	0.77	0.75	0.52	0.75
National Trust properties	0.14	0.00	0.00	0.50	0.64	0.55	0.68	1.00	0.45	0.36	0.23	0.00
RSPB reserves	0.73	0.45	0.45	0.82	1.36	1.18	0.91	1.00	0.64	0.73	0.55	0.45
The Wallace Collection	0.00	0.00	0.00	0.91	1.00	1.03	0.96	1.00	0.85	1.01	1.12	0.92
Imperial War Museum	0.71	0.95	1.01	0.85	0.73	0.71	0.88	1.00	0.64	0.88	0.71	0.50
Cabinet War Rooms	0.39	0.44	0.69	0.60	0.68	0.77	0.89	1.00	0.74	0.73	0.51	0.38
HMS Belfast	0.33	0.48	0.57	0.77	0.51	0.51	0.75	1.00	0.44	0.64	0.30	0.25
Duxford	0.39	0.44	0.69	0.60	0.67	0.77	0.89	1.00	0.74	0.73	0.51	0.38
English Heritage – mean	0.06	0.11	0.28	0.39	0.50	0.83	0.72	1.00	1.06	0.39	0.22	0.06
Dinton Pastures Country Park	0.00	0.00	0.00	0.00	0.94	0.65	0.74	1.00	0.72	0.76	0.47	0.42
Wat Tyler country park	0.04	0.15	0.12	0.42	0.38	0.35	0.50	1.00	0.54	0.23	0.08	0.04

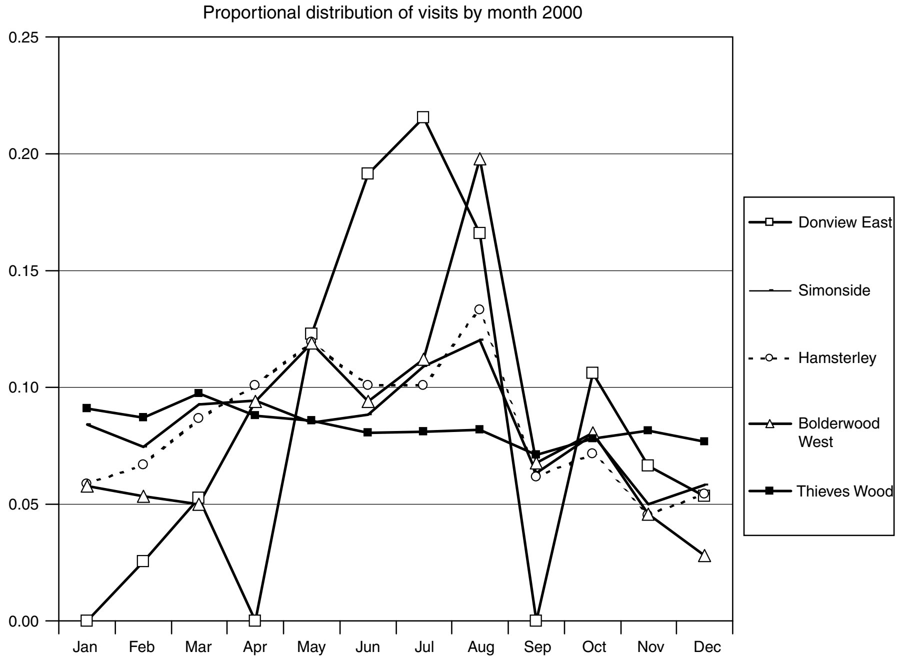

Figure 12.2 *Variations in growth curves for forests*

change to that site. If the site is improved, then either those who visit now may make additional visits or other visitors will be attracted away from alternative sites. Conversely, if the site degrades then some of those visits that are now made should be deflected to other sites or into other activities.

12.1.4.2 Predicting the number of visitors

The alternative to working from the visits actually made to a site is to predict the number of visits that will be made to the site from different residential areas. It is obviously necessary to use this approach when a site is improved and anticipated to attract more visitors, or when a new site is created. Although the travel cost method (Clawson 1959) was intended to be used for estimating the recreational value of a site, it can also be used simply to predict the number of visits (Bateman *et al.* 1996). In seeking to predict the number of visits made to a site, we are necessarily invoking a model of recreational choice, and the process through which people decide to visit a particular site.

The travel cost method is itself a reinvention by economists of the gravity model originally developed by geographers in order to predict the number of journeys that will be made between different urban areas (Haggett 1965), or to particular types of facilities such as shops and health care facilities (Smith 1979). It is an attractor model: it is assumed that a site pulls visitors from different residential areas against the friction of travelling: the more attractive the site and the fewer the competing sites, the greater the number of visitors attracted to the site and the further they will travel to the site.

Thus, the number of visitors received at a particular recreation site should be as follows:

$$V = \Sigma \times A \cdot P^y / c^z$$

where:

- V is the number of visits made to the site
- A is the attraction of the site
- P is the relevant population at each population centre
- c is the cost of travel from home to the recreation site

and x, y and z are coefficients.

As given, cost and time are assumed to be perfect substitutes; if the journey was slower but cost less than the current journey time, this change would have no effect on the number of visits made. But, as argued earlier (Section 4.2), it would be more realistic to treat time as a separate constraint to income. Thus, in making a visit, the constraint faced by the potential visitor is that the total travel time plus the time required for the visit must be less than the available time. In turn, time is lumpy, there being a difference between two one-day trips and a two-day trip. It has been found in the context of visits to the coast by local residents that a significant proportion of visits are apparently constrained by time (Garner *et al.* 1994).

Not surprisingly, therefore, the journey, in whole or part, is often part of the enjoyment of the trip: 'Recreational travel is unique in that the actual journey itself is frequently a part of the total recreation experience, rather than just a means to an end' (Patmore 1983). People may choose the destination, therefore, in part because of the anticipated pleasure from the journey, or choose the route because of the pleasure from that route rather than others. As much attention may be paid to the choice of the route as to the destination: 'It is clear from such work that the direct route to a destination is not necessarily the most preferred route, nor do outward and return journeys, even to a single destination, necessarily coincide' (Patmore 1983). Indeed, there is often a desire to minimise the proportion of the inward and outward routes which are duplicated. As with other forms of consumption, declining marginal utility applies: the more frequently the journey is made, at some point, the pleasure wears off and the journey becomes a cost.

However, in this model, the proportion of the population and the number of visits they make is solely determined by the attractiveness and distance to the sites. If, however, not all of the population want to undertake the activity or the number of days in which they can undertake the activity is restricted, then P should be adjusted to be this saturation figure.

The alternative model, developed in geography to explain migration patterns (Hagerstrand 1957), is the diffusion model. This is a push model; it assumes that people first want to make a recreational visit and the numbers who visit different sites depends on the number of intervening competitive sites and how strongly is the intention to make a recreational visit. In terms of recreational behaviour, the first approach is based on the assumption that someone thinks 'I want to go to xxxx' and the diffusion model assumes that the basis for recreational behaviour is: 'let's go out this Saturday, where shall we go?'

The number of visits made to a particular site is then explicable as follows:

$$M_x = kX^{-1}\mathrm{e}^{-ax}$$

where M_x is the percentage of in-migration to a centre from a zone at distance (or cost) X, k is a constant and a is the absorption coefficient (Haggett 1965) which here depends upon the attractiveness of the site.

In practical terms, the two models are quite similar in effect but conceptually they are quite different in emphasis. In the diffusion model, a central concern would be what is the pressure which drives the population to undertake this behaviour? The diffusion model also provides an explanation of Patman's (1983) demonstration that people in large cities travel further for recreational visits than people living in smaller urban areas. Put simply, they have to because the recreational sites are further away. Conversely, the gravity model would suggest uniform distance-decay functions with residents of large urban areas making fewer visits to recreational sites than those in smaller urban areas because the costs of making a visit are higher. In practice, recreational behaviour seems to be complex with a mixture of pull factors (e.g. unique attractors such as relatives and major theme parks) and push factors: a significant proportion of visits to some sites were only made on the way to somewhere else or were not planned when the journey was started (Cheshire and Stabler 1976).

Whether or not visitors are pulled to a site or are absorbed by it, a critical question is: what is the latent demand for that form of recreation? What proportion of the population, for example, wishes to go angling? How many days a year will they fish, or how much time do they have to go angling? For example, the number of visits that will be made to an angling site depends upon:

- what proportion of the population wishes to go angling;
- how many days a year anglers can go fishing, or how much time they have to do so;
- how they choose the places to go angling.

Whilst there may be a link between the second and third questions, there is no obvious link between them and the first question. Thus, if a new or improved angling site is created next to a population centre, it does not follow that the entire population will take up angling. Indeed, in some parts of Europe participation rates in angling have dropped significantly in recent years; thus, the number of anglers in France fell from 2.8 million to 1.4 million (Breton 2000). Clearly, those who would in the past have gone fishing are now doing something else, so there are issues both as to the degree of substitution between sites and between the leisure activities.

Nor, unless ease of access is the sole determinant of the choice of place to go angling, does it follow that the new site will be the preferred place to go angling or that local anglers will now make more angling trips. Only those for whom the number of angling visits they can make has been limited by the cost or difficulty of visiting a desirable angling site should be expected to make more angling visits in total or to visit this site preferentially. In then determining how that potential demand is distributed between alternative sites, a further question is: to what extent are different sites, and different forms of recreational activity, substitutes for each other? If we assume that all individuals have fully allocated their available time, then any visit must be a substitute for some other activity that would otherwise be undertaken in that time. Therefore, an increase in the number of visits to one site necessarily involves less time spent on some other activity either in the home or at some other recreational site.

Ideally, we would start with the individual's basic problem of maximising utility, given the constraints of time, income and other factors such as life-cycle stage. The individual then has to decide either jointly or separately which activities to undertake when and where. Whether this decision is taken jointly or separately is itself an important issue; for example, in the UK, many anglers belong to clubs and their fishing is largely restricted to club-owned waters. At the same time, preferences can change; notably the proportion of the population who wish to go fishing appears to be falling in many countries whilst both income, and to a lesser extent, time constraints (e.g. changes in the working week, retirement) are changing over time. There are equally large differences between countries; Walsh (1986) cites data showing that in 1979, 53% of the US population participated in fishing whereas in 1995, in England and Wales, only one household in nine contained at least one person who had been fishing for pleasure in the last two years (National Rivers Authority 1995a).

For the informal recreation that makes up the bulk of recreational use of rivers and lakes, a critical question is whether a river or lake site is a potential substitute for all other recreational sites, and equally potentially substitutable by those sites. Will an improved river corridor simply attract visitors away from other rivers or also from forests?

Figure 12.3 shows the results of cluster analysis of the responses to a question that asked visitors how much enjoyment they would expect to get from a visit to each of a variety of different leisure and recreational sites. The closer to the left the sites are linked together, the more similar were the amounts of enjoyment that respondents expected to get from visits to those sites. Thus, lakes and rivers

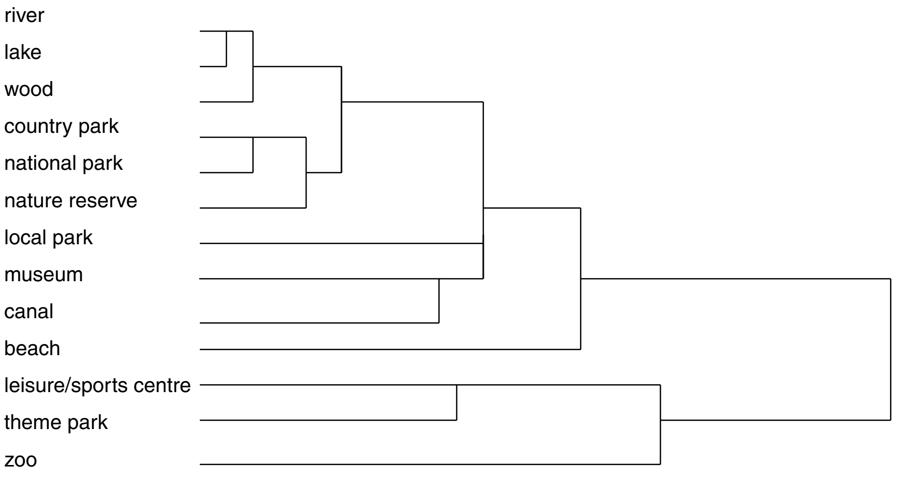

Figure 12.3 *Similarities between different recreational sites as a place to visit*

were seen as offering very similar amounts of enjoyment, whilst theme parks, leisure facilities and zoos were seen as being quite different to the other types of site. Intriguingly, canals are seen as offering similar amounts of enjoyment as museums, and so seem to be interpreted as historical sites, rather than being seen as similar to rivers. This cluster analysis implies that a canal is not a good substitute for a river as a place to visit, and that a leisure centre is no substitute at all.

In short, we need better models of recreational choice (Vickerman 1975) if we are to make reliable predictions of the number of visits that will be made to a particular site.

12.2 Methods of Evaluation

There are three general strategies for deriving values, and hence also opportunity costs:

- market prices;
- inferential methods;
- expressed preference methods.

12.2.1 Market prices

It can readily be shown for a priced good sold in a perfectly competitive market – one where there are so many small producers, all producing identical products, and consumers that none can affect the price; with entry as well as exit from the market being costless – then the prevailing price in such a market would equal both the marginal value and the marginal cost (Lipsey 1971). As a conceptual model the concept of a perfectly competitive market provides a useful starting point for estimating the value or cost of a priced good. In the real world, markets are commonly imperfect or distorted in some way. It is then usually necessary to make some corrections to the observed market price in order to estimate the economic value or opportunity cost, its shadow price, of the good or service in question.

For example, in assessing the benefits of flood alleviation schemes, one important correction is that for second-hand goods. It is argued that imperfect information on the part of the consumer means that the prices of second-hand goods are depressed below their true value (Akerlof 1970). Therefore, in evaluating the loss of, say, a five-year-old television the economic value is greater than the market price of an apparently identical second-hand television. Consequently, the values used for the losses of the contents of dwellings are based upon the use of straight-line depreciation.

It is also necessary to remove direct and indirect subsidies on both inputs and outputs of production. For example, in much of the world, irrigation water is heavily subsidised either directly or indirectly (Garrido 1999). If an irrigated crop is lost as a result of the flood, the real loss is given by calculating the market value of the crop less the real costs of all inputs; that is, by subtracting the real rather than the subsidised costs of providing the irrigation water. Again, agricultural outputs are commonly either subsidised or supported; here, too, the value of a lost crop needs to be adjusted downwards by removing the subsidy or price support element. In turn, where inputs or outputs are subsidised in this way, the capital value of the asset that produces the outputs is also artificially inflated. Thus, when assessing the value of agricultural land, the market price of that land must also be corrected downwards to that level which would exist were there no subsidies on inputs or outputs. It is generally safe to assume that agriculture is always subsidised, the only question being how cleverly the subsidies have been hidden.

There is an exception to the general rule that subsidies shall be removed and this is where a subsidy is intended to represent a positive externality. Some agricultural subsidies are in this form; those intended, for example, to promote environmentally friendly farming. For example, the bare moors of the Lake District in England are a product of sheep grazing but sheep farming in these areas is now only viable because of the upland sheep farming subsidies.

Indirect taxes must also be removed as they are simply a tax intended to generate revenue rather than a real opportunity cost. However, 'green taxes', those that are intended to reflect the externalities caused by the use of a particular good, are real economic costs for that reason and should not be removed. For example, any tax on pesticides intended to reflect the damage caused to the environment, or the cost of removing pesticide residues from potable water, is a real economic cost. The practical problem in analysis is then that it is necessary to determine whether any indirect tax is solely for revenue raising purposes or is designed to incorporate the costs of externalities into the cost of using the product. Where a resource would be put to no other use if it were not applied to the project then its opportunity cost is zero whatever the price actually paid for it. This situation is most likely to be found when looking at labour inputs. Where there is a high level of unemployment or underemployment, the wage rates paid to those building the project will overstate the opportunity costs of that labour and a shadow wage rate needs to be estimated (Squire and van der Tak 1975).

At times, where the good in question is not priced there may exist a near perfect substitute that is priced and this can then be used to set an upper bound on the value of the good it is intended to evaluate. The value of the good in question can be no greater than the cost of this least cost alternative.

One limitation of this approach is that the alternative must either not yet have been undertaken or all the costs can be recovered if it has already been adopted. Any irreversible expenditure, a sunk cost, must not be included.

12.2.2 Inferential methods

The use of market prices is often referred to as revealed preference techniques but, as can be seen from the above discussion, it is often necessary to make quite a large number of corrections to the observed prices in order to calculate the economic values and costs. The second group of techniques may be termed inferential methods and these use statistical techniques to infer the value of the variable of interest which does not have an observable price. They differ fundamentally from the revealed preference in that it is necessary to draw statistical inferences as to the reasons why individuals are behaving as they are from aggregate data. We have to fit the data to the theory, and consequently it is impossible to test the theory, and the theory is also underspecified.

The travel cost method, attributed to Clawson (1959), is a variant of the gravity model discussed in Section 12.1.4.2. It is a way of putting a value on a recreational resource by determining the distances that different visitors have travelled to a site and the costs they have incurred in doing so. By regression analysis, a relationship between the distance travelled and the probability of making a visit is deduced and the resulting function used to estimate the value of a visit to the site. It has been extensively used in the USA (e.g. Smith and Desvouges 1986) and quite widely used in the UK in the late 1960s and early 1970s (e.g. Smith and Kavanagh 1969). However, following some critical reviews of the adequacy of the method in the UK context, including Vickerman (1975) arguing that 'The assumptions of the approach are, however, very suspect on a number of grounds and whilst previous authors have expressed reservations the ease of use has been felt to outweigh any disadvantages', it fell into disuse in the UK, only to be subsequently revived. A problem is that any function can be fitted more or less badly to any set of data and we have no theoretical reason for expecting one functional relationship rather than another. Depending upon what relationship is actually applied, the values derived may then vary by a factor of about 10 (Common 1973). Nor do the assumptions about recreational choices made in the model actually seem to be consistent with recreational behaviour (Green *et al.* 1990).

The hedonic price technique (Rosen 1974) is intended to determine the influence of the land characteristic in question, such as a sea view, on the market price of the land or more usually houses. A number of studies have been undertaken on the effects of flood risks on house prices (e.g. Donnelly 1989) as well as other environmental attributes (e.g. Kirschner and Moore 1989). The reasonable assumption is made that the market price of a particular house is a function of a series of attributes, including the variable of interest, which make that house more or less desirable. Given enough data on the values of each such parameter for the houses sold in an homogeneous market, together with knowledge of the functional relationship between those parameters and the market price of each property, then we could determine how the market price varied as the parameter of interest varies. In practice, we do not know exactly which are the parameters that influence house prices, we cannot measure all of these parameters but have to use surrogate variables in some cases. Thus, in 1979, Freeman observed that: '... the selection of explanatory variables seems to be almost haphazard.... Convenience and data availability appear to be major determinants of this part of model specification.'

Overall, it is also inconsistent with models of residential mobility (e.g. Clark and Onaka 1985). In addition, we do not know what is the functional relationship between these variables and have to infer this relationship in order to undertake the statistical analysis. It appears that the actual functional forms are complex: Timmermans and Veldhuisen (1981) derived utility functions for a wide range of physical and locational attributes. However, Phipps (1983) reported finding two different subsamples, differentiated by their personal household characteristics, who used different utility functions; the first used variants of a multiplicative utility function; the second variants of a disjunctive utility function. Moreover, these different subgroups may use different attributes in making their assessments (Hourihan 1984).

In consequence, Ducci (quoted in Ardila *et al.* 1998) refers rather despairingly to the practical problems of obtaining results of any real value from this method referring to the time spent on 'torturing the data to provide a decent coefficient' and the hedonic price method being as '... more unreliable (than the contingent valuation method) with respect to whether you will be able to get a usable result.' More generally, both methods seek to explain the aggregate of behaviour that is individually determined.

12.2.3 Expressed preference methods

Neoclassical economists long resisted the use of the remaining approach, expressed preference techniques, which employ social survey techniques because these involving asking people what choices they would make. The basis of the criticism is that what people say they will do in a situation is necessarily not as reliable as observing what they do in such situations were we able to observe their behaviour, and that people are being asked to respond to hypothetical circumstances. The weakness of this criticism is that all choices that are important are hypothetical: everything else is history.

In particular, companies need to be able to predict how much of a new product they can sell at what price. Market research (e.g. Assael 1992) was therefore invented to fill the gap left by economics and one of the two techniques, conjoint analysis, was developed in market research (Huber 1987) where it has been extensively used (Wittink *et al.* 1994). There has been a comparatively small but an increasing number of applications around water management (Adamowicz *et al.* 1997).

In conjoint analysis, respondents are asked to make a series of choices between different combinations of different levels of what are understood to be the most important characteristics, including the one in which we are interested, of the good in question. For example, if we were interested in how proximity to a lake affected house prices, we would first determine what are the critical parameters that determine the amounts individual households are prepared to pay for dwellings. One of the characteristics then included in the study is price and another proximity to a lake. The respondents are asked to choose between pairs of houses having different combinations of levels of the different attributes. Then, by statistical analysis it is then hoped to determine how changes in the quantity of the characteristic of interest affect the amounts people are prepared to pay for the good (Orme 2001; Williams and Kilroy 2000). Conjoint analysis is thus the expressed preference equivalent of the hedonic price method and subject to some of the same problems but with the additional ones associated with the use of a social survey method. Firstly, the 'magic number seven' (Miller 1956) issue arises: there may be more attributes than can be used in making comparisons, in which case choices using samples of the different attributes must be used. Secondly, actually making the choices is difficult, particularly trying to make the choices in a consistent way. In turn, it is likely that in the first choices respondents make they are learning what are their preferences whilst in the last choices, those respondents have become tired or bored.

Contingent valuation method (CVM) is a rather simpler technique, originally proposed by Ciricacy-Wintrup, in that respondents to the interview survey are asked directly how much they are prepared to pay for a change in the availability of the good in question. In using either technique, it is essential to treat the approach as primarily one of social survey rather than economic analysis, following good social survey practice in terms of question design, sampling and fieldwork (Mitchell and Carson 1989).

Both techniques have a number of virtues. The first is that they are experimental techniques: we can therefore test whether or not there is a particular relationship rather than being forced to assume it. A second is that they involve listening to the public both through the qualitative research studies (e.g. Krueger 1988) that invariably should precede the quantitative interview survey, and in the quantitative study itself. Since the primary aim of benefit–cost analysis is to better understand what the choice involves, this is a significant virtue. Thus, the use of social survey techniques is potentially a good way of learning how members of the public, or of more specialised groups, interpret the choice and the issues it raises.

A set of criticisms levelled by psychologists and others (Fischhoff 1991; Burgess *et al.* 1997) is centred upon the task which respondents are set in a CV study. These criticisms centred upon the issues which social scientists raise as to the nature of preferences and how these are learnt (Section 4.1.1). Thus, three groups of question are raised:

- Can respondents answer such questions?
- How do they answer such questions?
- What do their answers mean?

Fischhoff (1991) argues that CV questions set respondents a very difficult task; some cannot be answered from memory or by instinct but respondents must construct an answer to them using some logical framework of analysis. Moreover, that the task involved may be one to which respondents neither know the appropriate form of analysis by which to construct an answer nor have the information available with which to calibrate such an analysis. Analogously, respondents asked what is two times two will generally know the answer from memory; failing that, they can count on their fingers. Asked what is the cube root of 512, some may know the answer from memory, others may know the formal procedure for deriving an answer and others may develop a heuristic by which means to develop an answer. Rather fewer people are likely to be able to give a correct answer than to the question on two times two and developing an answer is likely to take longer. Asking someone how much they are prepared to pay for some good may thus be closer in terms of task difficulty to asking them what is the cube root of 512 than to the sum of two times two. If respondents have to construct an answer then the questions of how they go about constructing an answer and what they need to know in order to construct an answer become important.

Thus, contingent valuation (CV) studies should be approached from an ergonomic perspective (Green and Tunstall 1997); as a task where the respondent has to decide how much s/he is prepared to pay, often for a good about which they have not previously considered or perhaps even heard. The issue then is to determine those conditions under which respondents can most accurately and reliably undertake this task. From this perspective, any format that involves a single question, including both the 'referendum' format promoted by the NOAA Panel (1993) and the single open-ended question, should be avoided.

Conversely, in general, economists have assumed that respondents know in advance of the CVM survey how much they would be prepared to pay for the good, and think in the same terms as the economist. In turn, economists have been concerned to minimise the ability of respondents to lie, in the form of 'free-riding' (Samuelson 1954); such a strong systematic bias has in fact only been found in samples of economics students (e.g. Marwell and Ames 1981). More generally, the experimental work on the Commons dilemma (Kopelman *et al.* 2000) has found that people's behaviour is more complex and more interesting than economic theory would lead us to expect.

What is critical is to differentiate between the proportion of the sample who are prepared to pay and the amounts that those prepared to pay then offer. There is a very significant difference between the situation where 80% of the sample are prepared to pay an average of £5 each and that where 8% of the sample are prepared to pay an average of £50.

The jury is still out on the validity of the results obtained from expressed preference approaches. It appears probable that the estimates of the proportion of the sample who are prepared to pay something are quite reliable. It is much less certain that the amounts offered by those who are prepared to pay are valid and reliable; computing a sample mean preparedness to pay gives a misleading picture by combining the two statistics together.

Table 12.2 summarises the results from a number of CVM studies carried out at the Flood Hazard Research Centre across a number of different goods. Essentially the same methodology was used in each case: a filter question that asked whether or not they would be prepared to pay at all for the good; then a bidding game followed by an open-ended question. Consequently, there can be some confidence that the differences are not simply the result of methodological differences. The bidding game format is known to suffer from an anchoring effect, but anchoring effects are a universal problem in social survey design (Poulton 1979). As compared to other CVM formats, the advantage of the bidding game is that we know the nature of this anchoring effect whereas with other formats the nature and extent of anchoring are unknown. Again, unlike the referendum format, the sample means do not have to be inferred by fitting a statistical function to the data.

That the proportions of respondents in each sample who were prepared to pay varied from 4% to 81% is encouraging; that the annual amounts that those prepared to pay offered varied between £3.80 and £35.56 is less encouraging. Since the distributions of preparedness to pay are always highly skewed, the logarithmic mean is a better indicator of the central tendency than the arithmetic mean.

Table 12.2 *Variations in the proportions prepared to pay and mean amount between different goods*

Study	Good	Those prepared to pay			
Social costs of sewerage		% prepared to pay	Mean (£/yr)	Log mean	Sample size
Visitors	River water quality – specific site	55	15.80	1.06	839
Remote sites	Water quality improvements to all rivers	49	18.65	1.16	319
Amenity	Water quality in neighbouring watercourse	40	14.40	1.05	303
Clacton – visitors	Prevention of loss of beach	64	5.13	0.18	146
Dunwich – visitors	Prevention of loss of beach	65	11.22	0.46	147
Filey – visitors	Prevention of loss of beach	81	5.62	0.45	152
Frinton	Prevention of loss of beach	58	4.11	0.32	150
Those living inland from the coast	Prevention of coastal erosion	66	12.35	0.39	412
Herne Bay – visitors	Prevention of loss of beach	56	3.80	0.35	143
Herne Bay – residents	Prevention of loss of beach	73	10.72	0.46	189
Hurst Spit	Prevention of breach in spit	74	24.49	0.69	550
St Mildreds Bay	Prevention of loss of beach and promenade	61	31.44	0.96	462
Cliftonville	Prevention of erosion of cliffs and loss of low level walkway	62	19.47	0.80	524
OFWAT	Reduced risk of supply interruption	4	30.66	1.28	997
OFWAT	Reduction in the risk of sewage flooding	30	28.77	1.17	997
OFWAT	Improvement in the taste of tapwater	26	35.56	1.3	997
OFWAT	All three services	43	39.25		997
Misbourne	Alleviation of low flows in river	63	26.11	1.18	412
Wey	Alleviation of low flows in river	39	24.32	1.09	351
Skerne	River restoration	43	22.45	1.02	121
Dtp	Reduction in traffic nuisance	59	10.57	0.77	620
GEV	Programmes of improvement in national river water quality				
	1st priority programme	54	29.63	0.42	542
	2nd priority	46	21.81	0.40	542
	3rd priority	40	20.46	0.39	542
	4th priority	26	21.32	0.41	542

In particular, in the OFWAT study in which respondents were asked about three water and sewerage services, the proportion of respondents who were prepared to pay for improvements in at least one of those services varied between 4% and 30%. However, those who were prepared to pay for an improvement in at least one of those services offered amounts which are not really different. Meta-analyses of the results of CVM studies (e.g. Brouwer *et al.* 1997) often result in the depressing conclusions that the majority of the variance that can be explained is accounted for by methodological differences between the studies.

In only a relatively few instances are these different techniques for estimating values alternatives. The travel cost method and hedonic price methods have very limited ranges of application, and both the inferential and expressed preference approaches were invented for those situations where market prices do not exist. Some judgements can be made as to the likely accuracy of the different techniques (Table 12.3).

For any stream of benefits or costs, the overall accuracy then also depends on the accuracy of the estimate of the number of beneficiaries. Clearly, we are unable to claim that the estimates of benefits and costs are highly accurate, certainly not so precise that it is sensible to seek to find an optimal level of provision of the good in question. This precludes the adoption of Pigovian taxes from being a sensible strategy – which would, in any case, require that all values were considered and not just economic values.

However, as discussed in Section 13.4.8.1, we often do not need highly accurate estimates of the different streams of benefits and costs when undertaking a benefit–cost analysis.

12.2.4 Benefit transfer

All benefit–cost analyses use benefit or cost transfers in some form: the cost of the project is predicted on the basis of unit costs derived for similar work

Table 12.3 *Comparative accuracy of different evaluation techniques*

Technique	Accuracy
Market prices	Within 15–25%? (given market failures to greater or lesser extent)
Shadow prices	As good as market prices?
Hedonic price method	Can we even get the right sign?
Travel cost method	Within a factor of 10?
Contingent valuation	Within a factor of three?
Conjoint analysis	Insufficient evidence to make a judgement

Source: Green 2000a.

tasks in similar construction projects. Similarly, it is rare for all benefit streams to be estimated specifically for the particular project. Thus, in estimating the benefits of an irrigation project, the predicted yields will be based on actual yields in supposedly comparable conditions. Similarly, the hydrological analysis will typically be based on data transfer: the use of data from another catchment or the use of equations calibrated from other catchments (e.g. IOH 1999). Hence the use of benefit transfer is simply the adoption of a well-established approach in other disciplines from which useful lessons may be learnt.

There are two basic methods of benefit transfer (Navrud and Bergland 2001): one method transfers data and the other transfers equations. In turn, there are three forms of data transfer:

- the use of standard data;
- the use of average values;
- the use of sparse point values.

Frequently, standard data values are derived specifically for use in benefit–cost analyses; in countries that routinely apply benefit–cost analysis to flood alleviation projects, it is routine to develop standard depth-damage curves that give flood losses for particular building types as a function of depth (e.g. Penning-Rowsell and Chatterton 1977). So, similarly, in the benefit–cost analyses of transport options is it normal practice to use standard values for the value of reduction of journey times (DTLR 2000). These values are specifically constructed for such purposes and in such a way that what are believed to be the principal factors resulting in differences in values are taken into account. Alternatively, in the absence of any tested hypotheses as to the factors that will create differences in values, the average value of some sample of values may be taken.

The third case occurs when there are no standard values but there are a limited number of different values for apparently similar changes in somewhat different contexts, or somewhat different changes in somewhat similar contexts. In this case, it is necessary for the analyst to reach a reasoned judgement as to which value in which context is likely to be closest to that which would pertain to the change that s/he is trying to evaluate. In the prefeasibility stage of a benefit–cost analysis, it is often necessary to use this approach. Only if it seems likely that the project is justified can a case be made for undertaking the survey work necessary to derive the specific values appropriate in the context of the specific project.

Given a sufficiently large sample of data, it is possible to move from such point estimates to a regression approach. This seeks to derive a general equation that explains differences in values by differences in the nature of the change and its context and so by the use of the appropriate local values for the explanatory variables, a specific value for the particular case in question can be derived. Once again, such general equations are routinely used in hydrological analyses where, for example, local stream flow gauging records are not available (IOH 1999).

In economics, such meta-analyses have been used to derive economic values for specific changes (e.g. Smith *et al.* 2000): by comparing across individual analyses, it should be possible to explain some real differences in the values derived in each analysis. Meta-analyses, in principle, offer a way to establish convergent and divergent validity: different techniques should yield the same value for the same change in the same good but each technique should give different values when either the change or the good are different. When there is not such a pattern of similarities and differences (Campbell and Fiske 1959), then some or all of the results must be suspect.

Thus, that meta-analysis potentially offers a means of testing convergent and divergent validity is probably more important than the chance of transferring values. The ideal test of techniques is then Campbell and Fiske's (1959) 'multitrait-multimethod' analysis where different measurement techniques are applied in a consistent way to different goods, and retests are also included. Unfortunately, the details of the measurement techniques adopted typically vary from good to good. In turn, apparently real differences in values may simply be the result of methodological differences (Brouwer *et al.* 1997) rather than real differences.

A second danger is that of falling into the ecological fallacy (Langbein and Lichtman 1978): of assuming that the relationships found between the means for different samples also hold within those samples, and to draw such a causal inference. The classic example of the ecological fallacy is to compare the cancer rates for the US states with their mean altitudes; it is found that the higher the altitude, the lower the cancer rate. This is the result of mis-specifying the equation because other known and suspected causes of cancer were omitted from the equation. Since meta-analysis works with sample means, there is an obvious risk of falling into ecological fallacy.

13
Project Appraisal

Project appraisal techniques are means of informing decisions; they can be applied to all decisions and not simply those where the options are for capital works. Project appraisal techniques are then equally applicable to what are conventionally called maintenance works, and to institutional or other strategies in addition to those that involve physical works on or in the ground. In each case, the different options will change the risk of some outcomes whether the outcome is a flood, drought restrictions, unacceptable taste to tapwater, the collapse of a sewer, or the failure to deliver a flood warning.

13.1 The Nature of the Appraisal Process

Earlier (Section 2.1), decisions were defined as being choices where:

$$\text{Choice} = \text{Conflict} + \text{Uncertainty}$$

Thus, a decision is a process through which we try to resolve the different conflicts between the available options so as to attain some degree of confidence that one option should be preferred to the others. Decision making is, or should be, a learning process; at the end of the process we should have a better understanding of the nature of the choice we must make than we had at the beginning. As a learning process, it is an iterative process as indeed is the process of design of which decision making is a part. It is also necessarily a process during which change will occur, since to learn is to change. Figure 13.1 is a generic model of such a decision process, starting with the definition of the problem that brings us to the decision in the first place, and of the objectives we bring to that choice. It differs in a number of ways to the usual diagrams of project appraisal techniques by being explicitly a model that assumes the entire purpose of appraisal is to learn which option should be adopted.

Unfortunately, the possible options do not simply sit there but have to be invented or discovered. The improved understanding as to the nature of the choice generated by the project appraisal may enable a better option to be created

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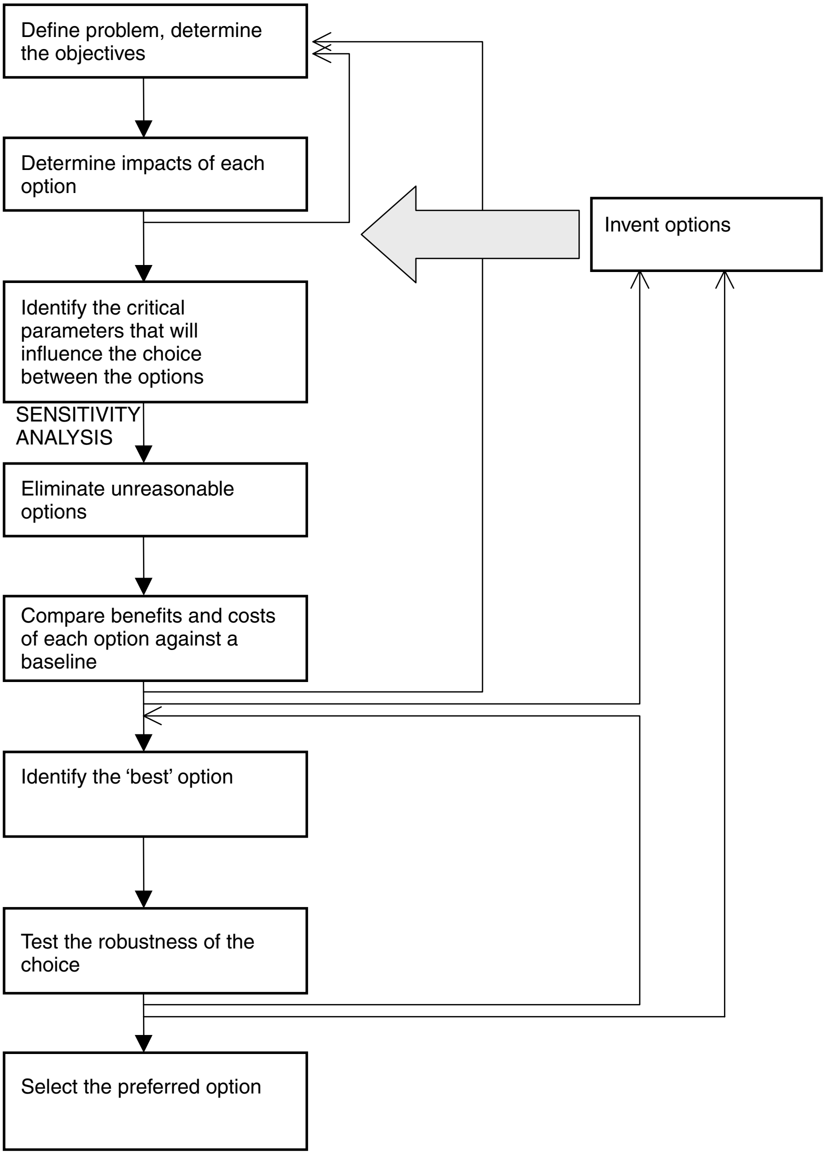

Figure 13.1 *Project appraisal flow chart*

or discovered. Thus, although the aim is to narrow down the option space to a single option, it is desirable to start by widening the option space, and the decision process may involve an iterative process of widening and narrowing the option space.

Nor do the options exist in fully detailed form, a rather important part of the design process being to determine what data to collect (e.g. hydrological data, soil samples, rapid rural appraisals) in order to develop the design options through an iterative process. In turn, the appraisal process must match the design process, beginning with strategic assessments when catchment plans are being developed. The techniques adopted at this level must necessarily be workable with sparse and coarse data. At the project level, prefeasibility or reconnaissance studies for individual projects must also be practical using existing data. In both cases, project appraisals should identify what data is necessary in order to refine the analysis; too often, those responsible for designing the strategy or project either collect every conceivable item of data in the hope that some of it will be relevant, or select only some data for collection and not necessarily that which is most important to the decision. Generally, the analyst will find themselves in one of two situations: too much data but not enough information, or too little data and too little information.

Reconnaissance level studies are more difficult to undertake than detailed benefit–cost analyses because they rely quite heavily upon experience gained from assessing similar schemes. They rely heavily upon experiential knowledge of what are acceptable simplifications and as to the key factors which determine the magnitude of the benefits and costs. The problems of undertaking broad scale appraisals of policies and programmes are similar.

In turn, it is important to undertake a sensitivity analysis early in the appraisal cycle. We need to know early on what are the critical parameters that will affect the choice of the 'best' option; it is on refining our estimates of the values of these parameters upon which attention should be focused during the remainder of the appraisal process. In turn, if one parameter does not differentiate between the options, there is no point in collecting data on that parameter. If we only discover these at the end of the analysis, it is far too late to do anything about them. With experience, the analyst will generally have learnt which are these parameters for particular types of project, but as a general rule it will be those which affect impacts that occur early in the project life; those that have the highest probability of occurrence; and those that affect the largest number of people or involve very large impacts on a few people.

Ideally, there will be too many options to examine in detail, given the costs likely to be incurred in collecting more data about each option. If one or more options is clearly inferior to another option against all of the objectives we bring to the decision then the inferior options can be rejected at this point. We may decide in the next iteration that we wish to reconsider our objectives, the process of comparing real options enabling us to learn more about our objectives, or what we really consider the problem to be. This may in turn mean that one or more of the options that we have just excluded now turns out to have virtues that were previously obscure.

Appraisal is by its nature comparative and relative, all the impacts being measured against some baseline. The choice of the baseline is consequently important.

The process of identifying the 'best' option can be more or less mechanical because the critical step is the next one: testing how confident we can be, given all the necessary uncertainties, that one option should be preferred to all others. This stage of testing the robustness of our choice is the core of the decision and takes place at the point in the appraisal process usually given over to sensitivity analysis. However, sensitivity analysis and robustness analysis are fundamentally different, performing different functions. Sensitivity analysis tells us which are the critical parameters whose values we should try to refine and so deals with uncertainty about the world; robustness analysis explores whether we should be uncertain as to which option to adopt.

13.2 Making 'Better' Choices?

The purpose of project appraisal techniques is then to help make better choices through learning about the nature of the choice that must be made. Two essential requirements of a project appraisal technique are that it addresses the conflicts that make the choice necessary in the first place, and that it does enable us to learn about the nature of the choice that must be made. In addition, the involvement of the public and other stakeholders in decision making means that project appraisal techniques are increasingly required to support the communication between the different interested parties, to share common understanding on the one hand and to highlight differences on the other. Hence, the four most important criteria for a project appraisal technique out of those given in Section 9.4 are:

- It aids understanding.
- It is comprehensive, encompassing all of the conflicts that make the choice necessary.
- It simplifies the elements of the choice to a level that is comprehensible as we cannot understand that we which cannot comprehend.
- It is feasible.

In addition, we want rigour but not to the point where it inhibits understanding and comprehension. Unfortunately, neither of the two available project appraisal techniques is superior to the other against all of these criteria (Table 13.1).

Table 13.1 *Criteria for project appraisal techniques*

Criterion	Benefit–cost analysis	Multi-criteria analysis
Elucidation	•	•••
Comprehensive	•	••
Simplification	•••	•
Feasibility	••	•••
Rigour	•••	•

• Poor; •• moderate; ••• good.

Benefit–cost analysis provides the greater understanding to the economist, but unfortunately this understanding is not usually shared by any noneconomist. There are ways of improving the degree to which a benefit–cost analysis can communicate with the nonspecialist, and, for that matter, make it easier for the analyst to both identify the crucial points and check for errors when the analysis is being prepared (Section 13.4.7.1). Multi-criteria analysis potentially performs much better against this criterion, provided that some rigour is sacrificed for the sake of transparency.

Benefit–cost analysis considers a single objective, economic efficiency, and hence is of limited value when the primary reason why a choice is necessary is because of conflicts between objectives, or because we cannot agree as to the relative importance that should be given to each objective. In addition, whilst some economists are optimistic as to the extent to which economic analysis can be extended to include all unpriced resources, it was argued earlier (Section 2.1.1.6) that this is a reckless claim when we do not know what it is people value and why they value it. Therefore, it is weak in terms of the nature of the conflict involved in the choice, not being comprehensive. Multi-criteria analysis is ideally suited to choices involving a conflict of objectives and some writers argue that it can also be used to promote a consensus between stakeholders (von Winterfeldt and Edwards 1986). Unfortunately, although it was argued previously that resource scarcity is typically an external constraint upon societal choices, it is none the less a real constraint. Even if we decide to make choices on the basis of moral or religious principles, we will still be limited in what decisions we can actually make by the scarcity of resources. One limitation of multi-criteria analysis, as we shall see later, is the difficulty in incorporating resource constraints in a meaningful way. Whilst the definitions of value and cost in a conventional economic analysis, and the equation of the two, elegantly resolves the problem of relating the two, multi-criteria analysis provides a way of valuing the achievement on noneconomic efficiency objectives but only at the penalty of breaking the linkage between value and cost.

Benefit–cost analysis certainly simplifies the choice, to a benefit–cost ratio or net present value, but in doing so, it oversimplifies the problem beyond the level necessary. Simplification necessarily involves imposing a structure and the loss of some of the detail and richness of the problem. If then we can cope with seven factors plus or minus two (Miller 1956), there is no need to simplify the problem beyond this point. Conversely, multi-criteria analysis starts with so much detail so that one cannot see the wood for the trees. It is quite common then to do some simple arithmetic which yields a single number in the same way as benefit–cost analysis. The same criticism then applies: simplification beyond the level necessary for us to be able to comprehend throws away information by imposing a structure. In addition, the procedures for obtaining a single number from multi-criteria analysis lack rigour.

Both techniques are feasible for most scales of decision but for decisions involving small amounts of money, MCA is generally cheaper and quicker to do.

Too much should not be made of the former virtue. Although engineers typically complain about the cost of undertaking project appraisals, the critical question is: how much is it worth spending to reduce the risk of wasting several million or hundreds of millions of public money? The probability of making such an error need only be relatively small to justify spending a significant amount of money, although one which is almost invariably considerably less than the amount spent on design.

Benefit–cost analysis is based upon a rigorous framework of analysis whereas it is, for example, difficult to apply a consistent approach to discounting in multi-criteria analysis. Almost paradoxically, the lack of rigour of multi-criteria analysis is a strength as a learning tool; it is easy to experiment to see how the choice would be changed if other values are used. But, the lack of rigour means that it is difficult to maintain consistency in treatment both between decisions and between options and criteria.

13.3 Benefit–Cost Analysis and Multi-Criteria Analysis

Benefit–cost analysis is now in widespread use for decisions involving water and the environment both by national government (e.g. US EPA (United States Environmental Protection Agency) 2000) and international agencies (e.g. Asian Development Bank 1997; Belli *et al.* 1997). Specialised methodologies have also been developed for such purposes as the evaluation of benefits of river water quality improvements (WRc/OXERA/FHRC 1996) or of flood alleviation schemes (DEFRA 1999). In general, such methodologies are based upon the use of standard data which has been derived in a variety of ways; this procedure is now often termed ‘benefit transfer’ (Section 12.2.4). In other instances, it is necessary to derive specific estimates of some of the streams of benefits and costs for particular options and sites under consideration using the techniques described in Section 12.2. Transfer payments, subsidies and other distortions also need to be removed (Squire and van der Tak 1975).

Consequently, it is almost invariably necessary to adjust market prices to obtain economic values and costs (Belli *et al.* 1997), to calculate the appropriate shadow prices. In the past, developing countries maintained artificial exchange rates and trade barriers, both of which mean that adjustments are necessary in carrying out a benefit–cost analysis. Finally, shadow wage rates are often used in developing countries where market wage rates often overestimate the opportunity cost of unskilled labour and, in the public sector, may underestimate the opportunity cost of skilled labour (Squire and van der Tak 1975). A convenient test of the likely quality of a benefit–cost analysis is whether unadjusted market prices have been used; if so, it is probable that the analysis is deficient and closer examination will reveal other problems.

Multi-criteria analysis covers a variety of methods that involve the use of what are commonly referred to as ‘scoring and weighting’, although the different methods available vary considerably in how this is undertaken. The technique has multiple roots: the concept of a matrix for assessing impacts has been adopted in a whole range of fields including the goal achievement matrix in planning (Hill 1966), and environmental impact assessment (Leopold *et al.* 1971). Again, under the name of multi-attribute decision making, it was incorporated into the market research literature relatively early (Green and Wind 1973) and into policy appraisal (von Winterfeldt and Edwards 1986). The method has not been used (e.g. Environment Agency 1999; Goeller *et al.* 1977) to anything like the same extent in water management as has benefit–cost analysis. But, importantly, the World Commission on Dams (2000) argued that multi-criteria analysis should be adopted; because of the nature of the panel and of the sponsors, the implications of the Commission's report extend beyond projects involving dams.

The essence of the procedure is to define a set of criteria against which the performance of the different alternative options can be tested. These criteria are in turn either explicitly derived from some set of objectives or imply those objectives, though it can often be easier to define criteria than objectives. The different criteria are then given weights in terms of the relative importance of satisfying each criterion. The different options are in turn scored in terms of their performance against each criterion.

Important decisions have to be taken in deciding how the score against each criterion should vary as the performance against that criterion; is, for example, a capital cost of 1 million euros twice as good as one of 500 000 million euros? The function of the score against the performance may have one of a multiplicity of functions, the most important being a lexicographic function, where the criterion is failed if the option's performance does not pass a particular threshold (Timmermans 1984).

13.4 Generic Problems of Benefit–Cost Analysis and Multi-Criteria Analysis

The two approaches differ substantially in detail but are faced with the same problems. First, each must confront the problem of comparing the unlikely consequences of each option across the three dimensions of choice: who, what and when (Chapter 5). Either explicitly or implicitly, widely different effects of different options must be brought together so that a choice can be made between the different options; we can change the way we do this, but we have to do it. The advantage of having an explicit procedure to cover each dimension of choice is consistency both within and between decisions. In principle, that there is an explicit procedure increases the transparency of the analysis.

13.4.1 Defining spatial and temporal boundaries

All analyses must have boundaries in time and space; how far into the future the analysis of the consequences of each option should be extended. The explicit use of discounting can be argued to enforce a form of myopia onto benefit–cost analysis but uncertainty necessarily increases rapidly as the future is extended. To the geomorphologist, 500 years may be a moment in time but no economist should hazard a guess as to the nature of the economy in 500 years' time. Any analysis should cover the engineering life of the longest lasting option but it is likely to be more important to examine the distribution of benefits and costs over time (Section 5.3).

The question of the boundary of the analysis also occurs for the geographical scope of the project. If the world was homeostatic then at some point many of the effects of a project would be offset by countervailing effects caused by the initial change. Thus, if one factory is closed by a shortage of water, some other factory would increase production so as to make up the lost production. Since economics developed at the time when the nation state seemed self-evident, it seemed logical to define the boundaries of the analysis by the national boundaries and hence the focus is on national economic efficiency. So, if the factory that is closed is in Spain and the factory that makes up the production is in Portugal, a real economic loss to Spain occurs. The naturalness of national boundaries is becoming less self-evident when on the one hand there is a movement towards greater cooperation between countries and on the other, towards a greater degree of devolution down from the nation state. Thus, if the factory that is shut is in Catalunya and the factory that makes up the loss is in Valencia, it could be argued that the analysis should be based on the boundaries of Catalunya and not Spain, or in the case of Spain and Portugal, on the boundaries of the European Union. If the analysis instead were to involve the benefits of wastewater treatment for an area of Germany on the Rhine, bordering the Netherlands, then using the national boundary would probably conclude that there were few benefits since the effects of the pollution were experienced in the Netherlands. That projects may then be partly or wholly funded by multinational bodies, such as the European Union, or through overseas aid simply makes the picture more cloudy. Furthermore, since the purpose is to implement an integrated catchment management approach, the boundaries of the catchment imply yet another set of boundaries. There is no self-evident answer to this question; it is one to worry about in each individual analysis.

13.4.2 Defining the baseline for measurement

All comparison is relative and all measurement made from some baseline. The choice of the baseline then matters, not least because it affects the level of measurement achieved and consequently the mathematical operations that can be performed on the resulting measurements (e.g. Galtung 1967). Only if the zero point given by the baseline is absolute, that it is entirely impossible for there to be any other, are multiplication and division valid operations (Galtung 1967). The zero in the Kelvin scale of temperature is such an absolute zero that it is meaningful to say that 200 K is twice as hot as 100 K. On the other hand, the zeros on the Centigrade and Fahrenheit scales are arbitrary. There is a debate as to whether in psychological or social measurement, as opposed to the physical sciences, it is possible to achieve as high a level of measurement as the ratio scale (Stevens 1975; Poulton 1989). In economic analysis, it is intended that money provides a more demanding scale of measurement than is achieved by the ratio scale; an absolute scale where not only is the zero point absolute but so too is the unit of measurement.

What points are adopted as baselines from which to make the comparison between the options then depends on what level of measurement can be achieved but that choice also creates some specific problems.

- absolute zero;
- arbitrary zero;
- current situation;
- worst-present case for each criterion/objective.

In benefit–cost analysis, the present situation is taken as the baseline. This baseline option is usually the 'do nothing' option, make no changes to the present situation at all. Thus, the present situation is not formally compared to the alternatives but all the alternatives are compared to the present situation. However, where the question is whether to renovate, enhance or repair some existing system, the appropriate baseline option is the 'walk away' option: abandon all maintenance and repairs to the present system other than those to make it safe before abandoning it. Therefore, one of the options to be considered is maintaining and repairing the current system.

That all of the changes that would result from adopting each of the 'do something' options are measured against the 'do nothing' baseline means that what is being measured is the changes, some of which are desirable and some are undesirable. It is then important to define what is a benefit and what is a cost because, unfortunately, their treatment makes a difference to the benefit–cost ratio (Table 13.2). For example, the loss of a valued view as the result of building a

Table 13.2 *Defining benefits and costs*

Present values	Benefits		Costs	
	Negative benefits	Gains	Negative costs	Losses
Capital			1000	1000
O&M			200	200
Loss of view	−100			100
Water supply benefits	3000	3000		
Sale of soil		80	−80	
Totals	2900	3080	1120	1300
NPV	1780	1780		
Benefit–cost ratio	2.59	2.37		

water tower could be regarded as a cost of the water tower or treated as a negative benefit and subtracted from the benefits. Similarly, if the soil excavated in order to construct a storage reservoir can be sold, then the income from the sales can be treated as a benefit of the project or as a negative cost, and subtracted from the estimate of project costs. Treating all desirable changes, such as the sale of soil, as benefits and all undesirable changes as costs results in the least distortion in the benefit–cost ratio – otherwise, for example, if enough soil could be sold then the costs net of negative costs could fall to zero.

Exactly the same problem occurs in multi-criteria analysis if the current situation is taken as the baseline. However, it may be desirable to include the current situation explicitly rather than to include it implicitly as the baseline. Since using the worst case on each criterion as the baseline means that potentially that baseline changes every time another option is added, the choice lies between an arbitrary zero and an absolute zero. In practice, an arbitrary zero point is usually used so that the scoring scale is an interval scale at best but probably only achieves an ordinal scale of measurement.

13.4.3 Identifying the options

Since the option identified as the best option can be no better than the best of those considered, defining a good set of options is critical to the exercise (Howe 1971). In the end, better decisions depend upon having better options. However, the definition of these options is usually a matter for engineers and others rather than for economists. The economist can help by ensuring that the problem or aims are defined in a way that does not artificially narrow the solution space: the nature of the question classically determining the answer that will be found (Rittel and Weber 1974).

Thus, the aim of a water supply system could be defined in two alternative ways:

- ‘To meet predicted per capita water consumption requirements in 2050’; or
- ‘To ensure that the probability of water restrictions being applied does not exceed 0.05 per annum in 2050’.

The former definition implies first determining predicted water demand in 2050, then defining some design standard drought year, and finally designing some water resource strategy that will meet the predicted water demand, given those drought conditions. The second definition would allow demand management options to be considered as well as resource reinforcement. So, the goal for the Melbourne water resource plan has been set as a 1 in 20 chance of water restrictions, lasting not more than 12 months and requiring a level three response within the Drought Response Plan (Government of Victoria 2001).

Feasible options vary between different types of project as well as from location to location. It is consequently not possible to define any rule that will ensure that the best of all possible options will always be included amongst those considered. However, it is possible to set out some guidelines to avoid options being prematurely discarded or not considered in the first place (Section 9.3): some if not all of these options should normally be expected to be amongst the options considered. More generally, widening involvement in the decision process should result in widening the option space and, in turn, options proposed by those involved in the decision process should obviously be considered.

Some of the past criticism of 'big bang' engineering approaches may be unfair in that in practical terms engineering analysis was limited in capacity to fairly simple approaches. Faced with a flooding problem from a combined sewer, one approach is to consider a number of different alignments and sizes for a new trunk sewer. Alternatively, it is possible to think in terms of some source control here, some underground storage there, and a flow constrictor somewhere else. Given a large enough network, the possible number of combinations of source control, storage and flow constrictors will rapidly approach the infinite. The same is true of using many small tanks or reservoirs to provide irrigation as compared to one large one.

Many of these combinations will perform poorly and at a high cost. Armed with only a slide rule and book of log tables, the chance of the engineer in the past hitting on a combination that was anywhere near optimal would be low; indeed, so too was the likelihood that they would even be able to assess whether the system would operate at all. Computers help but an infinite number of possible solutions to test still requires infinite computing time. To find a good solution from this universe of possible solutions, one promising approach being tried is the use of genetic algorithms to identify feasible solutions (Gill *et al.* 2001).

13.4.4 Identifying the consequences of the different options

At the initial stage, the net should be drawn too widely rather than too narrowly and the problems of measurement and evaluation ignored for the moment. It is necessary to identify the significant differences in the consequences of each option relative to the baseline option and between each of the options. At this stage, all the significant consequences should be identified. The only differences that may be omitted are those which are insignificant; however, at this stage, the only guide to the 'significance' of each will be experience, which can be a misleading guide.

There are some consequences which can be excluded;

- those which would occur irrespective of which option is selected; unfortunately, the greater the variety of options considered, the greater the variety of consequences which are likely to have to be considered; and
- those consequences which have an equal and opposite reaction. For example, if drivers along an existing road visit one petrol station and a new road will direct that traffic, and those visits, to a different existing petrol station. In this case,

the loss of business to the petrol station will be counterbalanced by the gain to the other. An equal and opposite reaction only takes place if the consumers gain exactly the same benefits at exactly the same costs; therefore, that a transfer of consumption occurs as a result of one option does not necessarily mean that no economic gain or loss take place. The same principle applies to the transfer of production; there is no economic loss unless the costs of production and supply increase or the value to the consumer falls, unless production is transferred abroad, it being convention to define the boundaries of the analysis as national boundaries.

Not all of these consequences will be certain and it is often also necessary to estimate the probabilities of each occurring. For example, in assessing the benefits of rehabilitating systems or undertaking preventative maintenance, the benefits of such works are the reduction in the probability of system failure and the costs of such a failure (Section 16.1.3). Similarly, the benefits of flood alleviation works arise as the change in the expected value of flood losses, the difference in the probability of a flood times the losses resulting from such a flood (Chapter 18).

The quantification of the different streams of consequences from each of the options is commonly not an economic problem but rather one which can be resolved as part of a concurrent environmental assessment (e.g. European Commission 2001; World Bank 1991), or as part of the engineering studies associated with the project development. Thus, for an irrigation project, the increase in yield, shift to higher valued crops or the reductions in losses as a result of the project are questions which the analyst will either rely on the predictions of agricultural engineers or can only resolve with the help of agricultural engineers. Similarly, the analyst will depend upon hydrologists and water engineers for estimates of the volumes of water which the irrigation system will yield.

The analyst will consequently need to have enough technical understanding of the other disciplines involved in the project to both ask sensible questions and to understand what the answers mean; and, more especially, to interpret the critical assumptions that are being made in making those predictions. What the economist needs to know and what the specialist is used to providing are often different, so that establishing a common dialogue can take some time.

The value of such consequences will not necessarily be a linear function of the magnitude of the effects and it is also necessary to identify when a consequence will occur. Moreover, some consequences will themselves take time to occur. For example, if a new irrigation scheme is constructed, then it will take a number of years for farmers to change their cropping patterns in response to the increased availability of water. The accurate assessment of the benefits from a scheme is often critically dependent upon the assumptions made about the rate of take-up of the benefits (Morris and Hess 1986; Morris *et al.* 1984).

In multi-criteria analysis, double-counting is almost inevitable but this is not a problem to which excessive attention should be given in the establishment of the criteria. Instead, it is more important to cover the domain of interest. In turn, that the consequences included are those that affect one or more criteria means that the identification of the consequences and the identification of the criteria are two sides of the same coin.

Double-counting is, however, a problem to be avoided in benefit–cost analyses; in particular, care needs to be taken to avoid including the same impact as a flow change and a stock change, given that the value of a stock is the present value of the flows it generates. Thus, for example, the value of agricultural land is given by the profits it produces. In general, that which is included is whichever it is easiest to calculate; for example, it is generally easier to calculate the change in the value of a dwelling than the change in the stream of utility provided by that dwelling.

In addition, benefit–cost analysis is effectively limited to the assessment of only those consequences that affect economic efficiency. For example, a change in the number of people employed is generally not included in a benefit–cost analysis since in the absence of the project those jobs would be maintained elsewhere. This then limits the analysis of projects that are specifically intended to provide employment or to result in socio-economic regeneration or development of an area to cost-effectiveness analysis: it is possible to determine which is the cheapest way of achieving such goals, and how this compares to other similar projects, but not whether the project is worthwhile.

13.4.5 Changes over time

All benefit–cost analyses are undertaken using real prices; that is, the rate of overall inflation in the economy is ignored. Generally, analyses are also undertaken using constant relative prices, demand and supply. However, in theory, changes in the relative prices, as well as the quantities, of the different forms of resources and consumption which make up the different streams of benefits and costs should be considered (Section 5.3.1.2). The use of a discount rate itself assumes some growth in overall wealth so that it is only differences relative to base assumption incorporated in the discount rate with which we need to be concerned.

Where changes over time are incorporated into the analysis, it is most commonly in the form of predictions of growth in future demand; for example, for increases in water or energy demand over time. Because of the long lead time between initiating a project and the project coming on-stream, often in the case of water projects 10–15 years, it is usually necessary to make such predictions. Moreover, the returns to scale for water projects also mean that building to meet anticipated expansion in demand can result in a more efficient future than a succession of small-scale projects to chase current demand. However, predictions of future demand are difficult and often markedly erroneous in retrospect, and have often been based upon the extrapolation of past trends, or on descriptive analyses, rather than upon causal models (Section 14.5). Thus, for example, demand may be predicted to grow without limit or satiation. Similarly, whilst demand is usually considered to be exogenous to supply, there may instead be feedback loops between supply and demand: it is found that new roads generate new traffic (SACTRA 1994).

Faced with a decision where it is appropriate to include predictions of future growth in demand, then response by the analyst should include the comparison of two alternative sets of options:

- Demand management: comparing an option which has the effect of reducing that projected growth in demand to zero by, for example, making more efficient use of the resource in question. For instance, if the project is a new reservoir to meet a projected demand for irrigation water, then an option to be considered might be promoting a shift to more efficient forms of irrigation.
- Alternative timings for the construction of works to satisfy the projected demand. Given the necessary uncertainty about levels of demand in the future, constructing a series of small-scale plant over time allows readjustment of capacity over time to actual levels of demand.

Incorporating changes in relative real prices over time is even more problematic. Two clear rules are that if a growth factor is applied to one stream of benefits or costs, then growth factors should be applied to all of the streams of benefits and costs. Secondly, since we are concerned with relative changes in real values and prices, an assumption about the general trend being embodied in the discount rate, of the different streams of benefits and costs, some streams will have negative growth rates. Consequently, the greater the number of streams of benefits and costs included in the analysis, the more complex the problem of assessing the likely trends in relative real prices and values.

The relative real prices and values of different forms of resource and consumption may change over time for a number of reasons:

- Differences in the income elasticity of demand for different goods; although the discount rate implies an overall growth in real income, the income elasticities of demand for different goods are different. Consequently, there should be a shift in demand towards goods for which demand is income elastic. There is normally an assumption that demand for environmental goods is income elastic.
- Increased scarcity of supply, notably for environmental goods which are non-renewable stock goods, should bid up willingness to pay for access to the remaining stock of such goods.
- Historically, technological improvements have led to real reductions in the prices of many manufactured goods, notably electrical goods.
- Overall, there has tended to be a shift towards capital investment in fixed assets, be these houses or factories. Thus, Kosmin (1988) argued that the real value of houses in the UK has increased by some 2% per annum over the post-war period. In part at least this is likely to be due to the increased investment in the performance of such properties in the form of fitted kitchens, central heating and other performance enhancements.

- For imported and exported goods, long-term changes in the exchange rate, reflecting a country's economic performance relative to the rest of the world, will have a significant effect. For example, in the evaluation of the Soar Valley land drainage scheme (Rayner *et al.* 1984), a major anticipated benefit was the shift from dairy farming to wheat cultivation where wheat production was evaluated against the price of Canadian Red Wheat in US dollars as the wheat produced would substitute for imports. In the 18 years since the scheme was evaluated, the pound to US dollar exchange rate has fallen significantly so increasing the scheme's economic efficiency. Again, such shifts are to an extent incorporated in the 'true' discount rate which should be used since an economy with a low growth rate in global terms, and hence a falling exchange rate, should imply a low discount rate.
- People's preferences may simply change over time in ways unrelated to changes in real income. For example, in the nineteenth century, a preference for neo-classical architecture was replaced by one for gothic revival; thus, the relative values of renaissance and medieval buildings will have changed at that time.
- Finally, new technologies will also change the values attached to existing products; thus, the development of cassette tape recorders and CDs radically reduced the value of, and demand for, record players.

Overall, it is appropriate to be reluctant to apply growth factors in the basic analysis; it is more likely to be appropriate to test the effects of the consequences in terms of choices between the options if growth factors are applied to the different streams of benefits and costs. Where a growth factor is applied to one stream of benefits or costs, growth factors should be applied to all. Since an allowance for growth is built into the discount rate, it follows that some of these growth factors must be negative.

The same general principles also apply to multi-criteria analysis but such changes are often only included in a subjective way with the consequent risk of inconsistency.

13.4.6 Evaluating the significant consequences

In a benefit–cost analysis, the consequences can then be evaluated by the methods described in Section 12.2 in each case specifying the year in which they occur and, where necessary, by their probability of occurrence or rate of take-up. A spreadsheet is the logical procedure to adopt for setting out these streams of benefits and costs over time; one column can then be allocated to each stream of benefits and costs. A second advantage of such a procedure is that it makes documentation of the analyses easier and retrieval of the analysis easier; most analyses generate vast quantities of material as the analysis is progressively refined. It is also almost inevitable that at some date some years after an analysis has been undertaken a reanalysis will be required which either embodies new information or is based upon a new option which has been identified, or is simply a post-project appraisal. If the analyses are not adequately documented and archived then the result is a nightmare.

There are at least two conventions as to how the years of the project life are to be defined. Brent (1990) suggests defining the base date for the analysis, the reference point for calculating the present values of the different streams of benefits and costs, as being the last day of year zero. The benefits and costs then start accruing through year 1 onwards; in the absence of more detailed knowledge as to the distribution of these costs occurring at the end of that year; the end of the year being taken for all subsequent benefits and costs. In the UK, common practice instead (DEFRA 1999) is to take the base date of analysis as mid-year 0 and all of the benefits and costs as accruing in mid-year, starting in mid-year 0. The convention which has been adopted locally should be followed.

In multi-criteria analysis, the distribution of the consequences is not usually formally considered; instead, scores are assigned to consequences according to the equivalent of their present values. Importance weights have also to be given to the different criteria and then these are standardised in some way, commonly by the proportion of each weight to the sum of the weights across all of the criteria.

13.4.7 Identifying the 'best option'

13.4.7.1 Benefit–cost analysis

The two normal tests for selecting the best option are the benefit–cost ratio, the present value of the benefits divided by the present value of the costs, and net present value, the present value of the benefits minus the present value of the costs. Both rules are forms of the Hicks–Kaldor compensation principle, or potential Pareto improvement. A third test which is sometimes applied is the internal rate of return (IRR); this establishes the maximum discount rate at which the present value of the benefits exactly equals the present value of the costs. This is sometimes also termed the 'switching value'.

The IRR has often been used but is both complex to calculate and a rather unsatisfactory test. It is usually calculated by iterative trial and error but Gittinger (1982) suggests a method to calculate it with the least effort. Unfortunately, there need not be a single IRR at which the present value of the benefits exactly equals the present value of the costs; indeed, the number of solutions is related to the number of times the sign changes of the annual net benefit (Brent 1990).

The three different rules do not necessarily give the same ranking for projects. The IRR rule should not generally be used, the decision lying between selecting the option which has the maximum benefit–cost ratio and that which has the greatest net present value.

When the projects are mutually exclusive in terms of benefits, then the net present value should be used to select the project to be undertaken. Where there is a budget constraint in the first year, depending upon the format used, year 0 or year 1 in the analysis, then the project with the highest benefit–cost ratio should be used. Indeed, when there are many different projects competing for the rationed capital, selecting those projects whose total costs sum to the capital constraint and which have the highest benefit–cost ratios will ensure that the programme of projects as a whole has the highest possible net present value (Brent 1990). If there are expenditure constraints for all years then operational research techniques are required to select the optimum programme of projects (Baumol 1972).

Since economic efficiency is not the only objective which the decision makers may want to consider, the choice of the option does not rest on the benefit–cost ratio alone but on the performance of the options against other objectives. Equally, almost all benefit–cost analyses are incomplete; some benefits and costs will have been omitted as being insignificant; more importantly, some benefits and costs will have been left as 'intangibles' because it is either not possible or too difficult to evaluate them. That they are left as intangibles does not mean that they should not be considered in taking the decision. How important they are depends upon whether the intangible impacts are common to all of the 'do something' options or whether there are significant differences between the options as to occurrence of intangible impacts. How easy it is to take account of the intangibles depends upon the extent to which it has been possible to measure them if not to evaluate them. For example, it is possible to make some predictions in quantitative terms about the health benefits of providing piped water and sewerage services (Esrey *et al.* 1998), and of reducing the risk from flooding (Green and Penning-Rowsell 1986).

Diagnostic analyses should also be undertaken both to check for possible errors and to identify the main contributors to the benefits and costs. For example, Figure 13.2 shows the incremental present value of flood alleviation benefits for different design standards of protection according to the land use classes

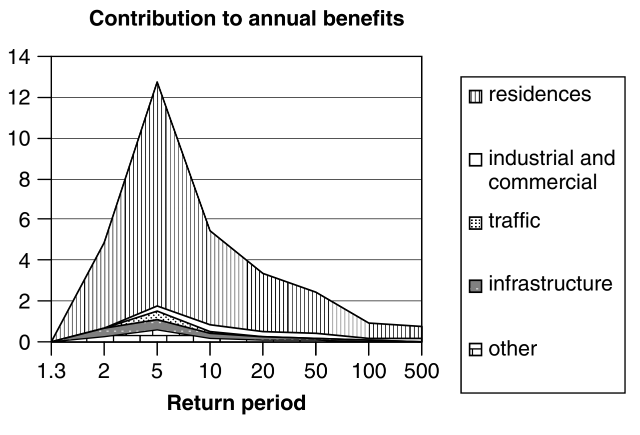

Figure 13.2 *Strategic urban drainage plan for Buenos Aires: components of flood alleviation benefits*

affected by flooding. It shows quite clearly that reducing the risks of flooding to dwellings produces most of the benefits and also the incremental benefits of increasing the design standard of protection is markedly peaked for the increase from a two-year design standard to a five-year design standard of protection, and then falls away rapidly thereafter. Pie diagrams are also useful for examining the relative contributions of the different streams of costs and benefits, and plots of the different streams over time should usually also be prepared (Section 5.3.1.1).

13.4.7.2 Multi-criteria analysis

The potential Pareto improvement offers an apparently simple rule by which to identify the 'best' option in benefit–cost analysis: no such simple rule exists in multi-criteria analysis. An apparently simple rule is to simply multiply each score (s_j) by the relevant weight (w_i) and choose the option with the highest score:

$$\Sigma w_i \cdot s_j$$

However, this procedure should be avoided for a number of reasons. The most important is that it destroys the main strength of multi-criteria analysis, that it enables a number of different criteria to be considered simultaneously. If the use of benefit–cost analysis runs the risk of trivialising the choice, this is even more true of the use of a such a crude device in multi-criteria analysis.

Technically, there are a number of other reasons for avoiding this approach:

- It is unlikely that the scores achieve higher than an interval level of measurement and hence multiplication is a mathematically illegitimate operation.
- It assumes that the choice should be made on the basis of an additive utility model (Moore and Thomas 1988); one of the most important things that we should seek to discover in the analysis is whether we are adopting an additive utility model or some other form.
- It unnecessarily destroys information; given that we can cope with between five and nine factors (Section 9.4), imposing an additive utility function reduces the complexity of the choice below the necessary level. However, a potential strength of multi-criteria analysis is that it can avoid unnecessary simplification. Moreover, it can be used to enable us to learn what we prefer.

Rather than reach a conclusion as to which option should be preferred, the best use of multi-criteria analysis is to move directly to the next phase.

13.4.8 Testing the robustness of the choice

13.4.8.1 Benefit–cost analysis

It is usual to recommend that the results of a benefit–cost analysis be subject to a sensitivity analysis; the values for key streams of benefits and costs and other factors being varied and the effects upon the benefit–cost ratio and net present values of each option determined. This is not a very useful exercise since it does not usually tell the analyst any more than they already know; if the results of analysis are not sensitive to the values of a particular variable then it is not very helpful to include that variable. What it is important to determine at this point is whether the rank order of preference across the different options is robust to the various inherent uncertainties.

We know, from the earlier sensitivity analysis, to which parameters the rank order of preference across the options is most sensitive. The issue is whether the uncertainties are sufficient to lead us to choose an option other than that with the highest NPV or benefit–cost ratio as appropriate. One approach is to associate probabilities with values of the different critical parameters and to undertake a Monte Carlo analysis but this, it was argued, cannot handle systemic uncertainty (Section 2.1.2.1).

An obvious guide to the robustness of the decision is the benefit–cost ratio; this shows by how much the benefits or costs need to change before the benefit–cost ratio falls below unity. Thus a benefit–cost ratio of 2.5 shows that the present value of the costs would have to overrun by a factor of 150% before the project ceases to be worthwhile. In turn, the larger the benefit–cost ratio, then the greater can be the errors in the predictions before the outcome would be a project which is inefficient. To test the robustness of the choice to outcome uncertainty, the appropriate procedure is to hit the choice with as large a hammer as possible until it breaks. Thus, to take a variable to which it is known that the outcomes are highly sensitive and to see how extreme a value may be adopted before the benefit–cost ratio falls below one. What variable constitutes an appropriate hammer depends upon the type of project being appraised and specific tests of robustness can be developed for specific types of project; Case Study 18.1 illustrates an example of such a specific analysis.

In fact, the benefit–cost ratio should not be treated as a 'pass-failure' criterion but as an indicator of the confidence we have that the 'do something' option can be preferred to the baseline option. A benefit–cost ratio of one is then the point of maximum decision uncertainty; the decision between the 'do something' and the baseline option is marginal. Conversely, if the benefit–cost ratio is well below one, then the smaller it is, the more confident we can be that the baseline option is the best option. Where the benefit–cost ratio is well above one we can be confident that the 'do something' option is preferable to the baseline option. However, if the benefit–cost ratio is very high then we should start to expect that some fundamental error has been made in the analysis such as failing to discount the benefits and costs (Figure 13.3).

This approach works well when all the 'do something' options are sensitive to the same parameters. If the decision is simply to identify the design standard or to identify to which parts of a system priority should be given for additional works, then generally each of the 'do something' options will be sensitive to the

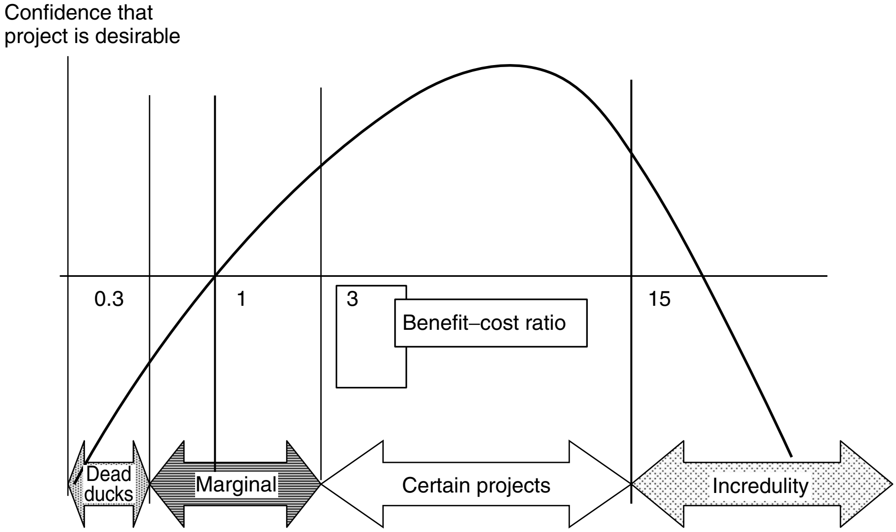

Figure 13.3 *The benefit–cost ratio and confidence that the 'do something' option is to be preferred to the baseline option*

same parameters. In other cases, the performance of each of the different options will depend upon different parameters. For example, two options to meet the objective set out for water supplies to Melbourne (Section 13.4.3) might be:

- Retrofitting all properties with water-efficient fittings and requiring all new construction to adopt rainwater harvesting for toilet flushing and external uses.
- Construct a new reservoir.

It may then be found that the performance of each of the two options depends upon different critical parameters and hence the order of preference across the two options (Table 13.3).

Such decisions are more complex than when the same parameters are critical for all the options. Without being able to attach probabilities to the likelihood that the different variables for each option will in reality differ from the baseline predictions or estimates, the decision makers may nevertheless have some preferences as to the risks which they would prefer to run and may want to modify

Table 13.3 *Critical parameters for two options for a hypothetical water supply study*

	Capital costs	O&M costs	Rate of take-up	Environmental impact
Demand management		•	•	
Reservoir	•			•

their preferences between the options to take their risk preferences into account. For instance, if an option is highly sensitive to the predicted growth in demand, then the decision makers may prefer options which instead are highly sensitive to capital cost. Whilst precautions can be taken to control variations in the out-turn cost compared to the predicted cost, it is more difficult to influence future growth in demand. What is of importance to the decision is not then the sensitivity of the outcome as such but the cause of the uncertainty and the degree to which actions can be taken to manage that uncertainty.

When, as is often the case, all of the do something options are sensitive to the same set of variables, then the order of preference between the do something options will not change significantly. What will change is the order of preference relative to the do nothing option; what the decision maker needs to know is how wrong can the analysis be and will the best option still be to do something rather than to do nothing? How robust is the decision to 'do something' to outcome uncertainty?

13.4.8.2 Multi-criteria analysis

Multi-criteria analysis leaves us with too much data to handle: a matrix of options against criteria. Table 13.4 presents analysis of the options for a hypothetical flood alleviation project; neither plotting the scores nor using an additive utility function show dramatic differences between the options. In addition, although scores have been given to each option against each criterion, and the criteria have been weighted in terms of their relative importance, neither scores nor weights should be considered to be definite. Equally, we do not know how to combine the different scores. The great strength of multi-criteria analysis is that it can be used to learn, argue or negotiate which option we actually do prefer. Moreover, it is easy to use graphical techniques to support this learning or negotiating process. A useful technique is then to rank the options against each criterion and then to plot the mean rank of each option against the standard deviation of the rank (Figure 13.4).

In the unlikely event that the rank order of the options against every criterion were to be identical, this plot would result in all of the options lying along the x-axis. In practice, we might hope that some options are clearly separated from the rest by lying close to the zero point whilst others lie close to the x-axis but off to the right. The former are then those which, on average, perform better against the criteria whilst the latter tend to perform poorly against all of the criteria. This latter group can be discarded. What this approach is doing is testing the extent to which the choice of the option depends upon the weights given to each criterion. In this case, flood storage and flood warning stand out from the remainder of the options.

The same technique can be used when seeking to prioritise different projects for inclusion of an overall programme of works. For example, the government of Hungary wanted to determine which of 151 flood basins were those upon which the limited available resources for maintenance and repairs should be

Table 13.4 *Hypothetical multi-criteria analysis of flood alleviation options*

5 = desirable
0 = undesirable

CRITERION population vulnerability

		Risk to life in consequence	Capacity to respond to flood	Capacity to recover from flood	Critical systems affected	Number of properties involved	Failure mode	Reliability	Local socio-economic impact	Flood risk changing	Positive environmental impacts	Negative environmental impacts	Flood losses	Other benefits	Capital costs	O&M costs	B/C ratio
		6 = low	6 = low	6 = low	6 = major, national systems	absolute numbers	6 = reduces the impacts of all floods	6 = probability of failure on demand is zero	6 = strongly positive	6 = increasing	6 = significant	6 = none	absolute number (present value)	6 = significant	1/absolute number (present value)	1/absolute number (present value)	1 + absolute value
		1 = high	1 = high	1 = high	1 = no		1 = rapid transition to failure and dangerous	1 = probability of failure on demand is high or uncertain	1 = critical negative	1 = decreasing	1 = none	1 = significant		1 = none			
	Weights																
	Importance	10	0	0	0	0	9	7	4	0	6	7	6	5	5	5	5
	stdised	0.14	0.00	0.00	0.00	0.00	0.13	0.10	0.06	0.00	0.09	0.10	0.09	0.07	0.07	0.07	0.07
Options	Baseline	2	6	4	1	4	2	1	1	6	5	5	1	2	6	6	1
	Maintain and repair	3	6	4	1	4	1	2	1	6	4	4	2	2	5	1	5.8
	Source control	4	6	4	1	4	6	2	3	6	5	6	3	5	1	2	1
	Storage	3	6	4	1	4	5	6	5	6	3	3	6	6	1	5	1.5
	Lower standard of protection	2	6	4	1	4	1	4	1	6	4	6	2	2	5	4	6.2
	Conveyancing	5	6	4	1	4	3	6	2	6	1	2	5	4	3	4	1
	Separate floods and land uses	4	6	4	1	4	6	5	2	6	1	3	3	5	3	5	2.4
	Flood proofing	3	6	4	1	4	5	4	4	6	1	4	3	3	1	3	2.5
	Flood warning	6	6	4	1	4	5	3	4	6	1	6	5	2	6	5	1.9
	std dev	1.3	0.0	0.0	0.0	0.0	2.0	1.8	1.5	0.0	1.8	1.5	1.7	1.6	2.1	1.6	2.0

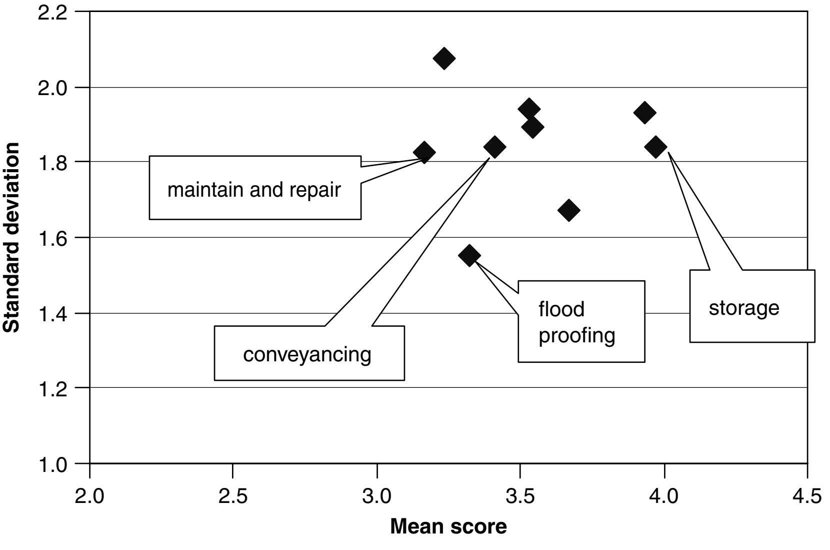

Figure 13.4 *Standard deviation of rank against mean rank against each criterion*

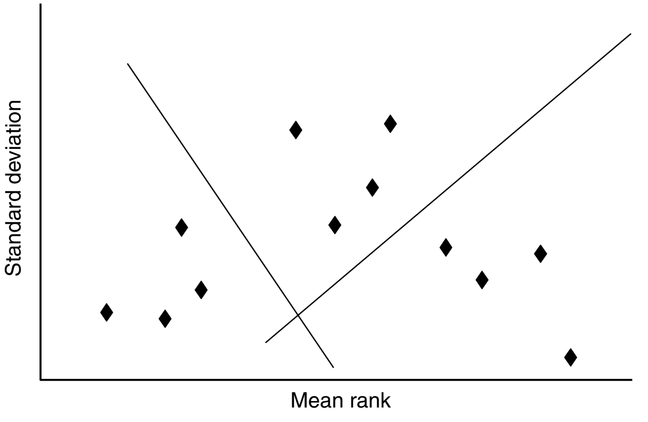

Figure 13.5 *Hungary: prioritising flood basins for maintenance and investment. Source: Green, Parker and Tunstall 2000*

concentrated (Evans *et al*. 2000). A number of different criteria were developed, including the risk to life if the embankments were to fail and whether the flood basin protected a critical national asset such as an oil field. However, they were unwilling to attach importance weights to the risk to life and the other criterion. Figure 13.5 then illustrates the pattern of results that was found when the ranking and plotting technique was applied to the 151 flood basins. One group of flood basins scores heavily on each of the criteria and clearly should therefore be treated as priorities; a second group scores badly against all of the criteria and equally clearly can be excluded from further consideration. It is then the middle group of flood basins that need further examination to determine whether the criteria on which they score highly are sufficiently important to outbalance those against which they score poorly.

The same procedure can be used when the different stakeholders each assign weights to the different criteria. In this case, the plot shows about which criteria there is relative agreement and those where there is marked disagreement.

A second plot is given if the total scores of the individual options using an additive utility function are plotted (Figure 13.6) against those using a multiplicative utility function ($\Pi w_i \cdot s_j$). In this case, flood warning and storage again stand out from the other options but the order of preference across the two options depends upon whether an additive or multiplicative utility function is adopted.

Janssen (2001) suggests another technique; setting each criteria in turn to an arbitrarily large proportion of the total weights and comparing the resulting weighted scores for the different options. All of these tests leave storage and flood warning showing up as the two options between which a final choice must be made in this case. In turn, we might then think of combining the two options and adopting this combined approach if affordable.

It is important to recognise that none of these techniques can reveal order where there is none; if Figure 13.4 simply showed a circle of points closely clustered about the middle of the x-axis and with very similar standard deviations of the ranks, then the choice of the option depends critically upon the weights given to the different criteria. In this event, it can be worthwhile to carry out a cluster

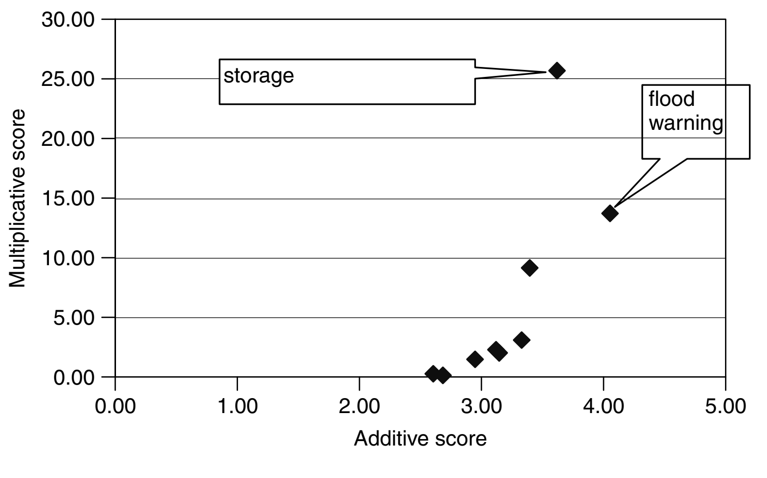

Figure 13.6 *Multi-criteria analysis: robustness analysis*

analysis on the criteria to determine whether the different options perform very similarly on several different criteria; if this is the case, then it suggests that there may be double-counting and in any case that there is some degree of redundancy amongst the criteria. A similar cluster analysis carried out on the options will show whether any of the options perform so similarly against the different criteria that it is possible to decide between those two options. Setting some of the criteria to be lexicographic – so that an option fails altogether if it does not score at least a minimum score on that criterion – is a further way of thinning down the number of options to be considered. But, sometimes the choice will clearly be a marginal choice with not much to choose between the options when all factors are considered.

14

Capturing Water for Human Use: General Issues

Beck (1996) has argued that the problem in wastewater management is to manage the entire time frequency distribution of perturbations in the quality of runoff, operating wastewater treatment plants so as to maintain the quality of the receiving waters within desired limits. Human actions change perturbations: suppressing or removing disturbances, transforming pulse events into persistent or chronic stress, or introducing new disturbances.

So, similarly, on the quantity side the problem is to bring the variations in supply and demand into alignment (Figure 14.1). Hence water resource management is about matching the variation in supply to the variation in demand where demand, especially for crops, is usually highest at the times when rainfall is least. Consequently, the greater the variation in water availability over the year and between years, the greater is the problem. Moreover, the necessity is to manage as a whole the variations in water availability rather than to treat separately some part as 'droughts', other parts as 'water resources' and the remainder as 'floods'. In arid climates, floods are the water resource and since a key quality characteristic is the reliability of supply, it is inappropriate to differentiate between water resource management and drought management, these areas often experiencing both drought and flood problems. Therefore, any water resource management plan should consider how to respond when the resources are unusually low and a critical question is: how much storage to provide in order to reduce the risk that supplies will have to be rationed (Section 14.2).

The basic choice in water resources management is between:

- enhancing the supply; or
- reducing demand by making more efficient use of the existing resources.

The appropriate strategy or combination of strategies depends upon the local circumstances, but, in developed countries in particular, the latter strategy will often be appropriate. Any enhancement strategy involves a combination of three components:

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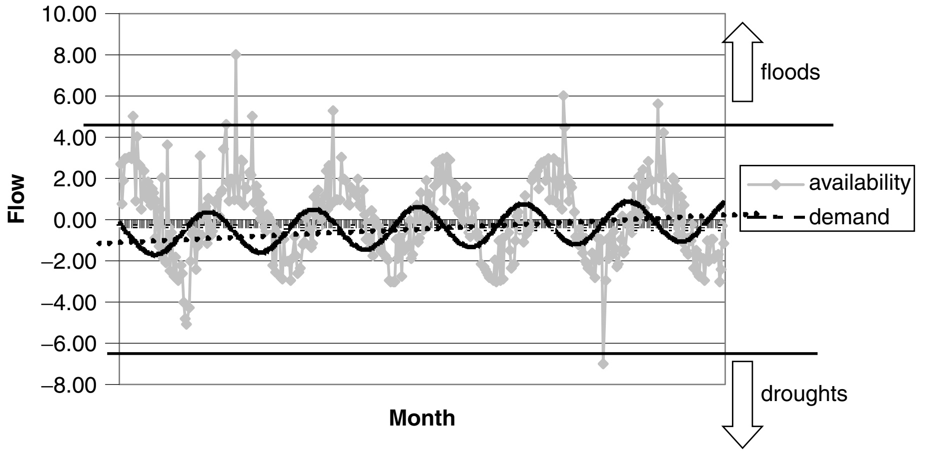

Figure 14.1 Managing perturbations in water quantity

- Capturing the water (as runoff or in the form of groundwater).
- Storing the water (surface or groundwater).
- Conveying it to the point of use.

In the simplest situation, the rainfall is captured on a field through infiltration, and stored for a few days as soil moisture where it is immediately available to the plants. Similarly, for urban uses, the simplest traditional approach is to collect rainwater runoff from roofs, store it in an underground cistern and raise that water with a bucket when it is needed.

In turn, there are major differences between agricultural and urban or industrial uses (Table 14.1). Crops are a consumptive use of water, the water being lost through evaporation and transpiration with 99% of crop water use being required by the crop for cooling. Moreover, plants are very heavy consumers of water, with hundreds and often thousands of tonnes of water being required to produce one tonne of a crop (Figure 14.2). Consequently, in every country, agriculture is

Table 14.1 Significant differences between agricultural and urban water uses

Agricultural	Urban/industrial uses
Consumer of water; most water used is necessarily lost through evapotranspiration	Most water used is available for reuse or recycling
The volume required is largely fixed through the needs of plant and climatic conditions	In large part, use is technologically determined
Very high water requirement	Relatively low water requirement

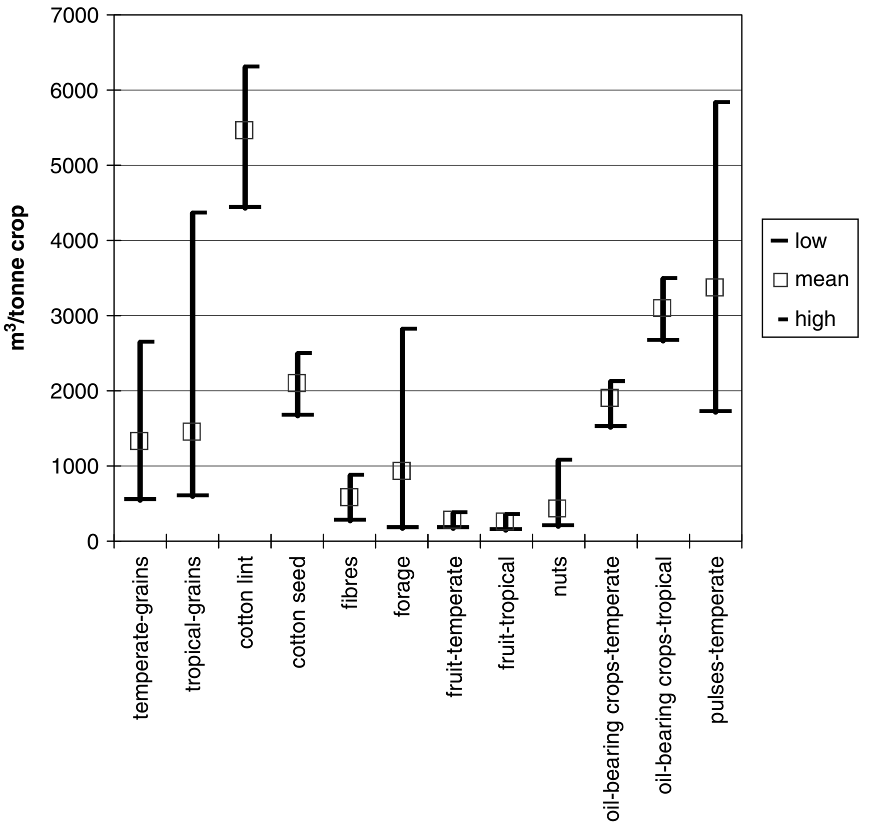

Figure 14.2 *Evapotranspiration of plants. Source: Rockstrom et al. 1999*

the largest consumer of water whether that water is directly provided by rainfall or indirectly by irrigation.

Turning to the availability of water, the first two questions then are:

- Is there enough rainfall locally?
- What is the variability of that rainfall?

For agriculture, if rainfall exceeds the crop evapotranspiration requirement then rainfed crop production is in principle possible. Thus, the ratio of precipitation to evapotranspiration for East Anglia in eastern England is 1.1 (Morris *et al.* 1997). However, a crude comparison of precipitation (P) to evapotranspiration (PET) is somewhat misleading because water can only be stored in the soil for a matter of days. If then on a monthly basis, evapotranspiration exceeds precipitation, then relying on local rainfall will not be enough. Thus, in the Taihu Basin (Figure 14.3), traditionally the grain basket of China, irrigation is

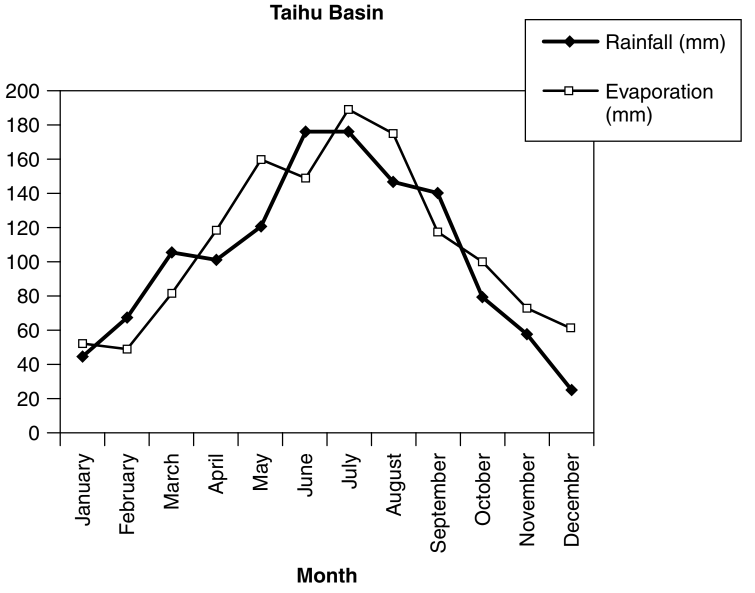

Figure 14.3 *Precipitation and evapotranspiration in the Taihu Basin, China*

necessary to raise output from one to two or three crops a year. Arid regions (P/PET ratio of between 0.03 to 0.20) are characterised by a concatenation of water management problems:

- Rainfall is concentrated into relatively short periods in the year.
- There is high variability in rainfall from year to year.
- Poor groundwater recharge occurs because the soil is seldom already saturated when rain occurs.
- Locally rainfall can be very intense (e.g. over 500 mm in one day in some areas of Spain when the average annual rainfall varies from 200 mm to 1315 mm – Estrela *et al.* 1996).
- In turn, the locally intense rainfall results in soil erosion.

If variability is high but overall average precipitation exceeds potential evapotranspiration, we can get by with local storage. If we are lucky, then storage will be available naturally either in the form of groundwater or as lakes. However, if potential evapotranspiration exceeds local precipitation, then we are forced to one of several options:

- rainwater harvesting;
- groundwater;
- importing water.

If rainfed agriculture is not possible, or additional water would increase the number of crops that can be harvested in a year, then rainwater harvesting is an option.

Cities are in practice very efficient systems for rainwater harvesting and when water is used for urban purposes, we get most of it back, significant losses occurring from transpiration and evaporation only when it is used for outdoor uses such as garden watering. So, for example, the output of water from Manchester in northern England is seven times as great as the potable water supplied to it (Green 1998a). Even in Melbourne, a much less dense and hence less impermeable city than Manchester, and one that is also located in an arid climate, the output of water from the city is over twice the amount of water supplied to it (Government of Victoria 2001). In principle, therefore, for urban purposes, there is generally sufficient rainfall on the city itself to support urban uses. The obvious problem is that the runoff water is polluted, as, in general, most uses of land by humans mean that runoff requires treatment before it can be put to use. The second problem is that water management has historically been about energy use: because water is heavy and incompressible, the use of potential energy, gravity, has been preferred to kinetic energy. Thus, the problem with using rainwater harvesting in cities has been the energy cost associated with pumping and historically cities have been supplied from higher areas, with the water being distributed by gravity.

The collection of the runoff from roofs for domestic usage has been traditional in some arid climates (Maalel *et al.* 1987) and is now being increasingly considered in developed countries, particularly for arid areas, to provide for external uses (Texas Water Development Board 1997). In urban areas, rainwater harvesting can save money twice since capturing rainfall also reduces the amount of runoff that must be disposed of through the drainage network. Requirements for new dwellings to capture rainwater from the roof are increasingly common: in Waterloo, Canada, 20% of lots in new subdivisions are required to have 5000–8000 litre cisterns to capture rainwater for garden watering (Cook 1994).

The primary resource is groundwater: assessments of global water availability (e.g. Shiklomanov 1998) suggest that the quantity of water stored as groundwater is of the order of 7 to 10 million cubic kilometres, roughly equivalent to 70 times the total annual precipitation on land. Given the quantity of water stored as groundwater, around 170 times the flow in all the world's rivers, groundwater is critical to water management. Unfortunately, knowledge of groundwater resources, and of the relationships between precipitation, runoff, groundwater resources and surface waters is often limited (Moench *et al.* 2001; Shah *et al.* 2000); Figure 14.4 gives the overall water balance for Spain.

The great advantage of groundwater is that its storage is free. Of those 7–10 million cubic kilometres, what is accessible depends upon the depth at which it occurs since there are limits in terms of the depth to which different forms of wells can be dug, drilled or bored; as are the limits over the depths to

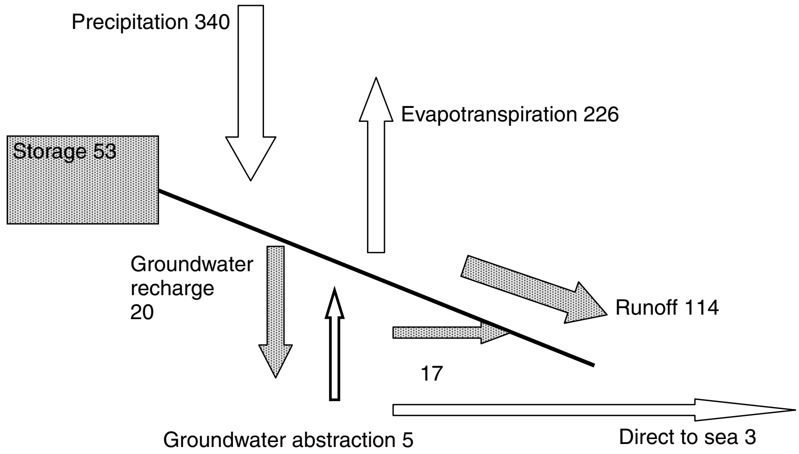

Figure 14.4 *Water balance for Spain. Sources: Estrela et al.; Mendiluce and del Rio n.d.*

which different forms of pumps can usefully raise water; and both the capital and O&M costs of raising water increase with increasing depths (Caballer and Guadalajara 1998). US AID (1982) gives a range of practical depths according to the means of constructing the well. In general, only high valued uses can justify abstracting from a depth of greater than 100 metres. Similarly, pumping requires electrical or mechanical power if substantial quantities are to be raised since the outputs respectively of hand, animal and wind power pumps are 3–5 m^3/day, 10–15 m^3/day and 50 m^3/day (Eberhard *et al.* 2000). The consequence is to greatly increase the demand for energy: thus, centre pivot sprinklers require 14 GJ/ha (Simmons 1989); 20% of Jordan's electricity supply and 12% of Israel's is used for pumping water (Brooks 1996).

It is necessary to differentiate between confined and unconfined aquifers, where the former have some form of outlet to surface waters. Fossil aquifers are those where the water has accumulated as a result of rainfall in the past, usually thousands of years ago, and where there is effectively no recharge as a result of current rainfall because that rainfall is too low. Thus fossil aquifers are a non-renewable, depletable resource and the question, as with any such resource, is when to deplete that resource and at what rate (Chapter 3); equally, as the aquifer is depleted, the costs of pumping will increase.

For non-fossil aquifers, the externalities of abstracting water from the aquifer depend in part upon whether the aquifer is confined or unconfined. If abstraction consistently exceeds the rate of recharge then in both cases, abstraction may result in subsidence; it may also result in saline intrusion from the sea or from linked aquifers of brine water. Where the aquifer is unconfined, abstraction will reduce flows to surface waters, reducing the availability of those waters for other uses. In England, the resulting low flows in rivers and reductions in the water supply to wetlands have created a number of major environmental problems with some rivers ceasing to have any continuous flow (English Nature and the Environment Agency 1999). Again, if abstraction consistently exceeds the rate of recharge, then the water level will fall increasing the costs of pumping and also eventually requiring the construction of deeper wells. In addition, major problems of arsenic and fluoride levels in groundwater, first identified in India and Bangladesh (Pearce 1998), now are, in the case of arsenic, being found to be quite widespread (Smedley and Kinniburgh 2002). Similarly, if groundwater levels drop, any naturally occurring sulphides in the soil will oxidise and the resulting acid will both damage the soil and when discharged to watercourses cause environmental damage (White *et al.* 1999).

The final option is to capture the rainfall at some distance from the point of demand and then transport the water to the demand centre. The most obvious and convenient way of doing this has been via rivers that carry away the runoff and snow melt from the areas where there is high precipitation but little use for that water, notably mountain areas, to those areas where human needs are high. Typically, these are the lowlands and flood plains that can be intensively used for agriculture. Estimates of the availability of water in this form are widely available and per capita availabilities of water of <500, <1000 and 1700 m^3/capita/year have been used (Falkenmark 1989) to classify areas as being 'beyond the water barrier', 'water scarce' and 'water stressed' respectively. However, on their own, these figures can be dangerous. For example, in East Anglia, the per capita availability of water is very low at 691 m^3/person/year (Environment Agency 2001a). This is not much more than the per capita availability of water in Jordan and Algeria but whereas Jordan and Algeria are confronted by major water management problems, there is no critical problem in East Anglia. In Jordan and Algeria, irrigation is required to ensure crop production whereas East Anglia is one of the richest crop producing areas in England and only supplementary irrigation is required, largely to ensure crop quality and the date at which at the crop can be harvested (Weatherhead *et al.* 1994). The critical measure of water availability is the ratio of precipitation (P) to the potential evapotranspiration (PET), or the moisture index I_h (UNESCO 1979). If agriculture can be supported through rainfed agriculture, then only relatively small quantities of water are necessary to support domestic and industrial uses, and substantially less than 500 m^3/capita/year.

Often rain occurs in the wrong place as well as at the wrong time. In India, whilst the average annual rainfall is 1.2 m a year, it varies between 200 mm in the Thar Desert to 11.4 m in Cherrapungi in Meghalaya state (Agarwal and Narain

1997). Whilst rivers have offered convenient ways of transporting the water to the places where it is required, the flood plains of the rivers offering the most fertile soils, these may have to be supplemented by canals, tunnels or aqueducts to transfer water between catchments. Equally, it is frequently necessary to distribute the water across the fertile area by canals.

Variability in supply is generally a greater problem than the overall quantity. Climate is a determining factor in water resource management. In arid climates, for example, the problem is not so much the low amounts of rainfall as the concentration of rainfall in short periods of the year and the variation of the rainfall from year to year. Smith (1998) notes that the variability of annual precipitation is inversely related to annual precipitation, whilst McMahon *et al.* (1992) showed that this relationship varies between continents, the coefficient being greatest for Australia where it is roughly twice that of Europe. The net result is that, depending upon the size of the catchment, four to eight times as large a volume of storage is needed in Australia as in Europe to give the same security of supply. So, for example, per capita storage for Sydney is 600 m^3 (Deen 2000). Again, whereas London has 90 days of storage capacity (de Garis 2001), Melbourne has storage for rather more than three years' demand (Melbourne Water 2001): however, it is experiencing a five-year drought (Haby and Fisher 2001). Overall, in Australia, with one of the most arid climates in the world, there are 5000 m^3 of water storage capacity per person (World Bank 2001).

Similarly, rainfall in India is also concentrated into four months of the year in the form of heavy rainstorms: Delhi's rainfall of 800 mm occurs in 80 hours during the year (Agarwal and Narain 1997). In turn, rainfall variability affects the variability of flows so that in the eastern USA, reliable flow (that available 9 years out of 10) is 60–80% of the long-term average, whilst this falls to 30% in the western USA and to 10% in the Middle East (Brooks 1996).

In turn, matching time-varying demand and supply means that the basic question in water resource management is one of how much storage needs to be provided and how? There are a number of options for storing water so as to bring demand and supply into alignment (Keller *et al.* 2000) but storage is inevitably required whenever the peaks of supply and demand do not coincide – unless the ratio of supply to demand is very large, even at the times of highest demand and lowest supply. The options are surface storage in lakes, reservoirs ranging from the very small to the very large, or wetlands is one option; underground storage, ideally in groundwater but also in cisterns, is another option; and combinations in the form of groundwater recharge and conjunctive use being the third option. There are typically strong economies of scale in water storage so that large bulk storage is cheaper than multiple small stores, and losses through evaporation and leakage also tend to be lower.

How water is to be stored has become a matter of major controversy, with large dams being viewed by some as inherently evil. However, this is somewhat to miss the point; the real problem is that all land and water is already being used in one way or another either by people or by ecosystems (Wood *et al.* 2000). Whatever we do will consequently impact on either people or ecosystems or both, and the choice in surface water storage is between the spatially extensive or intensive. A major determinant of whether it is people or the environment that is then affected is the density of population. Thus, in North America where population densities are incredibly low, it is possible to find areas in which very few people live but that these will be true wilderness areas. Over most of the rest of world, all useful land is already heavily populated and the remaining environment is often an artefact of several thousand years of human settlement. Here it is likely that it is people who will have to be resettled. The crunch in countries where populations are still increasing, especially where population densities are already high, is that there is seldom any available land or water available to accommodate them.

In addition, ecosystems develop around the prevailing water regime, the variations in water flows over time. Since it is those variations in water availability over time that we seek to change, water management can scarcely avoid having some environmental impact. Whilst it is the changes in flow regimes that result from dams that are most widely recognised (Acreman *et al.* 1999), meeting the demand from an unconfined aquifer, one with an outlet to surface water, will similarly impact on the environment (English Nature and the Environment Agency 1999). The only source of stored water whose use will not generally have an impact on the environment is then a confined aquifer.

14.1 Catchment Efficiency

It is necessary to consider the water balance over the catchment as a whole because so much water is reused after use rather than consumed, the only actual losses of water occurring when water is evaporated or transpired, or reaches a sink such as the sea (Seckler 1996; Merrett 1997). On a global basis all water is recycled; within a catchment, an issue is how much water can be reused or recycled, and how many times, before the remaining water is discharged to the sea or to another sink. Where the catchment is ‘open’ (Seckler 1996), where there is water which is not allocated to any apparent use, then the least cost option is typically as to the best means of capturing some of that water. Once the catchment is ‘closed’ then the choice is one of reallocating water between competing uses, reducing the losses from some uses, or increasing the degree to which water is reused (used for another purpose) or recycled (reused for the same purpose, commonly after treatment).

Apparent gains in the efficiency of water use may merely change the patterns of flows and stocks within the catchment rather than ‘save’ water: Seckler (1996) differentiates between ‘wet’ and ‘dry’ water savings, where the latter has no real effect on the total amount of water available within the catchment. During the last drought in California, the same distinction was drawn between ‘real’ and ‘paper’ water savings (California Department of Water Resources 1993); thus, if the losses from an irrigation canal are reduced by lining the canal, this loss will be a 'dry' or 'paper' saving if the only effect is to reduce the recharge flows to accessible groundwater. Similarly, low flush toilet cisterns do not increase the efficiency of use of water within a catchment if the wastewater is available for reuse.

'Wet' water savings occur when (Seckler 1996):

- Output is increased per unit of water that is lost through evaporation, transpiration or to a sink;
- Reducing water pollution and hence the availability of water for reuse or recycling;
- Reallocating water to higher valued uses.

14.2 Managing Extremes

Rainfall and runoff vary from year to year apparently randomly. In addition, there are cyclical patterns in rainfall and runoff of which the most obvious is the cycle associated with Niño. There are also trends in both demand and supply over time with climate change potentially affecting both future demand and supply. The critical question is then what should be the reliability of supply and hence how much storage should be provided? What risk of what extent of a shortfall in water is acceptable?

But, however low the probability of that drought, which is the worst with which the system is designed to cope, it is inevitable that in one place or another, a more extreme event will occur sooner or later. It is therefore necessary to consider from the beginning how such an event will be managed. Thus, in 1991, California adopted legislation which required any supplier of more than 3000 customers to prepare a water shortage contingency plan. Each such plan must (Department of Water Resources 1991):

- estimate the minimum water supply availability at the end of the next 12, 24 and 36 months assuming worst-case shortages;
- determine increasing stages of action to be taken in response to water supply shortages of up to 50%;
- outline specific water supply conditions which will trigger each stage;
- establish consumption limits;
- adopt mandatory no-waste regulations; and
- provide a method to overcome the revenue impacts.

In particular, it must outline how demand will be managed downwards to match the reduced availability of water. There are a number of ways of rationing supply:

- voluntary calls for restraint;
- bans on less important uses e.g. bans on garden watering, car washing;

- rationing through price;
- rationing by volume e.g. the fitting of flow constrictors, reductions in pressure;
- rationing by energy e.g. installing standpipes so that consumers must carry water;
- rationing through time e.g. cutting off the supply for part of the day.

These different strategies vary in terms of their effectiveness; for example, Husain (1978) reports that calls for voluntary constraint reduced demand by 25% during the 1976 drought. However, 60% of respondents in the Green *et al*. (1993) study in one of the two areas affected by a current hosepipe ban were not aware of such a ban. The different strategies also differ in terms of equity, and in costs. During the major droughts from 1991 to 1993, amongst the methods tried to reduce demand in the city of Bulawayo (Ndubiwa 1996) were rota cuts; supplies being cut off between 8.30 a.m. and 16.30 p.m. This method was abandoned after a week for three reasons:

- the heavy demand on labour to open and close valves;
- a significant increase in the number of mains bursts as a result of the pressure transients; and
- the hoarding of water by consumers.

Since the overall effect was an increase in water demand, the method was abandoned in favour of supply restrictions and rationing.

Moreover, the city of Bulawayo reports that when consumption was cut by two-thirds, the frequency of blockages and other problems with sewers significantly increased as flows were now no longer sufficient for the system to be self-clearing. The costs of running wastewater treatment works might also change but whilst flows will be less, the concentration of pollutant loads can be expected to be higher and the assimilative capacity of the receiving waters will be lower because of lower flows.

Systems that are wholly or partly reliant on groundwater have the advantage in that it is usually possible to overdraft groundwater on a short-term basis; equally, a common response to a drought is a switch either by the supplier or by the consumers to using groundwater. Thus, in the California drought of 1987 to 1992, farmers replaced some of the irrigation water that they had previously received by drilling wells (Frederick 1993). Whereas before the drought, groundwater provided 37% of the state's water supply, during the drought, this increased to an average of 60% and up to 90% in some areas. In turn, a number of aquifers were overdrafted: the cumulative change in storage in Fresno County being some 2 million acre-feet whilst the number of wells drilled rose from around 15 000 in 1987 to 25 000 in 1990 (Department of Water Resources 1993).

In general, analyses of past droughts (Russell *et al.* 1970; Schlemmer *et al.* 1989; USACE 1995; Wheaton and Arthur 1989) have found that the costs to urban consumers of water of managing down demand are very small, provided that demand is managed down rather than supplies being suddenly cut with little or no warning. The costs are instead borne by the environment and by farming, available water being switched away from agriculture to urban uses (Department of Water Resources 1993). The degree of advanced warning that can be given of a potential shortfall in supply then depends upon the pattern of rainfall. In the same way that in arid climates, a large amount of storage is required to bridge between the rainy seasons, the failure of one set of rains provides a long lead time before storage is expended. Thus, in Bulawayo, Zimbabwe, the city plans for potential droughts 21 months in advance (Ndubiwa 1996). At the end of the rains in April, the test applied is whether there is enough water in the reservoirs to last 21 months through a 10% low flow year to the beginning of the following rainy season. If the answer is no, then rationing is put in place such that the water will last the 21 months. A series of measures are adopted in the following sequence:

- publicity campaign;
- hosepipe bans between 6 a.m. and 6 p.m.;
- rationing based on occupancy per unit or a percentage of the last six-month period of unrestricted supply;
- penalties are levied for excess consumption with supplies being cut off for persistent excessive consumption; and
- flow restrictors also being installed.

In the 1991–93 drought, these measures were used to manage a reduction in consumption from 150 000 m^3/day in October 1990 to 57 000 m^3 in December 1992, at which time households of up to 15 people would be managing upon 300 litres per day. Whilst, at the time, there were grave concerns about the possible threats to health of such a minimal water availability, there were no epidemics.

Varying the pressure in the mains is thus another option; the pressure in the mains in the UK being higher than in some others, the network in Japan operating at pressures of 15–20 m compared with what is thought to be somewhere between 40–50 m in the UK (National Rivers Authority 1995b). Reducing the pressure at an outlet from 100 psi to 50 psi can reduce water flow by about one-third; a comparison of dwellings in high and low pressure zones in Denver, Colorado found consumption to be 6% lower in the latter (US EPA 1995).

One reason why the costs of droughts to urban consumers has been found in the past to be low, however, is that there has always been scope for consumers to reduce inefficiencies in the use of water. When average domestic per capita consumption is 280 litres/person/day, it is considerably easier to reduce demand by 50% and less pain is caused to the consumer than when the per capita consumption is 70 litres/person/day. Concern has consequently been expressed about whether the costs of responding to drought periods will increase as urban water use becomes more efficient.

Secondly, it is not clear how a switch to greater reliance on rainwater harvesting will affect the capacity of the system to respond to droughts. Because of the economies of scale, the capacity of on-site storage of rainwater is likely to be relatively low and perhaps only sufficient to bridge between the average wet and dry seasons in a year. The consumer will then rely upon storage by the water supplier to maintain supplies during droughts. This will increase the problems for the supplier, because the consumer will only want water at those times when it is most expensive to make that water available.

Similarly, where water is metered or the charge otherwise reflects the amount of water used, then a major problem for the water supplier is that a fall in the amount of water supplied as a result of a drought will result in reduced revenues (Braver n.d.). Since a large part of the supplier's costs are, however, fixed, revenue will fall to a greater extent than costs and so revenue may fall below costs. Thus to the supplier, metering increases risks. In turn, the supplier needs to consider how to balance costs and revenue when demand must be forced down to cope with reduced resources.

14.3 Water Sources

There is not necessarily a choice between using groundwater, rainwater harvesting or surface water since groundwater is only accessible in some areas. Where there is a choice, then in large measure the choice is between capital costs versus O&M costs; using groundwater, when available, tends to involve lower capital costs than abstracting surface water, not least because the storage capacity is inherent in the aquifer, but higher O&M costs because of the need to pump the water over a significant height. Economies of scale are, as ever, important; the costs of storage falling as a function of the capacity of the storage.

There are generally advantages in using a combination of ground- and surface water as a means of increasing reliability and redundancy. Typically, the time lag between precipitation and water availability will differ between surface and groundwater and hence it may be possible to reduce year to year variability in supply. In turn, the likelihood that the supply will fall below a threshold level will tend to be lower. Thus, conjunctive use, using surface water to recharge groundwater when demand is low, and drawing down groundwater in periods of high demand can be an attractive option.

Reliance on a single point of abstraction, of conveyance (e.g. an aqueduct), or of treatment exposes the system to risks such as transient pollution pulses and floods. The analysis should take account of the risks of such events, including those of common mode failure.

14.4 Understanding Demand

To predict or to manage demand, we must first know where we are now: we need to know how much water is used for what purposes by whom. But generally in water management, this is poorly known. Because water is a low unit-cost bulk product, it has not been worthwhile to invest heavily in monitoring flows within the system; equally, mechanical meters have not generally proved to be very reliable or accurate. So, estimates of leakage within potable water distribution systems are frequently derived as the difference between the guess about how much water is put into the system and the guess about how much water is delivered. Except for the Netherlands, it is only in the last five years or so that good data have been available about how water is actually used in the home. As Figure 14.5 shows, the largest component of potable water use in England and Wales is domestic demand; if we ignore cooling water, use in hotels is the next highest use after industry.

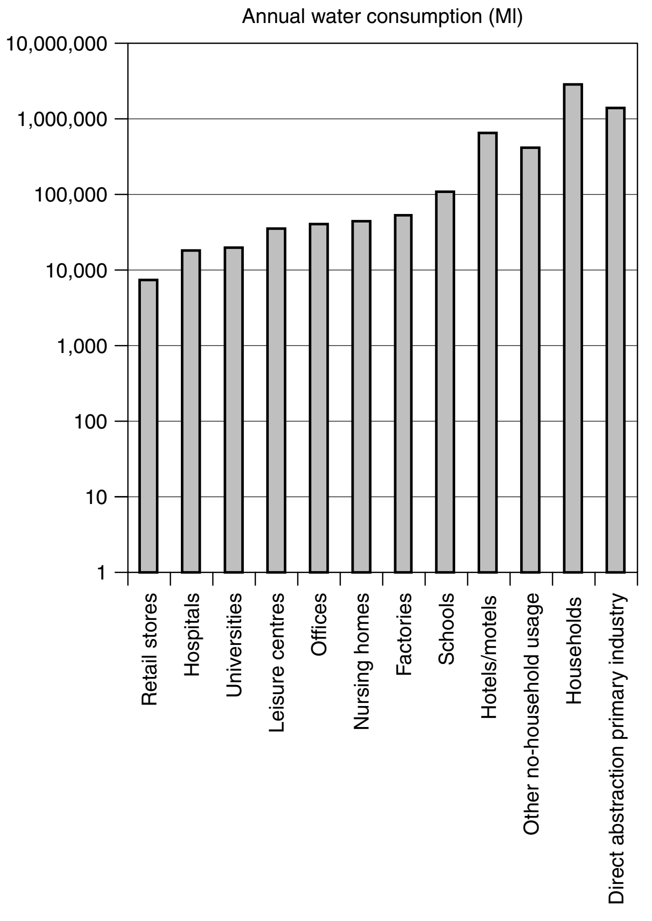

Figure 14.5 *Components of water demand in England and Wales. Source: Surendran 2001*

The need to predict future demand is, perhaps, sharper in water resource management than in any other area of water management; the time lapse between deciding to expand water resource capacity and the new capacity coming on-stream can be 15 years. Hence, it is necessary to assess what will be the balance of supply and demand at least 15 years in the future. Since the majority of potable water is then discharged to the sewers, the expected demand for water also predicts the demand for sewers and for wastewater treatment.

14.4.1 Domestic demand

What is most noticeable is the extremely large differences between countries (Figure 14.6) both in the total per capita daily usage and the individual components of usage. For example, it is not immediately obvious why in Perth, Australia, toilet flushing takes 41 litres/person/day whilst in New York City, 136 litres

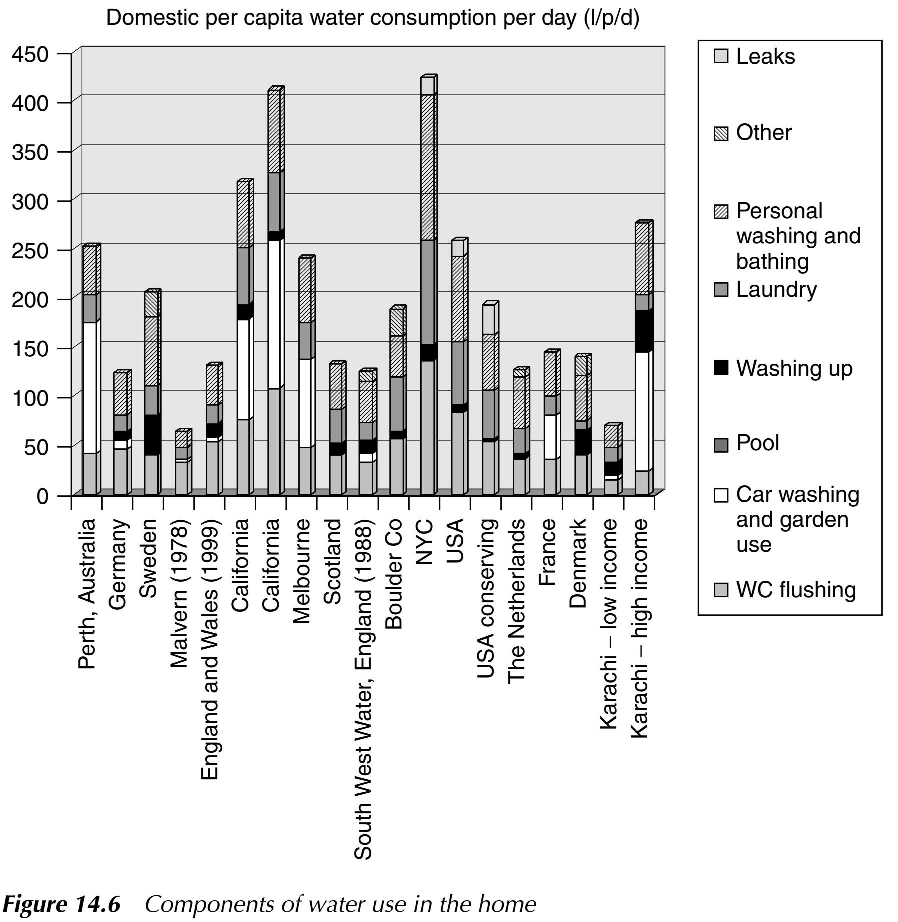

Figure 14.6 *Components of water use in the home*

Table 14.2 *Frequency of use of water fittings and applications in the home*

	Scotland 1991	England and Wales 1991	The Netherlands 1992	USA 1998
Bath				
Bath – households with shower	0.22	0.3		
Bath – households with no shower	0.47			
Bath – all households	0.33		0.62	0.05
Bath – power shower		0.52		
Shower	0.52	0.29		0.7
WC	4.84	4.01	5.94	5.05
Use of tap			0.92	
Kitchen sink			2	
Wash basin			4.2	
Washing machine			0.24	0.37
Automatic	0.34		0.155	
Nonautomatic	0.26			
Hand clothes wash				
Dishwasher	0.26		0.24	0.1
Bowls of dishes washed by hand			0.78	
Households with a dishwasher	0.51			
Households with no dishwasher	1.64			
All households	1.47		0.03	
Leaks				0.46

are required for this purpose, and 108 litres in California, whilst in the Netherlands, in 1998, domestic usage was only 128 litres per person per day for all purposes. There are apparently very large differences in the amount of water used by an appliance or fitting each time it is used in different countries (Table 14.2). For example, washing machines in the USA have traditionally been top-loaders as opposed to the front-loading machines standard in Europe. Top-loading washing machines are inherently less water-efficient than front-loading machines (Pugh and Tomlinson 1999). At the same time, the water used for washing machines in Europe fell from nearly 180 litres per cycle in 1970 to 70–80 litres per cycle in 1998; the consumption of water in dishwashers fell over the same period from nearly 60 litres per cycle to 20–30 litres per cycle (Lallana *et al*. 2001). Conversely, in the USA, the average consumption of vertical axis washing machines is 150 litres per wash and 98 litres per wash with high-efficiency horizontal machines (Tomlinson and Rizy 1998). On the other hand, it is not apparent why there should be such a difference in the consumption of dishwashing machines between France and Germany – as is frequently the case with statistics about water, the accuracy of the statistics is perhaps doubtful. Nor are the differences in the volumes used for flushing toilets accountable solely by differences in the capacities of the cisterns.

There are estimates of how often one person flushes a toilet each day (generally, the estimates are about four times a day) but not about how often a person uses a toilet during the day: the US figures imply that toilets are flushed more frequently. But, we do not know the likelihood that a toilet is flushed after each of the different purposes for which it is used. Consequently, the reductions in the water used anticipated by installing dual flush toilet cisterns will be less than expected if the probability that a toilet is flushed after urination is less than one.

Again, the frequency of the use of a shower in Germany and the USA averages out at about 0.7 per person per day; higher than in Scotland or England and Wales although there is anecdotal evidence that frequency of use is increasing in the UK. To explain the differences in the quantities of water used in a shower between England and Wales and the USA requires both differences in flow rates (USA, 9.5 litres/minute; UK 3.5–4.0 litres/minute) and the assumption that people take longer showers in the USA. The average volume used in a shower in each of the two countries implies that the average shower in the USA takes just over 14 minutes whilst one in England takes just under 9 minutes. What these figures do illustrate is the extent to which domestic water consumption is determined by the technologies adopted.

14.4.2 Industrial and commercial demand

Water is used in industry for heat transfer (cooling and heating), steam production, plant and vessel washing, product washing, air pollution control, vacuum systems, effluent dilution, domestic uses, housekeeping and it is also incorporated in some products. Table 14.3 gives some figures for the industrial uses in the USA and UK. Water usage per unit output shows very marked differences

Table 14.3 *Water use per unit output by different industrial sectors*

		USA			UK	Unit
		Range			Range	
		from	to	median		
Food and beverages						
Beer		8	13		6.1	m^3/tonne
Poultry dressing – chicken				38	8 to 15	per bird
Poultry dressing – turkey				87	40 to 60	per bird
Building materials	hydraulic cement			3	0.74	m^3/tonne
Metals	steel			159	28–62	m^3/tonne
Textiles	dyeing	25	49		17–98	m^3/tonne

Sources: ETBPP 1997, 1998b, 2000a; Gleick 1993; Mathieson *et al*. 1998; North Carolina Department of Environment and Natural Resources 1998.

Table 14.4 *Water use in industrial food processing*

	Min.	Mean	Max.
Asparagus	1.9	8.5	29
Snap beans	1.3	4.2	11.2
Broccoli	4.1	9.2	21
Carrot	1.2	3.3	7.1
Cauliflower	12	17	24
Pea	1.9	5.4	14
Pickle	1.4	3.5	11
Sweet potato	0.4	2.2	9.7
White potato	1.9	3.6	6.6
Spinach	3.2	8.8	23
Squash	1.1	6	22
Tomato – peeled	1.3	2.2	3.7
Tomato – product	1.1	1.6	2.4
Apple	0.2	2.4	13
Apricot	2.5	5.6	14
Berry	1.8	3.5	9.1
Cherry	1.2	3.9	14
Citrus	0.3	3	9.3
Peach	1.4	3	6.3
Pear	1.6	3.6	7.7
Pineapple	2.6	2.7	3.8
Pumpkin	0.4	2.9	11

Source: North Carolina Department of Environment and Natural Resources 1998.

within what would appear to be a homogeneous sector (Table 14.4). Unfortunately, the available figures are also largely in terms of water use per tonne output rather than for water use per unit value of output but the ratio of water to gross value added in the UK chemical industry varies between 0.008 m^3/£gva and 0.11 m^3/£gva (ETBPP 2000).

14.4.3 Agricultural demand

Agriculture is both so large a consumer of water and so important that the discussion of the determinants of agricultural water demand, the prediction of those requirements and the whole question of water management for agriculture is covered in Chapter 17.

14.5 Predicting Demand

Traditionally, water engineers sought to predict future demand for water in order to construct the necessary infrastructure to supply the required amount of water. This will continue to be true in those countries where supplies of potable water in adequate amounts are not yet available to all of the population. Now, increasingly in developed countries, estimates of forecasts of demand are required in order to determine the effect of demand management strategies, coupled with some degree of resource reinforcement.

14.5.1 Domestic demand

Herrington (1987) has identified a range of decisions which require consideration of demand responsiveness:

- Long-term strategic planning over a time horizon of 30–50 years to identify potential gaps between supply and demand, as a basis for prioritising the different options for bridging those gaps.
- Investment appraisal; the capital intensive nature of the industry requires building supply ahead of demand and hence is based upon predictions of the future demand–supply balance.
- Operations planning; to enable the minimisation of the costs of operating the system where that system typically includes storage, which will be drawn down, and may include multi-purpose storage facilities such as dams which act as hydroelectric stations as well as for flood control or water storage.
- Appraisal of demand management strategies.
- Medium to short-term crisis management ranging from a drought to a failure of an aqueduct or mains.

To predict demand, a time-dependent measure of demand also has to be defined: average daily demand or peak demand, for example. Demand varies over the day, the week and the month and it is variations in each of these that we will be interested in forecasting. These variations also imply that water has many marginal costs. Peaks in the day and in the week are mainly of importance in designing the distribution system; average daily demand and peak demand for determining how much storage to provide. Peak daily domestic consumption has been found to be 180% of mean hourly flow in one study in Scotland (Wilson *et al.* 1993), an effect buffered there by the requirement of in-house storage. Peak seasonal demands are commonly in the range of 1.4 to 1.8 times mean daily demand but in Melbourne, peak demand is 2.5 times average demand (Government of Victoria 2001). In general, the greater the proportion of demand that is for external domestic uses, the higher the ratio of peak to average demand.

A number of methods for predicting future water consumption have been conventionally used to predict the demand for water:

- trend forecasting;
- micro-component analysis (Environment Agency 2001b);
- input–output analysis (Tate and Scharf 1985; Tate 1986);
- price elasticity (Herrington 1987);
- scenarios (Environment Agency 2001a; Pinkham n.d.).

The first four techniques essentially assume that the future will be like the past, only bigger; change will be positive but quantitative rather than qualitative. Estimates in the past have generally proved to be gross overestimates of actual future demand. For example, in 1975, when consumption in the USA was about 350 billion gallons/day; predictions of demand in 2000 varied from 330 to 1128 billion gallons a day: actual consumption in 2000 was down on 1975 levels (USACE 1995). The more recent scenario approach (Environment Agency 2001a) is based upon a different conceptual approach and asks why could the future be different from the present and how will those differences affect the variable which we seek to predict?

The forecasting technique adopted should also be able to explain the past; why, for example, when per capita domestic water use in England and Wales rose from 98 litres per day in 1978 (Thackrey *et al.* 1978a, 1978b) to 160 litres per day in the most recent figures (Edward 1996), did the quantity of water used for toilet flushing increase from 32 litres per day to 53 litres a day and the amount used for personal washing and bathing more than double from 17 to 40 litres per day? Compared to the techniques used in other industries (Bright 1972), it will be recognised that demand forecasting in the water industry is somewhat unsophisticated – though not necessarily any more inaccurate.

The limitation of the techniques described for predicting demand is that change is not treated in a causal manner, but as either innate and constant (e.g. trend series analysis) or as a result of behavioural response (e.g. price elasticity). None of the techniques just discussed can really account for the increase in water consumption in England and Wales between 1978 and the present. In practice, there would seem in fact to be three drivers of changes in water consumption: technology, demographic factors and social/cultural reasons. Moreover, as others have argued, the really important elasticity is not price elasticity, but income elasticity, particularly at times when real incomes are rising and real prices are falling. This gives the matrix shown in Table 14.5.

Rising real incomes should be expected to result in increased water usage whilst increases in real prices will reduce the rate of increase in demand or yield a decrease in demand. Thus, it is the combination of change in income and price that will affect overall demand. For California, Renwick *et al.* (1998) estimated the price elasticity of residential water demand as −0.16 whilst the income elasticity was estimated as 0.25. In developing countries with rates of economic growth of 7–10% per annum, the latter figure would imply significant

Table 14.5 *Determinants of domestic water use*

	Income elasticity	Price elasticity
Technology	high	low
Demographic	moderate	very low
Social/cultural	high	moderate

increases in the demand for water when frequently the existing demand is not adequately met, with water often only available to part of the urban populations, or only for a few hours a day. Thus, Webb and Iskandarani (1998) report income elasticities of demand of 0.37 (Egypt), 1.2 for Sub-Saharan Africa, 1.0 for India, 0.8 for China, between 0.4 and 0.8 for different countries in Southeast Asia, and 0.6 for Latin and Central America.

There have now been a large number of studies of the price elasticity of domestic demand; summaries of these studies being given in Gibbons (1986), Herrington (1987), Winpenny (1994) and Young (1996). Typically, these show a short-term (2 to 5 years) price elasticity for internal uses in the range of −0.1 to −0.2, with long-term price elasticity (5 to 10 years) generally being in the range of −0.2 to −0.35. So, for example, an increase in the price of water in Bogor, Indonesia, from US$0.15 to US$0.42 resulted in a reduction in demand of 30% (Bhatia and Falkenmark 1993).

In comparing studies between different countries and different contexts, we should expect (Martin and Thomas 1986) that:

- the greater the current level of consumption, the more likely demand is to be price elastic or the greater the price elasticity;
- long-term elasticity will be greater than short-term elasticity as capital and durable goods are progressively replaced by more water-efficient equipment;
- for a given price and consumption level, price elasticity will be less where incomes are higher; and elasticity is likely to be greater where the tariff adopted is a rising block tariff rather than a flat rate tariff.

Consequently, we should expect differences between studies, rather than a single measure of price elasticity to emerge from each and every study. Whereas the majority of price-elasticity studies have used recorded data, such as meter readings and associated bills, Thomas and Syme (1988) undertook a contingent valuation study and were able, therefore, to test the extent to which most of these predictions were found in the responses. Thus, for example, price elasticity rose from 0 for households consuming less than 151 kl/year to −0.31 for those consuming more than 600 kl/year. Similarly, it fell from −0.19kl/year for households earning less than $A12 000 per annum to 0.13 for those earning more than $A26 000/year. Since the design was a social survey, they were also able to test price elasticity against some attitude questions; price elasticity for those who answered yes to the question 'Is water important to your lifestyle' was −0.14 whilst it was −0.52 for those who answered no. Where they can be compared to the results from econometric studies, the different sets point in the same direction. When Thomas and Syme's methodology was applied in South Africa, the overall price elasticity for indoor water use was −0.13 and −0.38 for external uses (Veck and Bill 1998).

Technologies have a marked and direct effect on consumption. A significant part of the differences between the USA and the UK in per capita domestic consumption for different purposes is explicable by technological differences (Section 14.1.1). Similarly, the difference in consumption between the AWWA's (2001) conventional and water-efficient dwelling is almost entirely determined by technical factors. So, changes in technology are, on the one hand, very strong drivers of water consumption but on the other, the most effective means of controlling demand is by influencing the technologies adapted.

Thus, consumption is being driven up by such factors as the 40% of homes in the USA which have whirlpool baths that consume between 75 and 200 litres per use (Vickers 2001). Similarly, hot tubs are available in a variety of sizes with capacities of between around 550 litres and 2100 litres, the average capacity being around 850–900 litres. Although hot tubs do not require emptying after every use, the recommended frequency of refilling implies an average weekly consumption of 90 to 350 litres per week (Johnson 2002). Again, the evaporative loss from a swimming pool in Arizona is 250 litres per day (Gelt 1995), roughly sufficient to supply all the daily household needs of two people in Denmark.

Demand for all of these high water using household durables is likely to be income elastic. Since water usage by equipment and fittings can only be significantly reduced by replacing them with more water-efficient appliance and fittings, technologically driven demand is likely to be price inelastic.

An ageing population has a direct effect on household water demand in that two age-related diseases, diabetes and, in men, prostate problems, result in an increased frequency of micturition: a frequency of urination of once an hour being a diagnostic test for prostate problems. For example, the percentage of males with diabetes mellitus rises from 1.7% in males aged 45 to 6.9% in males aged 75 (Malmesten *et al.* 1997). Garraway *et al.* (1991) report that the proportion of males with benign prostatic enlargement increases from 13% at age 45 to 43% at age 60–90 with higher rates being found in post-mortem studies. Since a number of studies have reported that the frequency of toilet flushing per person per day is in the range of 4–5 (Wilson *et al.* 1993), and assuming that a toilet is flushed every time it is used (something about which we have no data), the implication is for a substantial rise in the amount of water used for toilet flushing as the population ages.

Secondly, urinary incontinence also increases with age; the proportion of males reporting urinary incontinence rose from 3.6% at age 45 to 28% at age 90 (Malmsten *et al.* 1997). This in turn should be expected to result in an increase in the frequency of clothes washing and also in personal washing. Dutch data does show daily toilet flush volumes rising from 33 litres/person for ages under 24 to 49 litres for the over-65s. The quantity of water used in showering, on the other hand, is highest for those under 24 (54 litres/day), falls to 13 litres/day for the age band 55–64, and rises again to 29 litres for the over 65s. The quantity of water used for clothes washing falls significantly on retirement and but data is truncated to the over-65s.

Overall, single or two-person households have a higher per capita use of water than the per capita usage in larger households (Edward 1996): the existing data does not make it possible to determine the extent to which this is an age-related difference. It is notable that people in higher income groups tend to have a longer life expectancy than do poorer people.

Now, water usage is not purely functional, but carries with it strong cultural, psychological and social symbolic meanings. Thus, for example, the following quote about a Friday night bath is taken from one of a series of focus group studies undertaken by Odeyemi (1998): 'Yessss it is, I do enjoy it once a week ... to get rid of the tension, ... stress. It like washing away all your ... getting ready for the weekend ... it's a mental thing. Some people don't do that, it's my way of washing away the preceding week.' For this person, a bath is much more than a way of getting clean, a function fulfilled by their daily shower. Odeyemi also found that being brought up in a water-scarce country tended to leave people more cautious in their use of water than those who had been brought up in a country, such as the UK, where there is no apparent scarcity of water. Moral and social norms then appear to influence water use and more especially the likelihood that consumers will adopt sustainable water management practices (Government of Victoria 2001). Finally, some uses of water are required for religious reasons; Hengeveld and De Vocht (1982) estimate that in Islamic countries, ablutions before prayer require between 1–20 l/p/day and anal cleansing a further 2–5 l/p/day. For these reasons, it is not surprising that the price elasticity of internal domestic uses of water is very low (e.g. Herrington 1987), it being necessary on this basis to double the price of water in order to achieve a 10–20% reduction in demand.

There are three ways of determining existing patterns of usage. The first is to meter individual properties or groups of properties, determining the ownership and use of the appliances and fitting through interview surveys and asking the consumers to keep diaries of water use, and to undertake regression analysis to determine the contribution of each use to total demand. Diary recording does result in an under-recording of facility and appliance use but not as much as might be expected; 7–10% under-recording being reported (Wilson *et al.* 1993). The second is to fit data loggers to each and every water delivery point in a sample of properties so as to record the frequency of use and the amount consumed in each use. The final option is to fit data loggers at the meter which record and capture flow rate every few seconds (DeOreo *et al.* 1996). Once the time traces resulting from the use of each of the appliances and fittings in the property have been established, it is then possible to detect from the specific patterns of changes in flow over time which appliances have been used.

14.5.2 Industrial and commercial demand

In practice, in the developed countries, potable water use has stabilised or tended to decline in recent years. On the industrial side, key determinants are:

- The rate of growth in output and hence the rate of increase in production durables, with the new production durables being more efficient in their use of water (e.g. the predicted demand for ICI's ammonia plant was largely responsible for the Kielder reservoir being built – but the manufacturing process changed and the demand for water was dramatically reduced). Equally, the greater the growth rate, so will the average age of the capital stock tend to be younger, the rate at which existing stocks are replaced also tending to be greater than in slow growing or stable economies.
- The structure of the economy; the shifts away from the older 'metal bashing' industries towards service and financial sectors are a major cause of water demands falling well below earlier demand forecasts. The apparent current shift towards hyperclean industries such as microelectronics, pharmaceuticals and then to nanotechnologies may either reverse this trend or reinforce it. That the water used has to be extensively treated before it is sufficiently pure to be usable in these processes probably implies that recycling or reuse will be more efficient than disposal of the water once used.
- The rate at which technological innovation that improves the efficiency of water use is called forth.

Forecasting industrial demand, as with all aspects of demand, has always been hampered by the inadequacies of data on the nature of existing use. There is relatively little information on the nature of the demand for water in different industrial sectors (Table 14.3) or on the proportion of water that is reused or recycled in industry. A number of studies have also sought to determine the price elasticity of demand for water for industrial purposes (Rees 1969). The largest of these studies (Tate *et al.* 1992) shows the difficulties of these studies given the different uses for which water is required in industry, the differences in requirements for water as a factor of production, and the variations between companies in the structure of water costs. Nevertheless price elasticities between −0.50 and −1.20 were obtained. As discussed below, however, there is a great deal of evidence that industrial usage of water continues to be inefficient.

14.5.3 Climate change

Climate change means that it is necessary to predict the change in the resource as well as the change in demand. Overlaying the consequences of climate change on top of these other changes implies that changes in the concentration of rainfall in time and space, and in the variability of rainfall, are more important than changes in the absolute amount of rainfall. Changes in the concentration of rainfall over time and any increase in the variability of rainfall are likely to require increases in storage capacity, whilst changes in the geographic distribution of rainfall mean either moving the water or the human activities. Karl and Knight (1998) have shown that there has been an increase in overall precipitation in the USA of 10% since 1910 and that this has largely been in the form of high intensity events.

At the same time, relatively small changes in climate variables can have disproportionate effects on water availability. Thus, Nemec and Schaake (1982) show that small changes in inflows could result in large changes in the reliability of yields of reservoirs. Again, Gleick (2000) concludes that small changes in precipitation and temperature can, in some regions, result in significant changes in runoff and Sandstrom (1995) has shown that a 15% reduction in rainfall could result in a 45% reduction in groundwater recharge in parts of Africa.

14.5.4 Deciding the reliability of supply

Once demand has been predicted, then the required level of supply can be determined; however, a decision has to be reached on what level of security of supply to provide. For example, whether to ensure that supply, and, particularly water storage, will be sufficient to cope with the 1 in 50-year drought year or 1 in 100-drought year or the 1 in 200-year drought week, where specifying the period of the drought is itself a difficult question. What is the appropriate form of the target depends in part upon the form of the water resource, whether this is by direct abstraction of groundwater, or of river water, or by way of storage reservoirs. Traditionally, urban water supplies have been designed to very high standards of service, in the order of the 1 in 200- to 1 in 500-year drought. But, as water is used increasingly for less valuable purposes, and so, in a drought, demand can be more easily managed down to available supplies, the standard of service is also decreasing. When the average domestic consumer, for example, normally receives 50 l/day, a 50% reduction in supplies has more serious consequences than when the normal supply provides 400 l/day.

The same risk-based approach needs also to be considered in regard to other risks: of the failure of an aqueduct, a plug of pollution or a flood affecting a water treatment works, the failure of a dam, or a major pipe burst. The question is then one of evaluating the cost of reducing the expected value of the costs incurred by an interruption or reduction in water availability with a given lead time before that interruption or reduction occurs. Thus, for example, in the UK, the historical standard for a ban on garden watering and car washing has been 1 in 10 years (OFWAT 1998). It is possible to determine how much consumers would be prepared to pay for a lower risk of such a ban, or of other forms of supply variations (Green *et al.* 1993).

14.6 Value of First Time Supply

Since water is essential to life, we are always considering an improvement over the existing provision. The three dimensions of such an improvement are then:

- Reductions in the real resource cost – the time and energy required to obtain water, the cost of buying water, or the running costs of the existing system.

- Improvements in the quantity of water available where this is constrained by the real resource cost of use; essentially, where the resource costs are very high, a purpose of the improvement is to increase consumption to provide for basic needs for drinking, cooking, washing and other hygiene requirements.
- Improvements in the quality of the water available, notably in terms of health risk posed by using that water, but also in terms of other characteristics such as taste, colour, reliability of supply and pressure.

The relative importance of these improvements then vary with the characteristics of the existing supply. Thus, in rural areas, a primary benefit of installing a tube well or piped system is the reduction in the time and energy costs of collecting water. As shown in Section 9.2.2.1, this burden is predominantly borne by women and the time freed by making available a secure local supply can be used by women for better purposes, including making time available for girls to go to school. So, too, can the energy currently consumed by carrying that water be put to better purposes: Cairncross (1987) cites a figure of 14 hours per week in one case and Lewis (1994) reports that in some regions of East Africa women spend 27% of their caloric intake in fetching water. El Katsha *et al*. (1989) quote one woman's reasons for washing clothes in a canal rather than using water from a public standpipe: 'I prefer to wash in the canal because it is less strenuous. If I wash at home, I'll have to walk back and forth at least four times carrying clean and dirty water, especially since I have no water at home.' However, collecting water and washing may be one of the future social occasions open to women (Rathgeber 1996) and it should not be assumed that energy minimisation is the only criterion that women use to select a water point.

Because of the economies of scale, distributing water by pipes is typically lower in cost than carrying it on animals or vehicles. It is characteristic of urban areas that the higher income groups are supplied with piped water supplies whereas the poor have to buy water from water vendors, from neighbours or from other sources. The poor thus pay higher prices for water and also spend a higher proportion of their income on buying water, water being expensive (Briscoe 1993). Moreover, when the water is of poor quality, the household needs to boil the water before use. Briscoe (1993) cites a figure of 11% of income for households in the lowest income quartile in Bangladesh being required for this purpose and 29% for squatter settlements in Peru.

White *et al*. (1972) estimated the quantities of water that are used as these vary according to access and to the ease of disposing of wastewater (Table 14.6): at some point of consumption, the quantity of water used is constrained by the problems of disposing of that water after use (Chapter 16). Thus, Cairncross (1987) reports that the installation of a village standpipe or pump increases water usage four-fold because it reduces the time required to obtain water.

When the real resource costs of water are high, then use is constrained so that only the most essential needs are met: drinking and cooking. Only when the real resource costs of water are reduced are the less urgent, except where there are

Table 14.6 *Variation in water use by conditions*

Conditions	Likely range of usage (l/c/d)
Water carried from distant or low quality sources	4 to 20
Water carried from easily accessible abundant sources of good quality	10 to 40
Piped water with single taps and no indoor waste disposal	16 to 90
Piped water with multiple indoor taps and indoor waste disposal	25 to 600

Source: White *et al.* 1972.

religious or cultural prescriptions, needs of personal washing, washing cooking utensils, clothes washing and other uses supplied. Equally, where there are several sources of water, the apparently least important needs are satisfied by the apparently lowest quality water. The obvious potential improvement in water quality relates to health improvements. Cairncross (1999) estimates that 90% of the health benefits of improved water and sanitation result from a reduction in diarrhoeal illnesses. In turn, the direct economic effects of water-related disease can be significant. Thus, the 1991 cholera outbreak in Peru resulted in costs estimated to be around 1.5% of Peru's GDP (Idelovitch and Ringskog 1997). More generally, ill-health will reduce the amount of labour that individuals can employ in both productive and also leisure activities. However, evaluating that loss of labour capacity has proved extremely difficult (e.g. Mills 1994).

Lane (1996) differentiates between four different categories of health risks associated with water:

- **Water-borne:** transmitted through drinking water containing pathogens as a result of contamination with human faecal waste.
- **Water-washed:** diseases whose transmission is reduced by use of water for personal hygiene. These include diarrhoeal diseases transmitted by a faecal-oral route, bacteria and fungal skin and eye diseases (e.g. scabies, trachoma) as well as infections carried by lice and mites.
- **Water-based:** worm infections in which the pathogen spends part of its time in an aquatic host organism; for example, schistosomiasis, flukes and guinea worm.
- **Water-related:** diseases transmitted by insects that breed or bite near water such as malaria, Rift Valley fever, western equine encephalitis (Lane 1996) and onchocerciasis (Cairncross and Feachem 1993). Different species of insect have different preferences for water; thus, *Culex Pipiens* mosquitoes breed in sewage and sullage and are one vector of *Bancroftian filiasis*, the cause of elephantitis, although this nematode worm is transmitted by different mosquitoes in different parts of the world. *Anopheles* mosquitoes breed in fairly clean water (e.g. flood or irrigation water) and carry malaria whilst *Aedes Aegypti* carry yellow

fever and dengue fever and prefer clean water, especially that stored in pots and cisterns.

In turn, there are four different vectors involved (Feachem *et al.* 1983):

- viruses (e.g. poliomyelitis, hepatitis A, rotaviruses);
- bacteria (e.g. typhoid, paratyphoid, cholera, Weil's disease);
- protozoa (e.g. giardia);
- helminths, or parasitic worms (e.g. hookworm, whipworm, roundworm).

Women are at a higher risk of disease partly because of the gender division of labour (Lewis 1994), such as washing clothes (El Katsha and White 1989) and they are also exposed to other hazards in the course of collecting water (White *et al.* 1972).

The provision of clean water in adequate amounts then can potentially reduce the first two water-related health risks; clean water in adequate amounts forming a barrier to the transmission of water-borne vectors (Figure 14.7). However, to do so, the different elements of water provision must all be such as to reduce the risk of contamination. Thus, the source of the water, the means of transporting that water and storage at the point of use must all be appropriate. So, when wells are the source, both the means of carrying that water and its storage in the home are points of potential contamination (e.g. Brismar 1997). Similarly, in piped supply systems of the developed economies, we have discovered rather to our

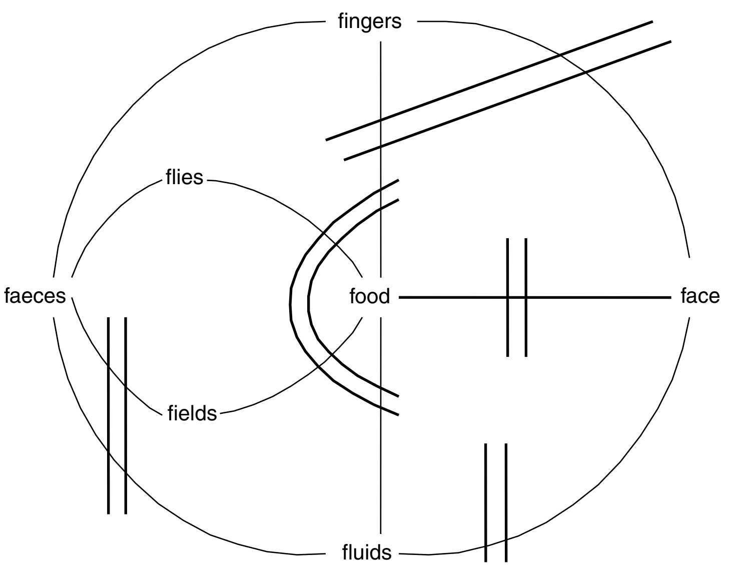

Figure 14.7 *Disease transmission routes*

surprise that Legionnaire's disease can occur as a result of the storage of warm water. The contamination of the water with heavy metals may similarly occur at the source, during transport (i.e. from the pipework) or during storage (El Katsha *et al.* 1989). Much of that contamination is natural but human activities also create additional risks from metal contamination but also from other sources such as pesticides, industrial chemicals, fertilisers and the like.

There is, however, no simple relationship between the provision of adequate water and sanitation and health improvements (Cairncross 1999). The consensus now is that education in the nature of disease and in the principles of hygiene are necessary if there is to be such an improvement in health status (e.g. Cairncross and Kochar 1994). Secondly, rather than the provision of an adequate supply being a technical problem, it is now seen very much more as an institutional problem. Table 14.7 summarises the interventions in one area in Ghana as the donor sought to achieve the anticipated benefits from the provision of a clean water supply (Akuoke-Asibey 1996). This pattern of learning is not untypical of many similar programmes of that period in what was seen to be the apparently simple problem of providing access to good quality water proved to be much more complicated.

In developed economies, there is a presumption that there are no health risks associated with piped water, and thus the problems recently recognised with giardia and cryptosporidum have been something of a shock. However, the water supply has other characteristics that influence its value and consequently those improvements for which consumers may be prepared to pay. These other characteristics of the water itself include taste, colour and odour. In addition, the characteristics of the service itself may also be improved; for example, the pressure at which the water is supplied, the quantity supplied, the reliability of supply and the likelihood that the service will be interrupted. When systems other

Table 14.7 *CIDA support for rural water sector in the Upper East Region of Ghana*

Date	Budget (millions)	Activities
1973–1981	$C17.00	Construction of 1648 boreholes; operation and maintenance system organised
1978–1983	$C2.00	Pump maintenance and site development; introduction of water caretakers and water user committees
1981–1987	$C8.05	Rehabilitation of hand pumps
1984–1990	$C8.60	Health/hygiene education programme; training of water organisers

Source: Akuoko-Asibey 1996.

than a piped connection to every home are being considered, privacy, ease of operation and maintenance can be important aspects (van Wijk-Sijbesma 1985).

14.6.1 Economic assessment

The standard condition applies of identifying the baseline condition and then evaluating the benefits and costs of a series of alternative 'do something' options (Figure 14.8). These 'do something' options obviously vary from place to place; the Asian Development Bank (Asian Development Bank 1998) has set out the basic economic principles involved and WELL (DFID 1999a) discusses the wider issues in appraising water and sanitation projects.

The easiest part of the valuation is to calculate the reductions in the costs of buying water and of boiling it to make it safe. Beyond that, the benefits lie in the increase in consumption and health benefits; further still beyond that limit, the concern is to evaluate the benefits of further increases in quantity and improvements in quality although reliability is an important requirement of water supply at almost any level of supply (Littlefair 1998). In turn, it is possible to make some estimate of the costs incurred as a result of interruptions in supply. Thus, Tate (1968), summarised in Herrington (1977), undertook a detailed assessment of the benefits of improving the reliability of supply to a rural area. The area was currently served directly from an aqueduct which had

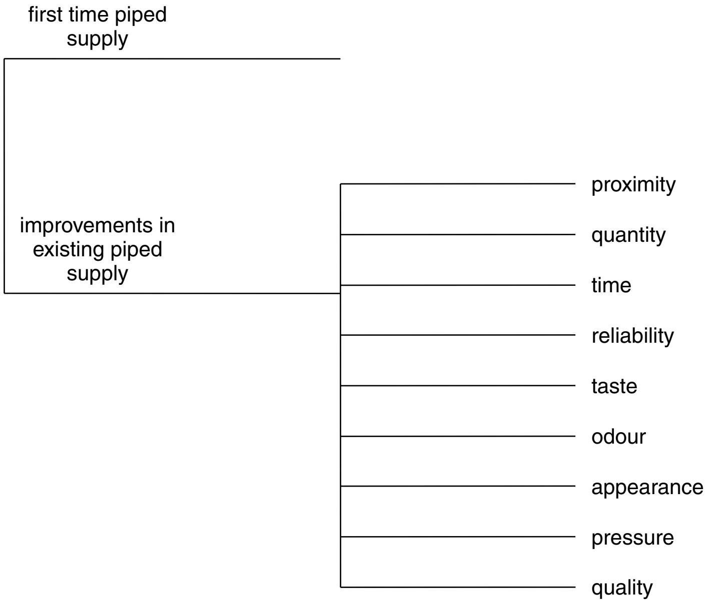

Figure 14.8 *Potential benefits of improvements in potable supply*

to be shut down and dewatered three or four times a year; several farms also suffered from low water pressure. Tate surveyed the consumers to determine what costs they incurred in transporting and storing water in preparation for these preplanned shutdowns and the losses of production, notably of milk, that were experienced.

Although in principle the health benefits may be evaluated, this is difficult for the reasons discussed in Section 14.6. Instead, the most common approach to evaluating the benefits of improvements in water supplies has been the use of contingent valuation. This has been extensively used both in developing countries (e.g. Altaf *et al*. 1997; Briscoe *et al*. 1990) and also to appraise the benefits of improvements in piped systems (Howe and Smith 1994; Carpentier and Vermersch 1997). The hedonic price method has been used in a few studies (e.g. Coeillie *et al*. 1991; North and Griffin 1993).

A very early contingent valuation study of the value of improvements in the quality of water supply was that conducted by the Central Water Planning Unit (CWPU 1978) during the 1976 drought in England. At this time, per capita domestic water consumption was 120 litres/day (compared to about 150–160 litres/day now). The respondents, 75 civil servants, were asked how much they were prepared to pay to avoid restrictions of varying intensities, up to 50% of normal supply, for periods of one month. The crude results were that the respondents were not prepared to pay anything to avoid a reduction of up to 12% per day and above that point, willingness to pay increased linearly at the rate of £1.35/m^3. Budge (1980) carried out a similar explorative study using Thames Water Authority personnel, followed by a small-scale survey of domestic users.

The three major differences between developed and developing countries are firstly that in the former there is an established institutional delivery system as well as a physical delivery system. Secondly, the former are, in relative terms, cash rich whilst the latter, in relative terms, are time rich. Thirdly, in developing countries, much land settlement takes place in the absence of any clear legal entitlement to the use of that land.

Where the issue is one of the value to the beneficiaries of first time supply, the institutional and physical systems cannot be separated, nor can means and value. One question is then whether to provide water kiosks, standpipes or individual house connections, and the second is how this system is to be initially funded and maintained. It is not clear that the two questions can or should be separated and, rather than simply seeking to determine how much people are prepared to pay, the more useful approach is to determine what system the community wants and can sustain (Black 1998).

It was argued (Section 4.2) that in poor communities the rate at which time and energy can be converted into firstly a cash income and then into priced consumption may be lower than the rate at which time and energy can be translated directly into consumption. In turn, estimating willingness to pay will then be a poor method of establishing the value of that consumption, and community-based provision (McPherson and McGarry 1987) will be more efficient. In particular, such systems often involve contributions of labour rather than cash. In this case, the decision is participatory; the only time the economic question of the value of the service then arises is when a government or international body is approached for a grant or loan, and it then is sharpest when part or all of the capital costs are to be subsidised for explicitly redistributive reasons. Conversely, in developed countries, the basis for priced provision is that the rate at which time and energy can be directly turned into consumption is less than the rate at which they can be turned first into income and then into consumption.

In poor urban communities, the problem is compounded by the informal nature of much settlement and the consequent lack of any clear legal title to the occupation of that land. Whilst the individuals typically make equally informal linkups to water and electricity where they can, the lack of a secure title will inhibit both the households and others (e.g. McPhail 1993) from committing investments to the area. A prerequisite to improving the standard of provision of water and sanitation in those areas may then be the creation of a clear legal entitlement to the occupation of those lands.

Case Study 14.1 Preparedness to Pay for Improvements in Water and Sewerage Services

The Office of Water Services (OFWAT) is the price and quality regulator for the water and wastewater industry in England and Wales. In large part, the price increases allowed to the companies is a function of their anticipated needs for investment; in turn, their profitability has been strongly influenced by the companies' success in then delivering that improvement in quality at a lower capital cost than they had predicted (Green 2001b). The price formula agreed at the time of privatisation, $rpi + k - x$, where rpi is inflation, k is the investment requirement and x is the predicted efficiency gain, gives the companies an incentive to increase investment and reduce O&M costs.

In large part, those investment requirements have been required to satisfy the standards of the different European Union directives on water and wastewater that had in turn been agreed by successive UK governments. At the same time, the Environment Agency and its predecessor, the National Rivers Authority, seek investment to reduce the environmental impact of water abstractions and discharges. In addition, there are a number of very powerful environmental NGOs in England and Wales, including the Royal Society for the Protection of Birds which has a membership far larger than that of any political party. Those NGOs also seek increased investment to reduce the environmental impact of the industry. Thus, all of the main players would like to see increases in investment. OFWAT then has the twin task of balancing the interests of the consumer in terms of the trade-off between increases in prices and improvements in service delivery whilst also ensuring that efficient firms in the industry generate sufficient revenue to continue to be commercially viable.

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The initial determinations of the *k* and *x* factors were made by the then Thatcher government on privatisation. The first quinquennial review of prices took place in 1994 and OFWAT commissioned FHRC to carry out a demonstration CVM study to illustrate to the water and wastewater companies the scope of the technique in determining customer requirements.

Three different areas of service were selected: the taste of tapwater, the risk of supply interruptions in the form of restrictions on the use of hosepipes, and the risk of sewage flooding. As an exploratory study, the sample size was limited to 1000 and four water company areas were selected (Green *et al.* 1993) on the basis of (a) the current and future levels of charges, and (b) the existing level of service in different areas (in terms of whether or not there was currently a hosepipe ban in force). Within each water company area, high and low income census enumeration districts (EDs) were selected for sampling. Random samples of addresses within each of the selected EDs were then drawn; a total of 1955 addresses in 85 EDs. Fieldwork was then undertaken by a fieldwork company selected by competitive tender on a specification set out in accordance with FHRC's quality assurance guidelines. A total of 997 interviews were conducted.

For each area of service, a theoretical model was developed to explain preparedness to pay for service improvements which worked from beliefs through attitudes to the behaviours (Fishbein and Ajzen 1975), notably preparedness to pay, that it was desired to predict. Since it was assumed that it is the individual's core beliefs or values that ultimately determine their preferences (Kelly 1955), the interview schedule contained a set of statements intended to tap the individual's core beliefs, measures of that individual's social value orientation (e.g. Stern *et al.* 1999) or environmental value orientation (Green and Tunstall 1991a; Spash 2000). A subset of the statements developed in an earlier study to measure environmental value orientations (Green and Tunstall 1996) were used. Then for each of the three areas of service, a series of questions specific to that service area were used. In the interviews, the order in which the three service areas were introduced was rotated to check for any order or context effects. For each area of service, respondents were asked whether or not they were satisfied with the present standard of service; 21% were satisfied with the then standard of service for sewerage flooding (no property should be flooded more often than twice in 10 years), 74% were satisfied with the taste of tapwater, and 86% with the risk of a hosepipe ban (once in 10 years).

Following a suggestion from Michael Jones-Lee (1993), a double bidding ladder format was used: each respondent being offered the opportunity to work from both starting points. The use of the bidding ladder format was introduced to the respondents as a way of helping them to decide how much they were prepared to pay: 'I am now going to ask you how much you would be prepared to pay. You probably will not have thought about this before and may want some time to think about it. Some people have found it helpful to start by deciding whether or not they would be prepared to pay particular amounts.'

During the pilot studies, the wording of the contingent valuation question was changing from 'willing to pay' to 'prepared to pay' after one respondent remarked that she was willing to pay but could not afford to do so. Having completed both bidding ladders, if they so wished, respondents were asked an open-ended question as to the amount they would be prepared to pay. The usual questions concerning the reasons by which they had made this decision were then asked.

In the final section of the interview schedule, respondents were asked to rate the importance that should be given to improvements in eight areas of service, including

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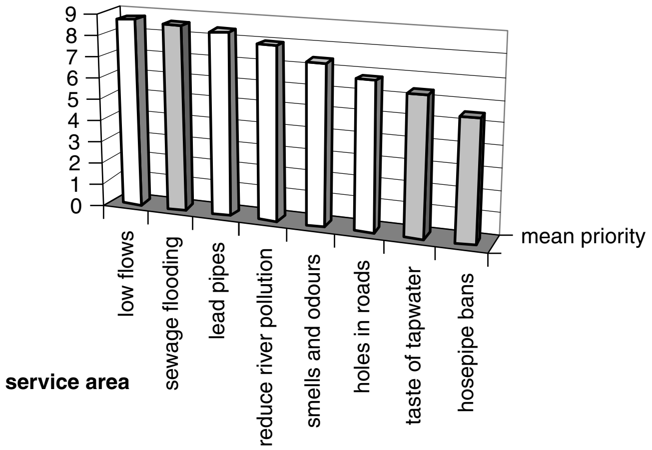

Figure 14.9 *Priority that should be given to improvements in different areas of service*

the three areas for preparedness to pay that had just been asked (Figure 14.9). Immediately afterwards, respondents were reminded of the amounts they had offered for improvements in each of the three areas of service that had been the focus of the study, and the total increase in annual payment they offered. They were then asked if they wanted to change any the amounts that they had offered. The proportions who wish to change the amount that they had originally stated varied between 19% (reduction in the risk of a hosepipe ban and a reduction in the risk of sewage flooding) to 29% in the case of an improvement in the taste of tapwater.

Detailed analyses are given by Green *et al.* (1993), including the results of the tests of construct validity (Carmines and Zeller 1979), but there were marked differences in the proportions of respondents prepared to pay for improvements in each level of service (Table 14.8). Thus, Figure 14.10 illustrates that the proportion of the respondents who would be prepared to pay for improvements in the taste of tapwater falls with the respondent's assessment of the acceptability of the taste of tapwater at present. Figure 14.11 highlights the differences in the importance that

Table 14.8 *Preparedness to pay for improvements in water and sewerage services*

	% prepared to pay	Of those, mean amount prepared to pay (£/year)
Reducing the risk of sewage flooding to the homes most at risk	30	30.34
A noticeable improvement in the taste of tapwater	26	37.50
Reducing the risk of restrictions on the use of water such as hosepipe bans	4	32.34

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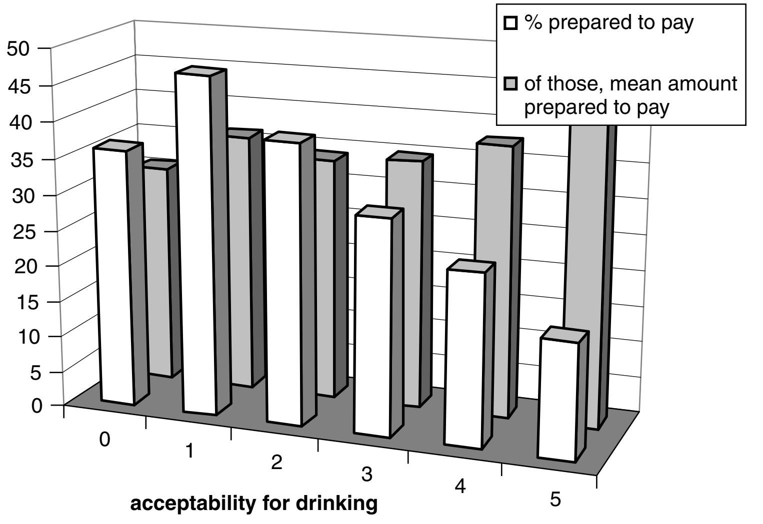

Figure 14.10 *Consumer assessment of the taste of tapwater and the proportion prepared to pay for improvements in the taste*

respondents gave to the different reasons why they were or were not prepared to pay for improvements in each service area. In particular, the importance given to the value to other people of reductions in the risk of flooding from sewers is notable; 30% of the sample were prepared to pay for a reduction in this risk whereas only 12% believed that their home or garden had ever been flooded by rainwater or sewage. It is only possible to speculate whether this 30% are being altruistic, accept sewage flooding as an externality of their own actions, include an option price, or simply find flooding from sewers as morally unacceptable.

There are a number of lessons to be drawn from the study. Firstly, that up to 29% of respondents, when offered the opportunity after considering all three levels of service and having prioritised a total of eight service areas for improvement, changed the amounts that they were prepared to pay shows the importance of setting CVM questions in context. Although neoclassical economic theory assumes that we have defined a complete set of trade-offs between different goods before we make any choice, this is an implausible assumption. In subsequent studies, we asked respondents to prioritise different policy areas for improvement before we asked about preparedness to pay for a single area (Section 21.6). Secondly, there are marked and significant differences between the proportions of respondents prepared to pay (Table 14.8), but those who are prepared to pay do not seem to differentiate between amounts that they are prepared to pay for improvements in each area of service. We should probably place more trust in whether or not people say that they would be prepared to pay than in how much they say they would be prepared to pay.

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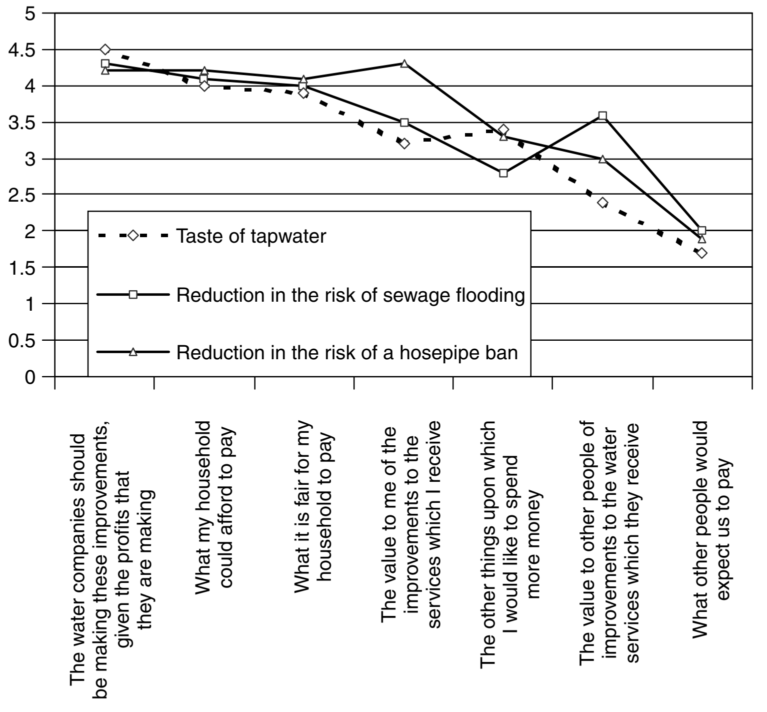

Figure 14.11 *Respondents' reasons for being prepared to pay for improvements*

Thirdly, at the time this study was undertaken, public attitudes towards the companies was markedly unfavourable, many respondents believing that they had already paid for high standards of service but that the companies were simply using that revenue to make excessive profits rather than delivering the standards of service for which respondents had paid. In other studies (e.g. House *et al.* 1994), a similar negative attitude towards the companies has been found either as to their trustworthiness or competence. Such attitudes create problems in contingent valuation studies, not least because it is difficult to ascertain whether those who refuse to pay do so because of their negative attitudes towards the service provider, or mask their refusal to pay by a claim that they will not get what they are paying for. One of the early questions in the study explored in more detail respondents' beliefs and attitudes towards water and its management: in addition to negative beliefs about the companies, on average the respondents also underestimated the problems of making water available although they also held a conservationalist view, believing that we can reduce the amount of water we use.

15
Demand Management

The point at which it becomes more efficient to shift from water resource reinforcement to demand management depends upon the levels of water consumption and of water availability (Chapter 14). The levels of domestic water use show very pronounced variations around the world (Section 14.4.1); for example, from an average of 140 l/c/d in Belgium to a peak of 700 l/c/d in Winnipeg. Once domestic demand has reached the 50 to 100 l/c/d range, then water is an almost pure private good. The needs of drinking, cooking, personal hygiene and sanitation have been satisfied and water is increasingly being used for 'luxury' uses including garden watering. Once water is a pure private good, then the emphasis switches from meeting needs to managing the demand.

Demand management is taken to cover both interventions which reduce the amount of water used by consumers and also the leakage from the distribution system; in effect, therefore the demand which is being managed is the demand placed upon the environment. Commonly, even ignoring the environmental costs of increasing abstractions or reservoir construction, the costs of demand management have proved to be lower than those of supply reinforcement (National Rivers Authority 1995). When the rate at which building stocks are replaced by new buildings is low (e.g. in England, less than 0.1% of housing is replaced each year (DETR 2001), then any significant gains in water efficiency will require retrofitting existing buildings. The rate of replacement for consumer durables will be higher but to the extent to which poorer households acquire second-hand or low first cost household durables, they will be differentially penalised by attempts to use price to control demand.

In economic terms, there are two different contexts to be considered:

- where demand is outgrowing the available resource; and
- where the available resource is capable of supplying the forecast demand.

In the first case, the primary economic justification for demand management is to defer or eliminate the high capital costs of resource reinforcement, together with the variable costs of putting that additional quantity into supply. The objective is typically, therefore, to stabilise demand at the present level. Actually

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cutting demand below the present level may cause revenue problems because of high fixed costs of supply. In assessing the benefits of deferring resource reinforcement measures such as the construction of reservoirs, increasing abstractions from rivers, conjunctive use schemes, water transfer or increased groundwater abstraction, the environmental costs of those options should also be taken into account. In the case of reservoir construction, there may be some environmental gains and there are often recreational benefits to be had (e.g. Shucksmith 1979) that may offset or outweigh the environmental losses caused by the conversion of the land to the reservoir and also from the change in the water regime downstream (Acreman *et al*. 1999). A reservoir may provide angling (Section 21.2.2) and boating opportunities as well as for informal recreation (Section 21.2.1). In assessing the environmental costs of the necessary increase in abstractions and works, the principles of critical natural capital and constant natural assets (Section 7.1.1) require to be applied.

In the second case, demand management may be justified as a way of reducing the environmental opportunity costs of abstracting water from the environment or to reduce demand to the sustainable yield of the resource. In many parts of the world, most famously the Ogallala aquifer in the United States, the level of a contained aquifer is falling because the rate of abstraction is greater than the rate of replenishment (US Congress, Office of Technology Assessment 1993). Again, abstraction from uncontained aquifers, or from rivers, is resulting in the destruction of wetlands or rivers fed by groundwater (English Nature 1996). There may be functional benefits as well as purely environmental benefits from allowing the recovery of these wetlands and rivers. In addition, there may be significant recreational benefits (Section 21.2).

15.1 Domestic Demand

Unfortunately, but not surprisingly, most work on demand management (e.g. US EPA 1998; California Urban Water Conservation Council 1994) has been carried out in North America where they start from a very high base of consumption and very inefficient water-using equipment (Surendran 2001). The relevance and effectiveness of some of those practices in countries where per capita domestic water consumption is in the order of 120–180 litres per day needs therefore to be considered when thinking of transferring some of the North American practices. The potential for reduction in domestic demand is also considered to be substantial; Gates (1994) argues that, in Canada, a 10% reduction is possible through low or no cost retrofits through to 40% for an aggressive whole house approach and up to 60–75% for those with a strong environmental ethic. Potential reductions will be less in those countries where domestic consumption is already lower.

The three strategies that need to be evaluated when considering demand management both against each other and against resource reinforcement are:

- information campaigns;
- the use of prices;
- retrofitting properties.

15.1.1 Information measures

Calls for voluntary constraint in times of drought are the normal first step and can result in reductions of 25% in demand (Husain 1978; USACE 1995) although Higueras and Lop (2001) report that whilst a public awareness campaign reduced water consumption in Madrid by 22%, consumption subsequently returned to pre-campaign levels. But, individual consumers will not be able to reduce their water consumption unless they are aware of the ways in which it can be done. Continuing publicity, information and advice are necessary parts of any demand management strategy; particularly vigorous campaigns have been mounted in South Africa. A baseline survey including consumer attitudes towards water conservation is likely to be a necessary baseline.

In addition to leaflets and educational packages, a number of water utilities, including Vancouver and East Bay Utility District now have web sites which include hints on how to save water. The United Water Company in New York State distributed kits and videos on garden watering, together with establishing a scheme whereby consumers could call to hear a recorded telephone message advising how much water gardens needed. However, it is not thought to have been very effective. Some utilities have also sponsored demonstration projects, such as xeriscape gardens. If water charges are to be effective in reducing consumption, then the consumer must be able to use the bills as a guide to how effective is their control over water use, particularly if the meters themselves are not installed in positions where the consumer can easily read them on a daily basis. Monthly or quarterly bills are required if this is to happen. The bill might also record whether the user's consumption was rising or falling compared to the same period in previous years. More problematically, the amount of water consumed might be shown in comparison to the average amount consumed by similar consumers.

In Germany, an 'eco-labelling' programme has been introduced; this is a necessary step if consumers are to have the chance to purchase water-efficient appliances and fittings. Commonly, building or plumbing codes are also modified to reduce the maximum allowable usage of water fittings, or, in the case of equipment such as washing machines and dishwashers, the appropriate standards are also modified accordingly.

Some utilities have offered domestic consumers free water audits (Clough and Ridgewell n.d.) and free, or subsidised, repairs of leaks on the consumer's property are also increasingly being offered. Utilities or governments have sponsored water audits of public, commercial or industrial buildings. The experience of energy audits, however, is that they are barely cost-effective, because frequently there is a low take-up of the audit recommendations (Judd 1993).

15.1.2 Prices

The case for metering in a particular case needs careful examination as there are a number of major problems with metering:

- It is expensive.
- In itself, metering does not save any water; it simply sends a signal and provides an incentive to save water: the cost of metering is a transaction cost.
- It assumes that demand is behaviourally controlled (Section 14.5.1).
- It assumes that without metering demand will otherwise rise.
- It is risky.
- The costs are likely to fall heaviest upon low income groups.

Metering is expensive; meters require replacement and renovation of about a seven-year cycle (OFWAT 2000a) if they are to be reasonably accurate. Reading meters, preparing bills, sending out bills and so forth is expensive; in England and Wales, OFWAT (2000a) calculated the additional costs of metering domestic consumers as £29.60 per year as compared to an average bill for water of £112 per year and £236 for water and sewerage combined (OFWAT 2002b). Therefore, whether or not metering is economically justified depends primarily upon the consumption figures, the marginal cost of water, and the reduction in demand expected to occur as a result of metering. A secondary benefit of fitting meters is that their installation helps to detect existing leaks and also since it is now possible to estimate how much water is being taken out of supply, to more accurately estimate losses through leakage.

In general, it will never be efficient to meter everyone because some households cannot reduce demand sufficiently to pay for the costs of installing, maintaining and reading the meter (Figure 15.1). Here, the x-axis is the quantity of water consumed by households, which varies in practice as some function of the number of people in the household, with the vertical lines representing households of different sizes. The y-axis is the reduction in water consumption per day. The different diagonal lines then represent the reductions in water consumption that will actually result from the adoption of metering. Of the two horizontal lines, the lower one is the additional cost of charging by meter over the existing charging system, represented by the reduction in daily water consumption necessary in order to recover those costs. Adding the costs to the households of reducing demand, either by investing in water-efficient appliances, or by the loss of utility from reducing demand, then the upper horizontal line is obtained. In turn, the darker shaded area then represents the households where it is economically efficient to meter once the costs of metering and reducing demand are taken into account. Therefore, two factors are crucial: the equivalent water cost of metering together with the cost of reducing demand, and the effectiveness of metering in inducing a reduction in demand. If the cost of water is high, if the alternative to metering is to construct an expensive new water resource system, then the

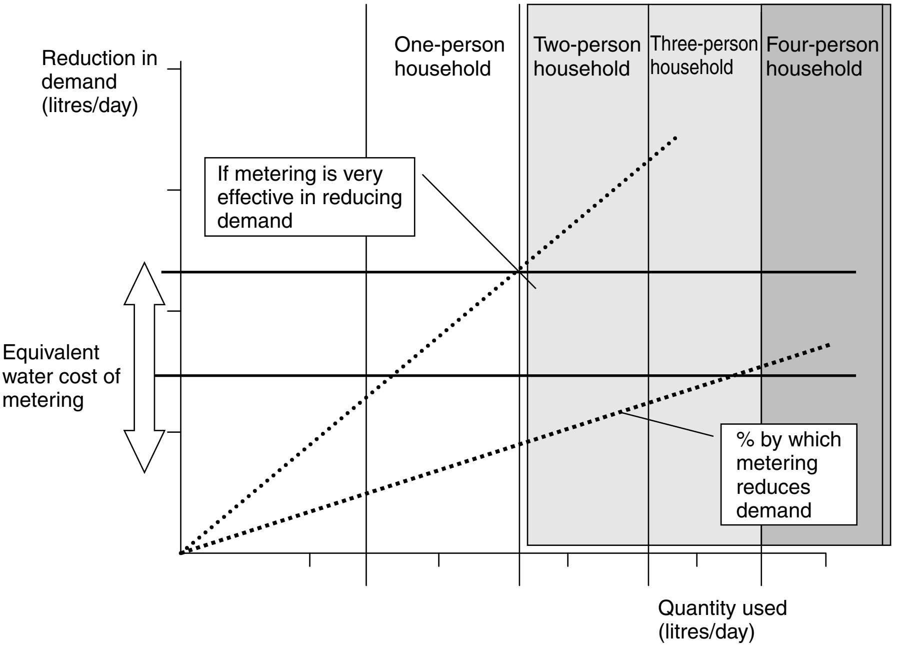

Figure 15.1 *The economics of metering. Source: Green 1998a*

horizontal line will be relatively near to the origin and in turn it will be economically efficient to meter more households. Conversely, if water resources are ample and the only saving resulting from a reduction in demand will be a reduction in treatment and pumping costs, then it will only be efficient to meter the very heavy users. For European consumption figures of 110–170 litres/person/day, it is extremely unlikely that a single person living in an apartment could reduce demand sufficiently to equal the additional cost of metering.

Thus, Yepes (1999) notes that in Guayaquil, it costs US$1 per month connection to collect charges, more than the income generated from each of the households that receive subsidised water. In turn, the utility therefore has no incentive to expand the service to the households that are currently unconnected because it would simply lose more money. But, unfortunately we cannot meter individuals but only the household and in turn this implies that it will be more efficient to meter large households who may tend also to be the poorer households. But metering targeted at high users is likely to be more effective, both because the reduction in demand is more likely to be sufficient to recover the costs of metering and because the price elasticity of demand is higher.

A further implicit assumption in the argument for metering is that otherwise consumption will grow unchecked. So, the rationale for incurring the additional costs of metering hangs on the likelihood that consumption will otherwise rise.

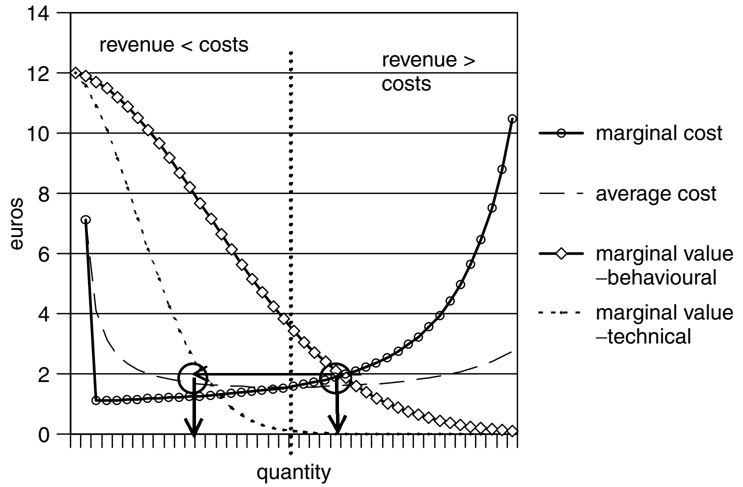

Figure 15.2 *Behavioural and technical price elasticities*

In turn, the possibility that demand may be falling, or even that metering will result in a real fall in demand, makes metering a risky business for the water supplier. Figure 15.2 shows how marginal and average cost vary with demand; if revenue is less than average cost times demand, revenue is below costs. The problem for the water supplier is then two-fold: firstly, to ensure that revenue exceeds costs. If marginal cost pricing is adopted, then this will occur throughout the region where marginal cost exceeds average cost. Secondly, from an economic theory point of view, to set the price so that at that point marginal value and cost both equal the price.

There is then a potential problem (Figure 15.2) if the predicted price elasticity is in error. Moreover, short-term and long-term price elasticities typically differ (Section 14.5.1). In Figure 15.2, the curve labelled as the marginal behavioural value represents the predicted price elasticity of demand on the basis of statistical analysis of the form discussed in Section 14.5.1. The other line, labelled as the marginal technical value, represents the potential to reduce demand as a function of the costs of investing in water-efficient appliances and fittings. Thus, the figure assumes that consumers, even when metered, are behaving inefficiently; this is certainly true for industrial users (Section 15.3).

The risk is that instituting marginal cost pricing or other factors will squeeze out the present inefficiency and demand will jump to the technical marginal value curve. For example, Brooks *et al.* (1990) report that in some cases the simple announcement that metering will be introduced is followed by a fall in demand. Any such fall is not an economic effect since that depends upon the price structure adopted. If demand jumps to the technical marginal value curve but price is set according to the behavioural marginal value curve, then the reduction in revenue will exceed the savings in costs. In turn, prices will then have to be raised to increase revenue to match costs; it will then be difficult to explain to consumers why reductions in demand are accompanied by rising prices. Conversely, to the utility, a charge per property guarantees the revenue stream. In turn, it is sensible when looking at price elasticities to consider the technical value curve as well as any predictions based on behavioural price elasticity.

Equity issues are also an important question; except in so far as there are differences in external uses, household size is perhaps the most important indicator of differences in per capita water consumption. Hence one of the targets of metering will be larger households but these are typically the poorer households. One option is then to provide a 'lifeline' allowance but unless this is specifically attached to large but poor households, it is a crude and inefficient way of targeting the poor. The alternative is forms of means-tested allowances such as have been used in Chile (Yepes 1999). More generally, when considering any system of charging for water and wastewater, it is appropriate to assess the distributional impacts of the proposals (Gomez-Lobo *et al.* n.d.; Komives n.d.; Maxwell Stamp 1998).

In developing countries, a simple alternative to metering is to charge by the diameter of the connecting pipe, an approach developed in South Africa (CSIR n.d.). There charges are fixed according to the size of the pipe and the associated storage tank. The maximum daily consumption of the household cannot then exceed the volume that can flow through the pipe; the practical maximum daily consumption is then influenced by the size of the storage tank.

15.1.3 Retrofitting

Since building and equipment standards and codes are a major determinant of water usage, if demand is to be managed downwards, then these standards must be modified to allow and require the adoption of available best practice for water efficiency. The great advantage of retrofitting the existing stock is that the anticipated reduction in demand necessarily occurs. Whereas metering may have the effect of encouraging consumers to install more efficient fitments, a retrofitting programme ensures that they do. For internal uses, the economic advantage of a metering programme compared to a retrofitting programme is consequently problematic since metering must result in more savings compared to a retrofitting programme in order to pay for the additional cost of a meter on top of the costs of replacing fitments. In addition, some utilities that have metering have gone to institute retrofitting programmes which implies that metering is relatively ineffective at inducing such replacements.

The fittings which are generally targeted for replacement are: toilet cisterns by low flush toilet cisterns; conventional taps by aerated taps; and the adoption of low flow showerheads. Table 14.2 summarised the water usage of a number of water fitments and water using appliances; there remain marked differences in the performance achieved in different countries. Moreover, these examples do not represent the state of the art; Denmark and Singapore require toilets that flush with 4.5 litres and Australia has adopted a dual flush (3/6 litres) toilet (Baynes 2002).

The majority of these retrofitting programmes have started with replacing toilet cisterns (US EPA 1995), as, for example, in the programme in Santa Monica. The retrofitting programme in Phoenix, Arizona has been calculated to have yielded US$88 million for US$15 million in costs (Dziegielewski and Baumann 1992). The Massachusetts Water Resources Authority spent £22 million on a programme which yielded benefits of £89–396 million whilst in New York City, the cost of replacing 1.5 million high volume toilet cisterns with 6-litre cisterns is estimated as £0.6–0.7 million per Ml/d compared to £1.9–2.8 million per Ml/d for resource expansion (Amy Vickers 1996). Again, for the City of Rohnert Park's toilet replacement programme, the benefit–cost ratios of the different programmes varied between 1.7 to 2.7 (John Olaf Nelson Water Resources Management 1998). In England and Wales, devices for reducing the effective flush of an existing cistern have been given away by a number of water companies.

Most of the retrofitting programmes in the USA include low flow showerheads. For other fitments, self-closing spray taps are considered to offer up to a 50% reduction in water consumption compared to the conventional screw type (National Rivers Authority 1995b). Similarly, compared to a flow rate of 40 l/min for the standard domestic tap, flow regulators can be fitted which limit this to between 6 l/min and 17 l/min (Anon 1997).

These retrofitting programmes have been relatively successful and achieved demand reductions of 6–23% (Amy Vickers 1996) but these have been in the USA where, given the initial high consumption of water, these reductions have been very valuable but have still left per capita domestic water consumption much higher than is found, for example, in Europe. Braver (n.d.) also warns that it is possible that customers who volunteer to participate in retrofitting programmes may have lower than average uses. However, there is experience outside of the USA and Canada, most notably in Mexico City (National Research Council 1995) and a number of small-scale programmes in Germany (Rees *et al.* 1993). In the UK, the National Rivers Authority Demand Management Centre (National Rivers Authority 1995b) compared a range of demand management against some indicative costs for resource reinforcement. The estimates of the costs of resource reinforcements were taken from the lower range of costs for such reinforcement, £0.75 M/Ml/day which generally relates to direct ground or surface water abstraction up to £1.50 M/Ml/day which would include some indirect effluent reuse and reservoir schemes. Compared over a 40-year time horizon at a discount rate of 6%, efficient washing machines, controllers for urinals, leakage control to reduce losses to an average of 6 l/property/hour as compared to the current industry average of 11.9, either conversion of pre-1981 WCs with 7.5 litre flush or with a 9/5 dual flush, were all more efficient than demand expansion. These results were national averages and for the regions with the narrowest margin between available resources and demand (National Rivers Authority 1995b), resource reinforcements might require inter-regional transfer schemes which have costs of more like £2–5 M/ML/day (Cryer 1995).

Different strategies to encourage and promote retrofitting have been tried ranging from cutting water bills if consumers agree to adopt such fittings, subsidising the purchase of such fittings, giving them away or actually installing them. In addition, the utility may carry out free water audits of properties and repair leakages. Since the new equipment will not last forever, continuing maintenance is likely to be necessary. In some cases, the costs of retrofitting programmes have been recovered by special charges on developers (Braver n.d.).

Where, as is generally the case, a single meter serves an entire apartment building, there is scope for a market solution in the form of a contracted water service company as is to be found both in France and the USA (Judd 1993). The building owner contracts such a firm on a fee for service basis or a shared savings basis; the water service company and the building owner share the savings made on the existing water bill. The water service company typically then undertakes some retrofitting as well as repair and maintenance. Judd reports that two US water service companies report savings ranging up to 70% with one company reporting an average saving of 29%.

A number of cities have gone on to develop long-term water management plans in which demand management plays a key role; for example, Seattle (Seattle Public Utilities 1998) and Melbourne (Government of Victoria 2001). Melbourne's plan includes the expectation of a 50% take-up of low flow showerheads, saving 12 000 ML/year; a reduction in garden watering from every day to twice a week during dry periods (8000 ML/Year); a 5% take-up of the use of greywater for toilet flushing and garden watering (6000 ML at an equivalent cost of A$ 1700/ML); and a 10% take-up of rainwater tanks to provide water for garden watering, car washing and toilet flushing (12 000 ML at A$2100/ML).

15.2 Reuse, Recycling and Rainwater Capture

The emphasis in the domestic sector has been upon increasing the efficiency with which water is used; using less water to achieve the same ends: reuse rather than recycling. However, as the price of water and wastewater collection and treatment increase, then economics of recycling will improve.

Depending upon the country, two different directions have been taken. In North America, where garden watering consumes a substantial proportion of domestic water demand, the emphasis has been upon the reuse of greywater for garden watering. Thus, in California the use of greywater for subsoil drip irrigation via a 50–100 gallon surge tank or directly through a minileach field has been legalised. However, the sodium salts from soap and detergents can build up and destroy soil structure, especially in clay (Grant *et al.* 1996). In those countries where external uses constitute a lower proportion of domestic water use, attention has been on recycling greywater for use in toilet flushing. For example, a condition of the construction of the Oasis Holiday Village in Kent, England was that greywater should be collected and treated for use in toilet flushing (Guy and Martin 1996). Hills (1995) reports that in Tokyo in buildings over eight storeys water must be collected for recycling, and Tokyo also reuses a significant proportion of wastewater for industrial purposes (Asano *et al*. 1996; Tokyo Metropolitan Government n.d.). Studies of greywater reuse for toilet flushing (Surendran 2001) have not yet shown these to be viable for the individual domestic consumer. The advantage of greywater recycling is that the water may then be returned via a wastewater treatment facility to the water environment for further abstraction and use whereas greywater used for garden watering is essentially lost through evaporespiration.

Reuse of wastewater after treatment for irrigating parks and similar purposes is also increasingly commonplace (e.g. Sala and Millet 1997), whilst Windhoek has pioneered the reuse of wastewater for direct potable use (van der Merwe 1999). Booker *et al*. (2000) compared costs of a conventional water/wastewater system to three alternatives – including local treatment plants for grey- and blackwater for reuse in dwellings. There were no significant differences in costs but the benefits of reuse included a 45% reduction in phosphorus and 10% in total nitrogen to the environment.

A third way of reducing potable water consumption is rainwater capture by collection from roof and other hard surfaces (Texas Water Development Board 1997). In Germany, this is increasingly widespread (Hermann 2002). A second advantage of these techniques is that such a form of source control (Section 16.2) thereby reduces the problems caused by surface water runoff. In some rural areas, consumers traditionally had no choice but to be self-reliant in terms of water collection, treatment and wastewater disposal. The great advantage to consumers is the availability of land so that rainwater collection and cistern storage together with wastewater treatment in lagoons or by reedbeds can be undertaken (UNEP 2000), which will make the water available for reuse. Whilst systems to recycle a significant proportion of the influent water have been tried in urban areas, the costs and land requirements are high.

15.3 Industrial Demand

It is almost invariably found in waste minimisation studies (e.g. Porter and van der Linde 1995; Johnston 1994) that industrial users should cut water use by 15–25% if they are to maximise profitability, where those waste minimisation studies include only actions with a payback time of less than two years. The three options available are: reduce demand, reuse water and recycle water. The possible potential for water recycling in industry and the resulting reduction in the intake of water was reported by Tate (1989) as varying between 44% for beet sugar refining to 90% for organic chemicals. Similarly, van der Merwe (1999) reports on a brewery that requires 4 litres of water per litre of beer produced as compared to an average of 5–7 litres in Europe. The ETBPP has published a whole range of guidance on means of improving water efficiency in different areas of industry, coupled with data to tonne per tonne consumption figures (e.g. ETBPP 1997).

In the Aire and Calder project in England, a study of 11 companies identified savings in the use of inputs such as water, energy and raw materials (Johnston 1994). Water savings of £512 000 and effluent savings of £462 000 a year, with a three-fold reduction of the amount of water discharged to the sewers, were achieved out of total savings of £3 350 000 per annum. Seventy per cent of these savings had a payback period of less than one year and only 10% a payback period of more than two years. Whilst there may be an element of self-selection by the companies choosing to take part in waste minimisation studies, the implication is that water prices fail to induce companies to perform efficiently. Rees *et al*. (1993) argued that this might be because water costs are generally so low a proportion of total manufacturing costs that companies do not consider them. The problem with that argument is that it implies that companies will seldom maximise their profits since there will usually be one input whose total cost is too small for the company to consider it. The potential benefits of demand management in industry are so large because it is potentially possible to save money four times: a reduction in metered water use, a reduction in the energy required for heating or cooling, a reduction in the charges for wastewater treatment, and through the recovery of materials from the wastewater. Nevertheless, the evidence is persuasive that prices are ineffective in optimising consumption.

The different waste minimisation studies have shown major differences between companies in the same industrial sector in the efficiency of use with which they use water (e.g. ETBPP 1997, 1998a, 1998b, 1998c, 1999a, 1999b, 2000a, 2000b). Similar differences exist between countries; Table 15.1 gives figures for the proportion of water that is reused in different countries. The high figures for water reuse for Shanxi Province in China reflect the critical water problem in that Province (Yang 2001).

Table 15.1 *Proportion of water that is reused (%)*

	USA 1983	Canada1991 – sample survey	China 1996
Metal mining	77	78	
All manufacturing industries	70	48	83
Paper and allied products	74	48	
Chemicals and allied products	65	67	76
Petroleum and coal products	87		
Primary metal industries	60	0	72

Source: Gleick 1993; Tate and Scharf 1995; World Bank 1997.

15.4 Leakage Reduction

It is possible to calculate the economic rate of leakage but one of the main reasons for seeking to control leakage is often to promote the message that water should be conserved and hence to promote demand management by the consumer. Unless the water utility is seen to be pursuing a rigorous programme of leakage control, any message to the consumers to control their demand is likely to be undermined. A series of distinctions need to be drawn: 'unaccounted for water' is the difference between the amount of water put into the supply and the amount of water received by the consumers. A 'leak' involves the escape of water from a joint or from a crack in a pipe. However, the structural integrity of the pipe continues and the loss of water through that particular leak is small relative to the flow along the pipe. 'Leakage' is usually taken to refer to losses in the distribution system between the treatment works and the consumer and 'wastage' to refer to losses within the consumer's property. When the structural integrity of the pipe is lost and all or most of the water is lost through the breakage point, a 'burst' has occurred. The effects and consequences of 30% of the water put into supply being lost through leakage and through bursts can be quite different, as can the costs of reducing that loss. Unaccounted for water then also includes losses through leakage or theft, measurement error and also water used for fire fighting. Yepes (1995) notes that 50–65% of unaccounted for water is actually the result of meter errors or straight theft; and in a sample of zonal meters (covering 200 to 500 properties), only two-thirds had a systematic error of less than 10% (Wilson *et al.* 1993).

The amount of unaccounted for water varies markedly between countries and cities and there are controversies about how to measure leakage (Lambert 2002). For example, utilities serving low-density areas where the ratio of the length of supply mains to consumer is high will be penalised by a measure of leakage in terms of loss per consumer. The 4% figure for Singapore is generally considered to be the world's lowest whilst figures for Spain of 24–34%, France of 30%, the Czech Republic of 20–30%, Croatia of 30–60% and Albania of up to 75% are given in Lallana *et al.* (2001). The rate for Cairo of more than 60% (Coville (1996) and Bardarska (2002)) gives figures of 70% for large towns in Bulgaria, 60% for Estonia, 39% for Romania and 25% for Latvia. In 1993, in Malta, a water-critical island heavily dependent upon desalination for water supplies, unaccounted for water was estimated to be 65% of the quantity put into supply (Water Services Corporation 1994). Of this, leakage and theft was considered to take 29% whilst under-recording by water meters was found to account for 20% of the calculated difference between the water put into supply and that recorded as being delivered.

The total percentage of water lost is a function of the number and size of individual leaks. So, whilst the total costs of leakage reduction can be balanced against the costs of supply reinforcements, or reductions in service to the consumer, the total costs of leakage reduction depend upon how leaks occur. A total loss of 30% in a year through leakage might, for example, be the result of millions of small leaks through joints or a few major leaks. Similarly, different parts of the network are likely to have different leakage rates and associated loss figures; therefore, it may be efficient to concentrate upon leakage reduction in some areas of the network, and a uniform leakage rate across the entire network may be inefficient. A 'burst', where the pipe completely fails, is likely to justify a rapid repair where a major pipe is involved since in addition to the loss of water, there will be a loss of service, as well as the costs of flooding and other disruption: these are likely to massively outweigh the costs of decreasing the response time. Even here, there is the possibility of identifying the optimum response time as a function of the costs of a burst so that the response time is designed to vary as a function of the size and criticality of the pipe.

Consequently, one decision is which leaks is it efficient to reduce and by what means; another is how quickly should the response time be to identify major bursts; taken together, this will determine what is the optimum leakage rate. Where leakage rates tend to increase as some function of the age and material of the pipe, soil type and location (UKWIR 2001), the same concerns can be used to guide the decision as when to replace or rehabilitate a pipeline; or whether preventative maintenance is more efficient than waiting for a major leak to occur. Such decisions are analysed in relation to failures in sewers in Section 16.1.3. Operationally, since the loss rate is partly a function of the pressure in the network, varying as a function of pressure to the power 1.5 (Lambert 2002), the leakage rate is one consideration which should be taken into account in deciding what pressure to maintain in the network. Another decision is what is the leakage rate which should be sought for new pipelines, assuming that higher capital costs are counterbalanced by lower losses.

An economic analysis will focus upon the comparison of alternative programmes of leakage control. The same economic approach to leakage control can be adopted as for other demand management strategies: does the value of the water saved as a result of the anticipated reductions in leakage, together with the economic losses resulting from any leak, exceed the cost of the proposed leakage control? The economic losses from a burst of a mains can include flooding, the disruption of traffic, damage to other services and distribution to commerce and industry (Section 16.1.3), in addition to the value of the water lost. Moreover, the costs of an emergency repair are usually greater than the cost of precautionary maintenance or rehabilitation. Since precautionary maintenance and rehabilitation can also often be undertaken by 'no-dig' techniques, the costs of traffic disruption caused by open cut working (Read and Vickridge 1990) will also be lower. Therefore, the benefits of a leakage detection and response programme are:

$$(Q_{\mathrm{w}} - Q_{\mathrm{p}})V_{\mathrm{w}} + (P_{\mathrm{w}} - P_{\mathrm{p}})L_{\mathrm{b}}$$

where:

Q_{w} is the loss of water now;
Q_{p} is the loss of water with the programme;

V_w is the resource and environmental cost of the water;
P_w is the probability of a burst now;
P_p is the probability of a burst with the programme;
L_b is the cost of a burst.

This equation can, in principle, be used to determine how much it is worth spending on a leakage control strategy. The practical difficulties are in assessing the relative probabilities of bursts and the likely losses under the different alternative programmes. However the issue is addressed, a range of leakage control strategies should be compared including:

- responding only to complaints from the public, other utilities or highway authorities thus effectively responding largely to bursts;
- reducing pressure in parts of the distribution system;
- district or local gauging of the distribution network to detect flow anomalies (in New York City, some sewers have also been gauged to detect such unexpected flows which then trigger searches for leaks);
- leakage detection either on some predetermined cycle or as part of other activities; and preventative maintenance, rehabilitation or renewal of parts of the distribution system so as to reduce the probability of a leak occurring. This strategy may be based upon a risk analysis which identifies those parts of the system where the expected gains from such a strategy will result.

Such an approach is likely to be targeted at the critical parts of the system where failure would cause either major disruption or temporary loss of supply. For example, a burst in a 42-inch main in Leeds in 1985 left some 140 000 consumers experiencing water restrictions for several days (Jeffrey *et al.* 1986) Mains rehabilitation strategies may result in other benefits which also need to be included in the assessment of the benefits of this strategy. These include a reduction in the discoloration of water caused by corrosion, bacteriological problems, and nodular deposits on cast iron pipes restricting flow and pressure.

15.5 Charges for Abstraction

Neoclassical economic theory assumes that a perfectly competitive market will determine how a good is allocated between alternative users, and also that the market will both automatically determine the quantity provided and the price charged for the good. Thus, it provides very little help in determining how a fixed quantity of water should be allocated between competing uses when there are externalities associated with each. Rogers *et al.* (1998) sought to address this question. Figure 15.3 is a redrawing of part of Rogers *et al.*'s Figure 1 as applied to two alternative uses of some given quantity of water; the order of the elements has been changed for clarity of exposition. What they describe as 'environmental

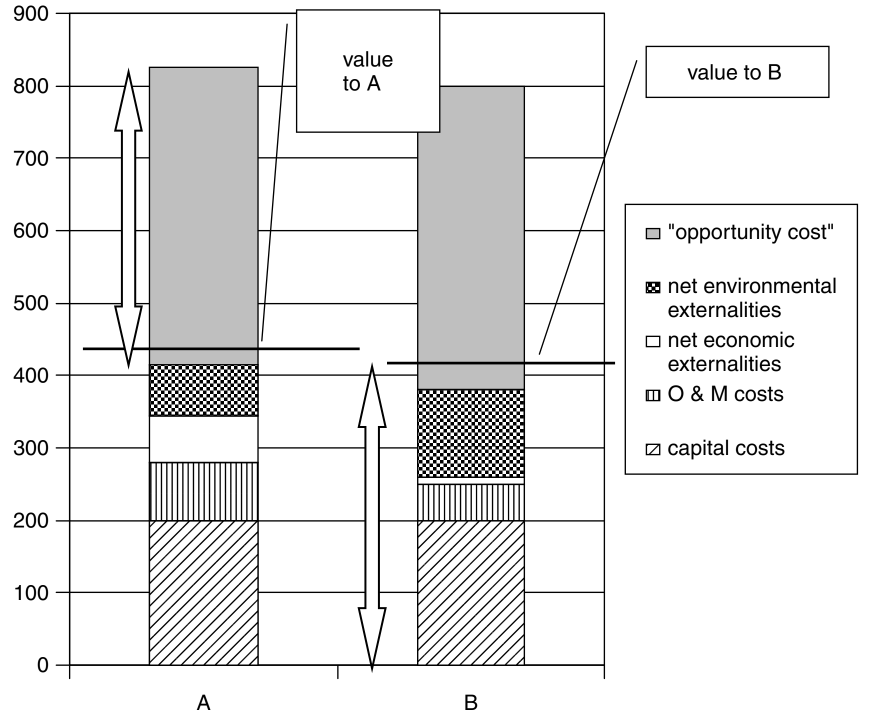

Figure 15.3 *Pricing water: the Rogers methodology. Note: 'opportunity cost' follows Rogers' terminology rather than conventional usage in economics*

externalities' can be expanded to include the effects of water use on all of the other objectives brought to the choice.

However, Rogers *et al*. then wish to add what they describe as 'the opportunity cost of water' in alternative uses, which they describe as the 'value' of the water in those alternative uses, to these costs in order to determine the appropriate price for each use. The use of the term 'opportunity cost' to describe this value in another use differs from standard economic usage which restricts the term to inputs to a particular activity. It would be more appropriate to call this value of water in an alternative use, its 'opportunity value'. This term does not appear in conventional economic theory because the perfectly competitive market is presumed to ensure that each product is allocated to the highest value use.

Nor is it quite clear what Rogers *et al*. mean by value. In Figure 15.3, it has been assumed that the value of the available quantity of water for use A is 420 and for use B it is 410: thus, that these are the maximum prices at which each user would be prepared to buy the water if it were to be offered. This is the standard economic use of the term 'value'. If the value to B of the water (410)

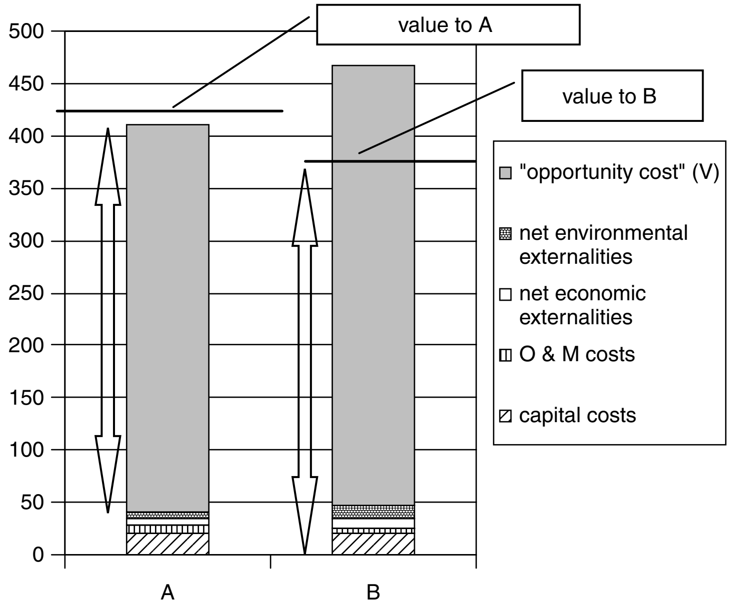

Figure 15.4 *Pricing water: values*

is then added to the other costs for use A, the resulting price that the Rogers' model would apply exceeds the value to A of that water. The same is also true for B. However, there is an economic gain from putting that water to use B where the difference between the itemised costs and the value of water in that use is 30. So, under the Rogers' model, for the available water to be allocated to any use, it is necessary that the value of the water in each use is high relative to all of the costs; Figure 15.4 illustrates such a case where the value to use A of the available water would exceed a price that includes the value to B of that same water.

Such a massive difference between the costs, including the externalities, and the benefits is unlikely and will only exist where there is no real allocation problem, when the basin is still 'open' (Seckler 1996). Moreover, economic theory defines the optimal level as being that where marginal cost and marginal value are equated: it is at this point of equivalence where the price should be set. Up to that point, we want to maximise the difference between benefits and costs. So, it is more usual to consider not just how a single unit quantity of water should be allocated but how much water in total should be made available. In particular, it is usual and generally reasonable to assume that as the quantity of water available for some use increases, its incremental value in that use falls. Equally, it is also assumed that the incremental cost of supplying an additional unit quantity increases as the total quantity supplied increases.

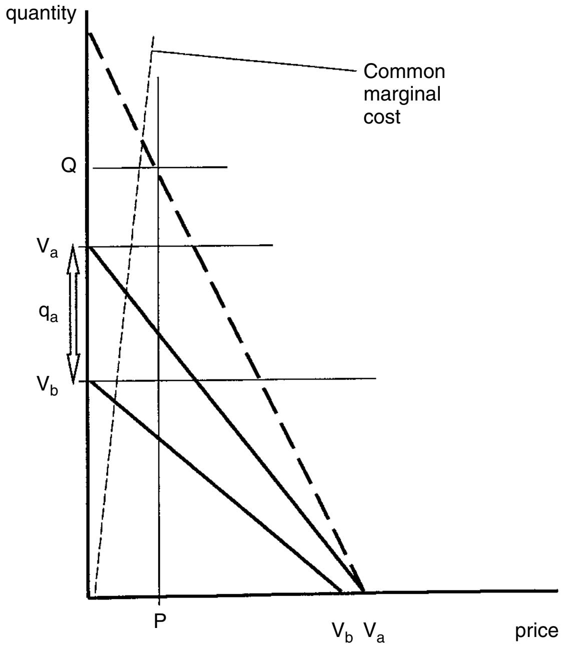

Figure 15.5 *Net marginal value of water*

The standard economic analysis assumes that the marginal cost of supply is identical for all possible uses and ignores externalities. However, the basic question that Rogers *et al.* (1998) sought to address was precisely that of how to allocate a fixed quantity of water when the marginal costs of supplying different uses and the externalities associated with each use differ. In these circumstances, even just considering two possible uses, the conventional 'scissors' diagram becomes essentially unusable; fortunately, it is easy to simplify it.

If, in the standard scissors diagram (Figure 15.5), the marginal costs are subtracted from marginal value, then the new line cuts the y- and x-axes at points which are the optimum combination of quantity and price. Similarly, in the more complex case of charging for water, we can also net out externalities as well as the marginal costs of the two uses, to give the net value of each use. However, it can be helpful to net out only the differences between the potential uses in terms of externalities and marginal costs, maintaining a marginal cost curve that covers the common costs.

In this diagram, the two lines $v_A - v_A$ and $v_B - v_B$ represent the net value curves for the two uses. Because the constraint on allocation is the quantity available rather than the common cost of provision, the allocation strategy is determined by the point where the demand curve cuts the quantity curve. Hence, we should charge price P in order to fully allocate the quantity Q of water available. To allocate this water between the two uses, q_A should clearly be allocated to use A since this is the amount for which use A has a net value greater than its net value to use B. The remainder, $Q - q_A$ should then be allocated between uses A and B in accordance with the ratio of net values of the two uses at Q. If the cost of provision is the dominant constraint, so that it is not efficient to allocate all of the water available, then the procedure is similar but the prices and quantities are determined by the point where the common marginal cost curve cuts the demand curve.

Like a lot of economic analyses, this appears more helpful than it actually is; given *n* potential uses, we need to know the marginal costs of supply, the externalities and marginal values for each and to be able to do so accurately. In reality, we are unlikely to be able to determine all of these precisely and, in particular, to be able to put a money value on some of the externalities (Chapter 21) nor, importantly, to be able to precisely assess the differences in externalities in different uses. In this case, it will not be possible to either set the correct price or to determine what the best allocation of water between the uses should be. If we recognise that we do not and cannot have such precise knowledge, the question becomes: what should we do?

An alternative is to auction fixed-term entitlements to abstraction. In this case, because the curves shown in Figure 15.5 are net benefit curves rather than demand curves, the users will bid more than the amounts implied in the diagram. The problem that remains is to determine by how much the bids should be corrected – the highest bids should not be simply accepted since the difference between these bids and the next highest bids may not be sufficient to take account of the differences in externalities and marginal costs. Therefore, we need to set some charges that reflect the relative magnitude of externalities without being able to be precise as to what these charges should be.

The approach adopted in Germany (Imhoff 1992) of a ratcheting system of charges for wastewater may be the most sensible strategy to adopt. This recognises the capital-intense nature of investment in water and hence the need to set price signals well in advance. At the same time, since the efficiency or 'optimum' level of pollution is unknown and probably unknowable, the charge can be adjusted upwards or downwards depending on the results. Moreover, as was argued in Section 2.1.2.2, in capital-intensive industry, by the time the investments have been made to achieve what was the optimum level, both the marginal costs and marginal values are likely to have changed so that the optimum has also changed. In short, optimality is probably a moving target which we can never catch. Secondly, Andersen (1994) has ascribed the success of the wastewater charging systems in the Netherlands and France to the institutional structure: recycling the monies raised in the form of soft loans and grants. So, it seems to matter less what are the prices than how the decisions are made, coupled to the hypothecation of the revenue.

There is a further question of whether such pricing will actually have any incentive effect. Given a monopoly supplier of water, if that supplier can pass the cost directly on to the consumer, there is no incentive for the supplier to reduce the demand for water either directly through cutting leakage or indirectly by promoting demand management by the consumers. For there to be any effect, then the consumer must be both metered and able to take action. Therefore, the logic is that if such a pricing system is introduced then its purpose should be to raise funds for investment in demand management (Green 1998b).

16
Sanitation

It is necessary to differentiate between faecal waste and other streams of wastewater. It is also necessary to distinguish between the problems of removing waste streams and the treatment of that waste once removed. Removal typically enables the producer to externalise the costs of that waste by depositing that waste on other people or in the environment. For faecal waste, the purpose of sanitation is to reduce the risk of faecal contamination of potable water, and disease transmission through other routes (Figure 14.7). In rural areas, this is the primary if not the only problem as far as domestic sanitation is concerned. In urban areas, sanitation is necessary in order to dispose of the other streams of wastewater left over after cooking, washing and other uses. In urban areas, the quantity of water that can be used for these purposes is effectively constrained by the ability to dispose of the wastewater produced, along with the resource costs, either monetary or energy, of disposing of that water. With wastewater, as with all water management, gravity is the ideal way of moving water.

In principle, therefore, it is useful to differentiate between the water used to move faecal waste, 'blackwater', and the other waste streams, 'greywater' or sullage. The amounts of human waste produced are relatively trivial: some 400–500 litres of urine and 50–100 kg (wet weight) of faeces per person per year (Esrey *et al*. 1998). In turn, the safe collection and disposal of this material is in principle relatively straightforward (Grant *et al*. 1996), the use of water to flush away and transport this material significantly increasing the problems. The urine stream contains reasonable amounts (Pickford 1995) of nitrogen (8.5 gm/day and of phosphorus (2 gm/day) which are either potentially recoverable or a problem to treat whilst the solids are only useful as a soil conditioner. The various disease vectors are predominantly concentrated in the faecal material although some specific vectors are transmitted via the urine. Hence, in principle, it can also be useful to differentiate between the urine and faecal waste as well as from sullage water. The fourth stream is then surface water runoff which generally is by far the largest in quantity; and in the 'first flush' contains significant polluting loads in the form of animal waste, organic material (e.g. leaves) and deposited material from vehicles. Industrial wastes are then to be distinguished from these other waste streams because of the wider variety of pollutants they

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contain (Gleick 1993). In principle, these four streams may be separated although the commonest notional separation is between foul and surface water systems. Such separated systems have perhaps been a better idea in theory than in practice, with high levels of misconnections being reported. In Sacramento, 50% of the water discharged from notional surface water sewers was in fact foul sewage (US EPA 2000): this level of misconnection is not uncommon in developed countries, with similar rates being reported in London. A further problem in developing countries is that surface water sewers are often also treated as convenient ways of disposing solid waste, and missing manhole covers pose a significant safety hazard.

In rural areas, the baseline option is typically defecation in the fields whilst wastewater is simply thrown out the door. There are a variety of options for the collection and disposal of human waste (Pickford 1995; Reed 1995). In urban areas, some sort of underground tank that leaks to groundwater, overflows on occasion, and needs to be emptied of accumulated solids is the common baseline option. Here, piped systems are necessary although the conventional large bore piped system is but one option (Cotton *et al.* 1995). Some of those systems are also based upon community involvement, such as the condominial system (Otis and Mara 1985; Wilson 1995) and that adopted in the Orangi study (Hasan 1990).

16.1 Economic Evaluation

The two main options are to evaluate the benefits in terms of the reduced costs to the community or to undertake a contingent valuation study to determine how much the community is prepared to pay for an improved system. There are problems with implementing both approaches: the former seeking to build up a model of what a hypothetical consumer who is fully informed and takes account of all externalities would be prepared to pay.

16.1.1 The benefits of first time sewerage

Firstly, in urban areas, the costs of the existing system of disposal will be avoided: emptying the tanks can be expensive. Foley *et al.* (n.d.) cite a figure of about US$9/household/year for tank emptying as compared to annual maintenance costs of US$1.20 for a community-based sewer system in Malang, Indonesia. Secondly, there will be expected health benefits. The assessment of the health benefits of sanitation are complex; it is improvements in hygiene behaviours that result in the improvements whilst adequate water supplies and means of disposing of faecal material are necessary but not sufficient preconditions for improvements in hygiene to be possible (e.g. Cairncross and Kochar 1994; Esrey *et al.* 1990). Thirdly, the leaking tanks will contaminate groundwater and hence where groundwater is used for drinking purposes, there is a second-order health effect.

One of the consequences of first- and second-order health effects is that those affected will be able to translate time and energy less effectively into income and consumption and, as a result, will experience lower levels of both than they would if a sewerage system were to be provided. One option for evaluating the second-order health benefits is to use the cost of providing an equivalent quantity of safe water by other means but this is likely to provide only an upper bound to these benefits.

Fourthly, piped collection systems for sullage water typically allow for increased water use and involve lower costs in using water. For example: 'Thank God I have a water connection in the home. Nevertheless, I prefer to wash in the canal so as not to dirty my house, since the septic tank we have is small. Therefore, I don't want it overflowing at short intervals' (El Katsha *et al.* 1989). Overall, it is difficult to assess all of these benefits in a reliable way.

The alternative approach is to undertake a contingent valuation study to determine how much the community is prepared to pay for an improved sanitation system and the nature of the particular system that they want (e.g. Altaf and Hughes 1994; Lauria *et al.* 1999). This is subject to the same problems described in Section 4.3. Moreover, part of the rationale for providing sanitation is that ill-health is a contributing cause to poverty, by reducing the potential effectiveness of translating time into income, as well as an outcome of poverty. Hence, potentially the provision of sanitation may result in an increase in income rather than, as the preparedness to pay format implies, resulting in a reduction in real income. Secondly, there is a problem in establishing the informed consumer: the rationale for hygiene programmes is that the connection between clean water, sanitation and health is not a self-evident truth, nor are recommended hygiene practices necessarily consistent with cultural traditions (Water and Sanitation Program n.d.). Hence, households may underestimate the true benefits of sanitation for their community and preparedness to pay will understate the perceived value to those households. Thirdly, piped sanitation in particular involves externalities: it is usually possible to arrange that when tanks overflow, they do not overflow into the household's home but into the street or into other people's homes. Similarly, the problem with diseases is that they may then be transmitted to the rest of community. This is even more true of piped systems where overflows are shifted either to watercourses or to areas downhill of the households contributing the load. Fourthly, piped sewerage is perhaps the archetypal collective good and there is an apparent contradiction between asking individual households how much each is prepared to pay for a system where it requires collective agreement and action to provide it. This is even more true with the shift to condominial systems (Otis and Mara 1985), and other low-cost systems (e.g. Pickford 1995), some of which also require households to contribute labour to the construction of the system (Watson 1995).

These points suggest that we reframe the question or rather questions. The two questions that are of concern are: is it the most desirable means of using available resources? And is it sustainable? There may be other problems that to the affected community are more pressing and to which any available resources, by whomsoever they are made available, the community would wish to allocate those resources. It does not matter whether those resources are contributed by the affected community or by a wider community, they should still be put to the highest use for the affected community. Secondly, the pragmatic approach is that inadequate O&M causes many water projects to fail in the medium- to long-term and hence a commitment to fund or undertake adequate levels of O&M is a prerequisite for a project to be sustainable. Therefore, a commitment by the affected community to resource O&M requirements is essential since the community is the most reliable source of such resources.

If then the community is prepared to commit sufficient resources, including money resources, to a viable system then there is no further economic question to answer. The only times when the economic question bites is when they cannot contribute at present sufficient resources to support a project and the issue is then one as to whether a wider community should contribute towards the cost of the project. This continues to be a difficult question to answer and one that is not measured by preparedness to pay.

16.1.2 Improvements in service

Generally, it is appropriate to analyse the choice in terms of a reduction in the probability of different forms of failure, including flooding, blockage or collapse (Figure 16.1). Simple look-up tables to enable the evaluation of the reduction of flooding and road closures are given in Green *et al*. (1989a).

16.1.3 Maintenance issues

Although some Roman sewers are still functioning after nearly 2000 years, sewers are prone to failure, structural failure resulting in collapse or, in the case of pressurised systems, to bursting. In addition, the sewer network comprises the greater part of the assets of water and wastewater systems – for England and Wales, the sewer network comprises 70% of the total value of the assets (OFWAT 2002a). Consequently, a critical issue for wastewater management utilities is: what is the most efficient maintenance regime to adopt?

The baseline option is to do no routine maintenance but simply to replace sewer lengths as and when they fail. But, failure will result in costs, possibly including disruption to other utilities, flooding and disruption of traffic, including access to adjacent properties. Undertaking works on sewers also causes disruption, notably to traffic (Read and Vickridge 1990) and operating on a replace on failure basis precludes the adoption of 'no-dig' technologies which would reduce that disruption.

Alternative do-something options then include renovation or rehabilitation using 'no-dig' technologies (e.g. Read and Vickridge 1990) or replacement using

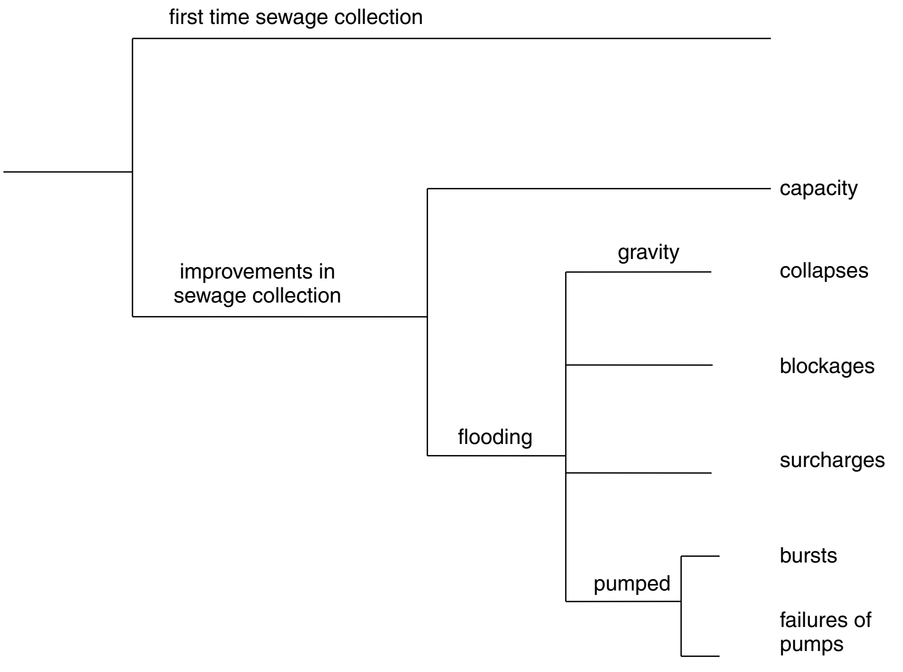

Figure 16.1 *Improvements in sewerage service*

open-cut techniques. The purpose of these 'do-something' options is to reduce the probability of collapse. The problem therefore is to determine whether the discounted present value of $P_1(F + R_1) - P_2(F + R_2)$ is less than $C_2 + D_2$ where:

P_1 is the annual probability of failure by the sewer now;

F is the costs of disruption and damages associated with the failure of the existing sewer – assuming that these costs are dependent upon the location of the failure rather than the construction of the sewer;

R_1 is the cost of repairing the existing sewer on failure including the disruption costs associated with these works;

P_2 is the annual probability of failure by the sewer when renovated, rehabilitated or replaced;

R_2 is the cost of repairing the renovated, rehabilitated or renewed sewer;

C_2 is the cost of renovating, rehabilitating or renewing the sewer;

D_2 is the cost of disruption associated with renovating, rehabilitating or renewing the sewer.

Table 16.1 *Structural performance grades and the estimated probability of sewer collapse*

Structural performance grade	1	2	3	4	5
Probability of collapse/manhole length/year (P_I)	5×10^{-5}	2×10^{4}	7×10^{-4}	3×10^{-3}	1×10^{-2}

Source: Green *et al*. 1989a.

Table 16.1 gives some indicative failure probabilities for sewers of different assessed conditions in England and Wales. However, in any given year P_I, the probability that the sewer will fail in that year depends upon what has happened before: given a long enough time horizon, the sewer will have already failed and have been replaced once. Hence, the probability of failure in a given year needs to take into account the probability that it has already failed and been replaced.

The probability that in year n, a sewer has collapsed and been replaced is:

$$(1 - (1 - P_i)^{n-1})$$

The probability of collapse in nth year is:

$$(1 - (1 - P_I)^{n-1})P_2 + (1 - P_1)^{n-1}P_1$$

This equation can be simplified to:

$$P_2 + (1 - P_1)^{n-1}(P_1 - P_2)$$

This formula is easily applied in a spreadsheet.

The disruption costs associated with failure, repair or other works include the costs of traffic disruption and damage to other utility systems. The disruption to business will typically be only a financial cost rather than an economic cost since the loss of business will simply be displaced to other areas and other firms. However, if the utility has a legal liability for these costs, then it will wish to include them when evaluating alternative maintenance strategies. Thus, the largest component of the disruption costs is generally traffic disruption. These costs of traffic disruption can be readily estimated using conventional traffic models and approximate values calculated per hour of disruption in different types of roads in the network (Green *et al*. 1989a). The expected costs of flooding can also be calculated relatively simply.

This same general procedure can also be applied to the evaluation of alternative maintenance strategies for water mains, although here it is necessary to include the cost of loss of service. It is also applicable to other elements in water management such as pumping stations. Where failure probabilities are expected to change over time, applying the approach becomes more problematic. Such changes should be expected when the engineering life of the component is relatively short or where conditions are changing.

16.2 Surface Water Runoff

The first effect of urbanisation is typically to increase both the quantity and the speed of runoff. The second effect is to change the pattern of pollution loads over time on the receiving waters (Beck 1996). The benefits of providing surface water drainage through either separate or combined sewerage systems are reducing local flooding, and perhaps also enhancing slope stability; the potential costs are increasing the flood risk downstream and the impacts on receiving waters. It will usually be the case that only a relatively low design standard of protection against flooding can be justified. For surface water drainage, commonly the effect is to reduce the extent of all flooding, 'above design standard' benefits forming a significant proportion of total benefits (Chapter 18).

Increasingly, attention is being given to source control approaches to managing surface water runoff (Maskell and Sheriff 1992; Sydney Water Board n.d.). There are two main forms of source control: those that reduce or delay the amount of runoff that will eventually be released to the watercourse; and those that reuse some of the rainfall for potable water purposes. The former may affect both the runoff from ground surfaces and from roofs; the latter rely upon rainwater harvesting from the roof. The benefits of the former are then restricted to the reduction of local flooding and the impacts on watercourses, and any resulting downstream flooding; when rainwater is harvested from roofs, a second potential benefit is given by the potential value of the water harvested (Section 15.2). These latter benefits will obviously only arise when water for potable use is scarce. The major cost disadvantage of source control is that it is spatially extensive so that more land is required for development than might otherwise be the case. In turn, this tends to make source control most viable when development takes place at the very low densities characteristic of North America (Center for Watershed Protection 1996) or where the harvested rainwater is of high value (Asano *et al.* 1996).

16.3 The Reuse of Wastewater

All wastewater is reused in one way or another; a widely cited figure is that the water drunk in London has already been through six pairs of kidneys. In turn, there are eight possible options for the reuse of wastewater:

- environment (quantity and quality);
- groundwater recharge;
- golf courses (Sala and Millet 1997);
- agricultural irrigation (Shevah 2000);
- fish farms (Rose 1999);
- industrial water (Asano *et al.* 1996);

- potable water (van der Merwe 1999);
- completely closed systems.

The last three systems were discussed earlier (Section 15.2). The standard of treatment varies according to the form of reuse intended; in general, there is a trade-off in treatment between the spatially extensive forms of treatment, reed beds (Cooper *et al.* 1996) and waste stabilisation ponds (WHO 1987), and the spatially and energy intensive forms of conventional treatment. Thus, Rose (1999) quotes a land requirement of 0.5–1 m^2/person equivalent for conventional treatment versus 5–10 m^2/person equivalent for natural treatment systems. In addition, each form of treatment yields at least one other waste stream, in addition to wastewater, which requires safe disposal (i.e. the product from screening, grit, sludge or dredged material from the ponds or reed beds).

Using the environment for treating wastewater incurs costs as discussed in Chapter 21; improving the treatment standard so that wastewater can be directly reused then generates the benefits associated with that use. In urban areas, the high value uses for wastewater often turn out to be for golf courses (Sala and Millet 1997) or green urban areas. Thus, roughly 25% of the wastewater that is reused in Mexico City is used for irrigating parks/green areas, with the remainder of untreated water being used for the Tula irrigation district (Scott *et al.* 2000). The reuse of wastewater for irrigation has long been practised, being almost routine in mid-nineteenth century Britain (Shuval *et al.* 1986). As the pressure on water resources is felt more clearly, attention is increasingly being given to using treated domestic sewage for irrigation after various levels of treatment. There is an obvious potential risk to health (Edwards 1992; Feachem *et al.* 1983) but this can largely be ameliorated by the appropriate wastewater treatment method and the appropriate combination of crop and application method (Shuval *et al.* 1990). In some water-scarce areas, a large proportion of wastewater is already reused for irrigation; in Israel, 275 mcm, or 65% of generated wastewater, goes towards Israel's total irrigation demand of 1200 mcm (Shevah 2000).

The benefits of treating and reusing wastewater for irrigation depend necessarily upon what is the alternative. If there is no system for collecting sewage at present then the benefits of treating and using the wastewater are to be compared with the costs and negative benefits of otherwise disposing of the effluent, be this to a river or to the sea. To the conventional benefits of irrigation should be added in the case of wastewater reuse the savings in fertilisers which the farmers can obtain from applying wastewater.

If there is some existing system of collecting sewage, then it is highly likely that if the resulting effluent discharges are in any way accessible to farmers then some of that effluent is already being used for irrigation. In this case the benefits of wastewater treatment are the improvements in health to both farmers and consumers as a result of the reduction of pathogens from the effluent and also the possible benefit to the waters which would otherwise receive the effluent. Typically, the critical determinant as to whether a project to reuse wastewater is economically viable is the difference in height between the area which may be irrigated and the wastewater treatment plant. If the wastewater has to be pumped up to farmers then the costs of pumping rapidly wipe out the potential benefits of irrigation.

The reuse of wastewater to provide food for fish is also a traditional practice (Rose 1999), where the ponds required to treat the wastewater (WHO 1987) can also produce fish, the effluent from the ponds then being available for other forms of reuse (Rose 1999).

Finally, where raw water is very scarce, then treatment to the standards required for immediate reuse may be justified (van der Merwe 1999; Tokyo Metropolitan Government n.d.)

16.4 Charging for Sanitation and Surface Water Runoff Collection

Effectively the only two ways of charging for sanitation are by a flat rate or property tax, or as a multiplier on the cost of water supply where water supplies are metered. The former method is effectively a tax and hence must be set by a government body and not a private profit-seeking company. In turn, historically, sewers have been provided by municipal or other levels of government (Hietala 1987), probably in part because otherwise a private company could have no guarantee of a return on investment, it being impossible to stop people illicitly connecting to a sewer where one is provided.

Using a multiplier to the charge for water supply is convenient when the wastewater collected for treatment is equal to or less than the volume of water supplied, and where the costs of wastewater collection and treatment are roughly equivalent to those of supplying the water. When the consumer engages in rain-water harvesting then the volume of wastewater to be collected and treated will exceed the quantity of water supplied, and the simple multiplier approach will result in such consumers being cross-subsidised by other consumers.

Hence for domestic consumers, charging for sanitation is always something of a crude instrument and two advantages of a tax approach are that a property tax can be relatively cheap and simple to collect. Secondly, the public good nature of sanitation means that individuals should be encouraged to connect to a system once it has been provided. Moreover, in such circumstances imposing a charge simply increases the likelihood that illegal connections will be made. Lump sum ‘connection charges’ are more logical when incomes are higher and dwellings are provided through a market rather than being constructed by the occupants themselves. In principle, those connection charges should represent the marginal cost of extending the sewerage network to serve the property in question and hence should vary by location. As the balance of the costs shift from water supply to wastewater collection and treatment, the purely theoretical argument for adopting this approach becomes stronger. However, unless charges for every one of the externalities associated with development are imposed, the risk is of distorting development, resulting in higher total external costs. Where a land use planning and control system is effective, then it is more logical to include the impacts on the water and wastewater systems into the planning considerations rather than seek to develop a sophisticated system of varying connection charges. Where no such system of land use control is practical then the likelihood is of illegal connections being made, so that a subtle system of charging will be pointless.

However, for industry and other large users, charging according to the volume of water discharged to the sewers and the quantity of pollutants in that water is logical, the 'Mogden' formula being an early example of such a system (Ingold and Stonebridge 1987). Here, the polluter has three costs to compare: the cost of discharging to a sewer, the cost of treatment on site, and the cost of discharging directly to a water body. For many pollutants, there should be economies of scale and so the cost of treating the wastewater via a treatment works connected to the sewer network should be expected to be less than the costs of treatment on site except in so far as on-site treatment allows a reduction in water demand, as well as allowing the recovery of waste materials and heat. Nor does it particularly matter which of the two strategies the polluter adopts. But care may be needed to avoid giving the polluters a perverse incentive to discharge directly to a water body. Equally, when a monopoly supplier is charging for wastewater, there is an obvious danger that the charges levied will be determined by what the market will bear rather than the true costs of wastewater treatment. Price and quality regulation will be essential to avoid monopoly profits from being extorted in this way.

In principle, the charge for collecting and treating surface water runoff should vary according to the quantity and rate of discharge of runoff. It is only with the development of GIS systems that it has realistically become affordable to introduce such charging structures. Such charges have, for example, been introduced in Los Angeles, Palo Alto, Santa Cruz and San Jose in California (Null n.d.). In Santa Cruz, areas are estimated from aerial photographs with the 'basic assessment unit' being a single family residence on a plot of 7723 ft^2; as this attracts a charge of roughly US$1/month (Null n.d.), this charging system probably costs more to administer than is collected.

Fort Collins in Colorado sets a charge based on the estimated runoff, adjusted for on-site runoff controls, that varies between basins with the rate taking account of both O&M costs and capital works. Of the average monthly charge for a single family residential plot, about US$3.42 is levied for O&M costs and US$6.41 for capital works (Center for Urban Policy and the Environment n.d.). In addition, developers are required to provide stormwater facilities for new parcels and a development fee is levied on all such parcels where the fee per parcel varies between basins from US$2175 to US$10 000.

Case Study 16.1 The Greater Cairo Wastewater Project

Cairo has negligible rainfall and consequently essentially all of the water entering the sewerage system has already been put into supply. At the same time, the water table is very near the surface and connected to the River Nile. That high water table in turn means that the old sewerage system was a pumped, pressurised system rather than relying on gravity. The sewerage system was already inadequate when it was completed in the 1930s and, following the massive growth in population over the next 40 years (Shorter 1989), was failing badly by the 1970s. By that time, almost 100 failures were occurring each day causing flooding; in addition, large parts of the city were not served by a piped sewerage system (Coville 1996). Following the Camp David agreement, substantial aid monies were made available to fund the implementation of the sewerage master plan that had been drawn up in 1977 (Taylor Binnie and Partners 1977). In implementing that master plan, the USA focused on the West Bank of the city and the UK on the East. On the West Bank, the initial works concentrated on extending piped sewerage (FAR projects) to areas previously unsewered whilst the main focus on the east bank was on building a new deep spine tunnel up to 5 m in diameter (Surr *et al.* 1993). The Overseas Development Administration carried out an interim evaluation of the project in late 1992 (Surr *et al.* 1993), by which time total investment was £1.5 billion; one of the objectives of that study was to define the data requirements for a full economic analysis to be undertaken on completion.

Cairo has experienced rapid urbanisation (Shorter 1989), much of it informal so that around 46% of the population now lives in such settlements (Coville 1996), with 50% of new construction in 1992 being unlicensed (Surr *et al.* 1993). One typical development pattern for informal developments has been for, first, the construction of vaults under the buildings: an estimated 73% in the case of Abou Qetada. These vaults are concrete boxes that leak, retaining solids whilst allowing much of the water to escape. The second stage is the construction of tube wells. Thirdly, through community self-help an unofficial water main is laid connected to a trunk mains so that by 1996, there were 500 000 legal connections and an estimated 200 000 illegal connections (Coville 1996).

The benefits of extending piped sewerage are thus:

- since the capacity of a vault limits the water which can be consumed, a piped collection system allows for an increased consumption of potable water;
- overflows from vaults and the disposal of sullage water to the streets result in flooding and health hazards;
- the costs of cleaning and emptying the vault are significant; and
- vaults, with the uncontrolled leaching, result in a build-up of waste material in the soil, the contamination of groundwater and a possible increase in groundwater levels.

The cost of constructing a vault depends upon its size – it is usually shared between several households and may be up to 20 m long. Based on five to six families sharing, the likely cost of construction is of the order of LE500:LE15–16 per capita. Once constructed, this cost is a sunk cost which cannot be counted against the costs of the subsequent provision of a piped collection system.

The capacity of the vaults is limited and it is reported that sullage water is thrown on the streets and, in other areas, children are encouraged to use waste land for a

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toilet (El-Katsha *et al.* 1989). Since water supplies are limited, it is not clear which is the greatest constraint: the availability of potable water or the capacity of the vaults. However, it is clear that the higher consumption levels in some parts of Cairo (average domestic per capita consumption equals 159 l/c/d) could not be sustained in areas served by vaults. The probable resulting restrictions on hygiene are a possible explanation of health problems. Thus, that it is not sewage spillages on the streets which are the cause of disease but the inability, either because of shortages of water or because water consumption is limited by difficulty of disposing of wastewater, to wash hands, food and surfaces so as to avoid cross-contamination.

Furthermore, flooding of streets as a result of overflows from vaults is quite common, as are backflows from latrines into ground floor apartments. One test of the effectiveness of the project is then to determine whether per capita water consumption increases in newly sewered property. Widely varying estimates of the frequency with which vaults needed to be emptied and the costs of so doing were obtained. Both are likely to vary from locality to locality: in areas where the clay layer is near the surface, the rate of water loss from the vaults will be relatively low, and hence the required rate of emptying higher. If no water leached away from the vault, then the cost of donkey trailer collection per individual per year in a low consumption area (49 litres/day) would be LE41 – over LE220 for the average family. The low estimates of the costs of emptying were in the range of LE12 per year; say, LE0.33 per capita per year. However, in the Abou Qetada area, a study by ES Parsons reported that a significant number of vaults require emptying every three days or less. The reported cost is 50 pt per load of 200–300 litres; LE1.70–20.00 per capita/year, depending upon the number of residents served by the vault. This cost is also equivalent to LE1.50–2.50/ m^3 of material removed.

One of the project reports for the FAR works compared the cost of a range of different options based around the use of the existing vaults or modified systems. The range of computed cost varied from LE1.35/m^3 to LE3.55/m^3; the amortised cost of a donkey trailer being, for example, LE2.27/m^3. On this basis, the cost of a piped collection system will be considerably less than the cost of collection from vaults even at present low consumption levels, unless at least 90% leaching rates are both possible and acceptable. Assuming a 90% leaching rate, then the marginal cost of collection associated with increasing water consumption to the average domestic consumption in Cairo is LE9 per capita per year, or about LE50 per family. In their sample survey, Hoehn and Krieger (1996) report that the mean cost of vault cleaning reported in the four weeks prior to the interview was some LE14. Moreover, those without piped water and sanitation incurred costs of LE18 a month, plus 28 hours labour, as compared to LE5.5 a month for those connected to both water and sanitation networks. The waste collected from the vaults is then disposed of in a number of ways: some is reported to be sold as fertiliser; the balance to be simply dumped into the nearest watercourse, sewer manhole or piece of waste ground.

In turn, it was reported that in Zenein land values had increased following the FAR schemes by a factor of approximately 10: from about LE30–40/m^2 to LE300–400/m^2. This gives an increase in the value per hectare of, say, 2.6 million LE which, given the land densities, comes to a gain of c. LE1300 per capita. Because of rent controls, this gain is reported to be captured by the resident population rather than leading to their displacement. However, the existing informal potable water supply network is replaced in the course of the FAR works, and, as it would be reasonable to assume that the replacement work is of a higher standard, so that some part of this

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gain should be attributed to improvements in the water supply. The implication is that the economic benefits of first time sewerage, coupled with adequate supplies of potable water, are substantial.

On the East Bank, the purpose of the spine tunnel and associated pumping stations is to reduce the frequency of failure of the existing local sewer networks and to allow the expansion of the network. Thus, one project report stated that 225 000 out of a population of 650 000 lived in areas subject to fairly regular flooding. In approaching the economic evaluation of the works, it was not clear what were the causes of these failures of the existing sewerage system. Breakdowns of the pumps and ejectors were common, but the proportions of failures caused by blockages, under capacity, and bursts are not uncertain. In 1993, after rehabilitation of the pumps and ejectors, the reported rate of failures for the ejectors was an average of three per day: a failure rate of 1 in 13 per day. Another report estimated that 35% of flooding incidents were attributable to blockages caused by some 800 small industrial plants scattered throughout the city. Certainly, a significant proportion of 'floods' were concentrated in the leather working district, suggestive of blockages being caused by the discharges from tanneries. The latter cause of failure might be effectively and rapidly reduced through a Trade Waste management programme. Rather mixed views were expressed on the frequency of sewer collapse in Cairo, varying from that these pose only an infrequent problem at present to that these were a frequent occurrence – one which could be identified by the presence of bypass pumping. One example given was the Cairo Tower in Zamalek which is reported to have taken six months to repair; a not unreasonable figure. Other recent incidents reported were near the Wimpy in Mohandiseen, and another in Ein Shams. Hence, for a full economic analysis, rather better data is required on both the causes of the failures in the existing system and the frequencies and consequences of the different forms of failure.

Wherever there is flooding, then people take action to minimise the losses which occur. This should be expected particularly where flooding is frequent. In turn, the losses from floods should be expected to be small but the costs of taking action and the inconvenience caused by those actions should be expected to be high. A usual adaptation is to construct mini-walls to protect property or to install flood boards to close entrance ways. Such mini-walls may be seen in parts of Maadi although they may alternatively be simply ways of demarcating private space in front of property. But a survey by ES Parsons reported the construction of brick barricades in the Athar el Nabi area specifically for the purposes of flood protection. In economic terms, any such existing mini-walls are potentially 'sunk' costs; the labour used to construct them cannot be 'recaptured' if the risk of flooding is reduced although the materials could be reused. A further loss is incurred by occupiers of the areas that are flooded; since the entire flow in the sewers is returned potable water, flooding is minimised by cutting off the water supply to the areas affected.

Flooding also causes serious damage to road surfaces. As a result of poor quality control during construction, road surfaces are slightly crazed and the high axle pressures force flood water down these cracks under very high pressure into the subsurface. As a result, large areas of surface break up, as can be seen in the underpasses below the railway lines. The Roda subway leading from Old Cairo to El Roda and the Giza Bridge has been rebuilt three or four times in the last 25 years; the most recent rebuilding cost LE3 million. The normal expectation would be that a road will only need rehabilitating after 10 years: that is, levelling and resurfacing. The life expectancy of roads is estimated to be reduced by at least 50%. Flooding

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causes major disruption to traffic in Cairo partly because local drivers do not like driving on wet streets and proceed extremely carefully: tyres are often bald and the risk of a skid is high. The last time there was flooding outside the National Institute for Transport, three accidents were counted over a distance of 300 m. The evaluation of traffic disruption is relatively straightforward (Parker *et al.* 1987) but no traffic count was available at the time of the interim evaluation.

A second reason for taking care when driving through flooding is that the standard way of relieving flooding is to remove manhole covers. Therefore, vehicles drive in single file through flood waters to avoid falling into an open manhole. In the flood near the Corniche, rocks were observed to have been placed in one carriageway, apparently to warn of some underwater danger, and in the remaining carriageway, used by traffic, there was either a serious pothole or other depression.

In addition to flooding or surcharging, and bursts, a third potential problem was the exfiltration of water leading to contamination of groundwater. Exfiltration from the sewers and surcharging sewers may both raise the level of groundwater and add pollutants, notably sulphates and chlorides, to that water which may attack structures. Faecal contaminants may also spread to wells for potable water. There is a widely held view that the level of groundwater has been rising in Cairo in recent years: this was the focus of a proposed study by the Academy of Sciences. This rise may have occurred through a number of reasons including exfiltration from the sewerage system or from the water supply system. The view was also expressed that water levels have risen in the Islamic quarter following the construction of the Metro system. The predominant pattern of groundwater movement is towards the north-west and it was argued that the Metro acted as an underground dam to retain groundwater on the 'downstream' side. Insufficient data was available to determine to what extent the present state of the sewerage system was responsible for changes in the level of groundwater, not least because very little data on groundwater levels was available. From the limited data available, the groundwater level is very near the surface in a number of areas.

Damage may be caused to existing buildings, antiquities being a particular concern, and additional protection may be required for new buildings to reduce the risk of damage. The two potential damage mechanisms are:

- rises in the groundwater level; and
- salts in the water.

Osmosis will lift water to varying heights above ground level and sulphates and chlorides will attack materials, particularly steel and carbonate materials (e.g. concrete and calcareous stone–limestones). The accepted limit values for sulphates are chlorides are 300 ppm. A limited amount of data was obtained on groundwater levels and the concentration of salts.

The benefits of improvements in the sewerage system are thus the degree to which this would result in changes in the combination of the groundwater levels and salt concentrations that would reduce the risk of damage. Therefore, it is necessary to be able to compare the 'with' scheme levels to the 'without' scheme levels. Estimation of the 'with' scheme levels might be estimated as the background levels; given the gypsum outcrops in the Cairo area, some nonzero level of sulphate salts in groundwater is to be anticipated. Equally, the groundwater level in Cairo is associated with the Nile; and the effect of leakage from the water system also requires to be estimated. Furthermore, there are significant variations in ground conditions

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within Cairo, particularly between the East and West Bank. No longitudinal data could be obtained (although it was reported that 40 years ago the water level could not be found in Heliopolis by conventional boring but is now found at around 4 m); such data is clearly desirable not only to enable the economic evaluation of the project.

For existing buildings, the effect of heightened groundwater and salts is to shorten the life of those buildings by damaging the foundations and fabric of those buildings. The economic impact of this life shortening depends upon the reduced life expectancy versus the actual life expectancy: many buildings are demolished before their theoretical life expectancy of 50–60 years because of obsolescence. The damage will, however, increase the maintenance costs in the interim. This loss could, in principle, be evaluated provided that groundwater conditions were mapped.

More critically, inspection of the Islamic Quarter, a World Heritage site, showed the marks of rising damp to heights in many cases of 2–3 m, coupled with major spalding of the limestone surface. At the entrance to the Madrassa and Khanqah of Sultan Barquq, a slap on the surface of the external wall resulted in spalling from the surface.

The cost of repairing the damage which has already been done to the some 550 Islamic monuments in Cairo and to other antiquities is a sunk cost. Improvements in sewerage will only reduce the potential of further damage to these monuments; it will not undo the damage that has already been done. Whilst there is major above-ground damage to these monuments, the real concern is the damage to the foundations and the consequent risk of collapse of these buildings. Many of these buildings are constructed on fill up to 10 m deep, including organic matter, and water saturation is affecting the bearing strength of the soil. Indeed, a few experts expressed the fear that some buildings would collapse before the long-term improvements resulting from the Greater Sewerage Project were achieved. For this reason, the Department of Antiquities has undertaken some sewerage works of its own to deal with critical problems.

In this case, the 'do nothing' alternatives are either to allow the destruction of the monuments to continue, which is unacceptable, or to adopt the least-cost alternative to reduce the risk of further damage. This alternative would involve dewatering; this was carried out by the Department for the Mosque of al-Hakim at a cost of some LE500 000. Hence an approximate order of magnitude of the benefits of preserving the Islamic monuments through an adequate sewerage system is LE275 million. In a full benefit–cost analysis, these benefits would, as would the costs, have to be phased in over time as the extension of the sewerage system protected individual monuments. Additional benefits would also arise through the protection of other categories of monument, such as the Coptic area where standing water can be observed in the Hanging Church and at the Babylon Roman western gates.

Overall, the study brought out a number of general lessons. First, in Cairo, essentially all of the water entering the sewerage system has already been put into supply. In turn, reducing leakage and wastage saves money twice, leakage from mains pipes under high pressure being likely to infiltrate the sewers which operated under a lower pressure. It proved difficult to get good data on the rates of leakage and wastage, but infiltration was estimated to contribute 30% of the total load on the sewers, some of which was from natural groundwater. Wastage rates were clearly high, one study concluding that in the apartment buildings monitored it reached 35% and one World Bank report claiming that night-time water consumption in the Mugamma office

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building reached 95% of daytime usage. Estimates of the overall rate of leakage and wastage thus reached 60%. In turn, one way of improving the effectiveness of a sewage system could be to reduce leakage and wastage (Surr *et al*. 1993).

Secondly, in Cairo, 40% of sewer connections were estimated to be illegal. In areas undergoing rapid rates of informal development, such illicit connections to piped sewers and to mains water supply should be expected. Indeed, given the health and other benefits associated with such services, they should be welcomed. The institutional question is then how such informal connections are to be encouraged, an adequate standard of construction and service is to be promoted, and the necessary trunk sewer capacity is to be funded.

Thirdly, because of the septicity of sewage, the main collector tunnels had to be lined with blue engineering bricks. The analyses undertaken as part of the development of the master plan recognised that the requirement exceeded the then capacity of the Egyptian brick industry; it was not surprising therefore that shortages of bricks delayed the completion of the project. It is therefore important to consider the availability of resources in such projects, not least to avoid imports being sucked in by the project.

Fourthly, as is fairly common, construction and operation, together with maintenance, were the responsibility of different organisations. In turn, O&M requirements were somewhat neglected in the design phase; the preparation of priced O&M schedules should be regarded as an essential element of design.

Fifthly, one of the main functions of public bodies in Egypt has been to provide work, particularly for graduates. Since wages are low, employees then seek to move into the private sector and their mobility is improved if they are trained. In turn, those who are given training then tend to leave the public organisation. One approach, therefore, is to treat public organisations explicitly as part of the technical education system and to give them a continuing and funded training role.

Sixthly, there are logical hierarchies in the provision of sewerage services. Downstream provision of sewers logically precedes upstream provision; equally, separation of industrial waste loads from domestic sewage logically precedes the provision of high standards of wastewater treatment. Not only does industrial waste contain heavy metals and other pollutants that are difficult to treat, but those pollutants can also threaten the integrity of the sewer system.

17
Water for Food

Growing crops is by far the greatest consumer of water in the world: what is called the 'water crisis' is actually a 'food crisis'. Since land is also scarce, it is essential to manage water and land effectively if the world is to be fed. At the same time, most of the world's farms are very small, less than 5 hectares in size, and farm policies are as much about rural development and poverty relief as about food production. Again, across much of the world, agricultural production contributes a substantial production of GDP, the cost of food consumes a substantial fraction of the income of most people, the largest part of the population lives in rural areas, and agricultural development is both essential to development and to prevent an uncontrolled migration from the rural areas to the urban areas of the world. Conversely, in the developed world, agriculture contributes a negligible proportion of GDP, employs an equally small proportion of the workforce, food is cheap and agriculture is very heavily subsidised. So, it is a world of two parts and any economic analysis must reflect the local realities.

Arable production is a far more efficient way of producing food value than livestock (Table 17.1). In turn, crops provide 77% of the world's food, with livestock another 16%, and fisheries the remaining 7% (Global Vision on Water, Life and the Environment 2000), with aquaculture producing an increasing proportion of the output of fisheries. Thus, agriculture provides 93% of the protein and 99% of the calories consumed by people (Wood *et al*. 2000). But, in 18 countries in Africa and Asia, fisheries provide at least 40% of the animal protein in the diet (Edwards 2000) and generally provide trace elements and vitamins that are otherwise absent in diets. In addition, aquaculture can provide synergies with arable land, particularly when that land is irrigated (Moehl 2000).

But arable production requires the joint availability of water and land where both are scarce. Only a limited proportion of land is suitable for arable usage – for instance, only 5–6% of Canada is suitable for arable use. Much of the land that is suitable is subject to constraints that limit its productivity (Wood *et al*. 2000). To these soil constraints must be added those of topography, that of the slope of the land. Much of the land is also becoming degraded after centuries of use: some 70% of the 5.2 billion hectares of drylands used for agriculture is degraded.

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Table 17.1 *Protein and energy output by foodstuff*

		Protein kh/ha/year	Energy MJ/ha/yr
Crops	Dry grass	1100	180 000
	Cabbage	1100	33 500
	Corn	430	83 700
	Wheat	350	58 600
	Rice	320	87 900
	Potatoes	420	100 460
Livestock	Rabbits	180	7 400
	Chickens	92	4 600
	Lamb	43	4 800
	Beef	43	7 900
	Milk	115	10 460

Source: King n.d.

In addition, around 10 million hectares are lost each year through desertification (Sweet 1999). Some of these problems are a result of the interaction of water and soil: salinisation becomes a problem if the soil contains salts and the water table becomes too high either as a result of excessive irrigation, or a reduction in demand allows the water table to rise. In Australia, salinisation of dryland farming is becoming a major problem because of the removal of trees and shrubs which previously lowered the water table (Land and Water Resources Research and Development Corporation 1998). Conversely, in acid sulphate soils, if the water table falls, the soil oxidises to form sulphuric acid, in turn the acid destroys the productivity of the soil and the acid drainage water damages the ecosystems in the river, estuary and coastal fringe (White *et al.* 1999).

Traditionally, the poorer quality soils and conditions were used for extensive livestock use, particularly in arid climates. In turn, whilst on a global basis meat does not contribute a significant proportion of food needs, it is considerably more important in arid regions. Moreover, some cultures and societies are woven around livestock production and the effects of droughts are then particularly devastating in such cultures (Hazell *et al.* 2001), and the poorest suffer most (von Braun *et al.* 1999).

Arable land is scarce because it is only made available by converting land from other uses, notably from wetlands, forests and grasslands, areas that are also already scarce and environmentally valuable. Thus, around 30% of the potential area of temperate, subtropical and tropical forests has already been converted to agriculture and agriculture takes up nearly 70% of land area in Europe and more than 70% in southeast Asia (Wood *et al.* 2000). Of the remaining 1.8 billion hectares of land with rain-fed crop potential, most is in Sub-Saharan Africa (44%) and Latin America and Caribbean (48%) whilst there is virtually none in South Asia, Near East and North Africa; the majority of this land is currently under forest and is subject to soil and terrain constraints (FAO 1996).

Some 800 million people currently receive inadequate amounts of food and Seckler, Molden and Barker (1999) estimate that cereal production will have to increase by 38% to meet future food needs. But increases in wealth also increase food consumption and shift the pattern of demand away from grains and legumes towards meat. Per capita demand for meat is projected to double between 1995 and 2020: poultry by 85%, beef by 50%, and pigmeat by 45% (Pinstrup-Andersen *et al*. 1999). In turn, livestock production is supported by grain production and so the net effect of an increase in meat eating is an increase in the demand for grain, the grain requirements to produce 1 kg of beef, pork and poultry being 7, 4 and 2 kg respectively (World Water Council 2000). Moreover, the shift in diet to meat consumption drastically increases the requirement for water. Thus, in California, wheat requires 1.3 m^3 of water per kg, poultry takes 5.8 m^3/kg and beef 16 m^3/kg. Consequently, the typical Californian diet requires about 2200 m^3 of water per year, of which 64% is used in meat production. Conversely, in Tunisia, the dietary water requirement is 1100 m^3/year of which 27% is for meat (FAO 1996). This pressure on land will only increase as the demand for industrial crops (e.g. for pharmaceuticals, raw materials for plastics, fuel etc.) expands to replace reliance on fossil fuels.

Thus, the two basic options are either to convert more land to arable use or to increase the productivity of the land that is currently in arable use. Whilst regional food demands may be partly met by 'virtual water', importing food (Allen 1994), globally the problem of expanding food and the resulting demand for water remains.

Whilst countries typically seek to prohibit the conversion of high-value agricultural land to urban uses, urban pressures are almost invariably so great that agricultural land adjacent to existing urban centres is converted to allow the expansion of those areas. Therefore, part of the benefits of, say, converting rainfed agriculture to irrigated agriculture could be the avoidance of the conversion of that equivalent area of forest to arable uses which would otherwise be required to achieve the same increase in production. In so far as improvements in agricultural productivity in one area would prevent other land being converted to agricultural use then there are potential environmental benefits associated with that improvement. Conversely, in other instances, a benefit of such an improvement in the agricultural productivity of one area may be to release some land that is currently under arable management for other uses. Equally, an improvement in the efficiency in the use of water may release some of that water for other uses. Finally, in some instances, it may be desirable to allow some agricultural land to revert to its natural state. For example, in England and Wales, it is a requirement that in assessing the benefits of renovating an existing agricultural drainage system, the environmental benefits of allowing that area to revert to a wetland be considered (DEFRA 1999). In England and Wales, some land is worth more in environmental use than in its current agricultural use, after subsidies are removed.

Therefore, making efficient use of arable land is a critical issue and maximising crop production involves providing water to the plant during the growing period. Too much water and there is a drainage problem and the risk, in some soils, of salinisation of the soil; too little water and the crop will be poor or fail altogether. Therefore, it is necessary to consider water provision and drainage together; the relative importance of the two aspects of agricultural water management vary from place to place. In some instances, both problems occur: for example, in Bangladesh, crop production has been inhibited by scarcity of water at some periods of the year and flooding at others (Rogers *et al*. 1989).

Moreover, over large parts of potential arable land, there is either insufficient rainfall to support crop production, or the rainfall is highly concentrated, sometimes even in the form of floods, in parts of the year and not when needed for crop growth, or is so variable that farmers have to be very risk-averse in their practices. The Sahel region is characterised by a climate in which 20% of annual rainfall may fall in a single day, and the Tropics by rainfall being concentrated into a single period of around three months. In turn, the growing season is limited to less than 100 days. The high variability of rainfall in arid regions (Chapter 14) means that many Sub-Saharan African countries experience complete crop failure every four years; for Ghana and other more humid countries, it is every five years.

Conversely, farming results in significant negative externalities (Figure 17.1): pesticide runoff can destroy fisheries and the ecological value of receiving waters, as can nitrates produced both from livestock and by the use of fertilisers. Thus, of the rivers assessed in the USA, in 59% of cases, agriculture is regarded as the leading source of pollutants (USEPA 2000b). Diffuse agricultural pollution is increasingly the primary cause of poor water quality in rivers and estuaries (Nixon

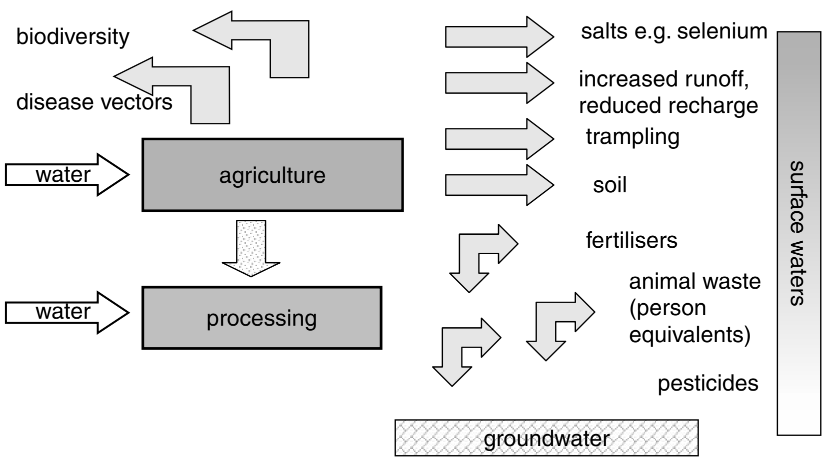

Figure 17.1 *Negative externalities associated with agriculture*

2000). Pollution by both pesticides and nitrates also results in significant increases in the cost of treating water before it can be put into potable supply (Water UK 2001). Drainage water from irrigation use often contains high concentrations of salts and minerals such as selenium which have adverse effects on wildlife (Postel 1992). In turn, agricultural products are processed and both the water demands of and pollution loads discharged from agribusinesses such as dairies, tanneries and meat processing plants are substantial (Gleick 1993).

Water management for agriculture is complicated by a series of factors:

- There are a great variety of different agricultural systems across the world, many of which have resulted from adaptation to local conditions over the centuries.
- Crop production is often only one part of the web of activities that provide sustainable livelihoods (Ashley and Carney 1999).
- Agricultural systems are intimately linked to local social systems and institutions.
- The agricultural policies of different governments are seldom primarily about agricultural production.

At the same time, the demands for water for crop production are both enormous (Figure 14.2) and consumptive, with the majority of the water supplied to a field being lost through evaporation and transpiration. Because by far the largest proportion of water use is agricultural, it is commonplace to call for a reallocation of water away from agriculture towards the 'higher' valued urban uses, particularly as urban demands for water grow.

17.1 Agricultural Systems

The large monocultural arable farms of North America and Western Europe are a recent development. Traditionally, agricultural systems are complex systems of crops, livestock, game, fisheries and trees (e.g. Zhu *et al.* 1991), typically including common property resources (Shackleton *et al.* 2000). Complex laying systems of multicropping have also been frequent; for example, coffee has traditionally been grown in the shade of other crops such as bananas. Similarly, the *montadas* and *dehesas* in Portugal and Spain are both vertically and horizontally layered systems combining trees, shrubs, arable crops and livestock (Goncalves 2000). Such multicropping systems perhaps reached their peak in the agroforests of Tanzania (the 'Chagga') and in the Pekaranga of Java (Fernandes n.d.). The integrated pest management approaches (e.g. DFID 1999b) increasingly being adapted involve a shift away from the monocultural approach.

Livestock and arable farming have typically been symbiotic and complementary; for example, the traditional rice–fish farming in parts of China where the fish both manure the rice and eat pests (MacKay 1995). In Africa, the interactions between both the ways in which different areas of land are used (Brummett and

Chikafumbwa 2000) and between arable farmers and pastoralists (e.g. Drijver and Marchand 1987) have been particularly complex, especially the ways in which the uses of wetlands (e.g. the fadama of Nigeria and dambos of southern Africa) fit into this broader system (Marchand 1987). In the past, some interventions to increase arable production have failed because they assumed a much simpler pattern of use and ignored these interactions (Adams 1992).

Critically, farmers have to be risk managers; each planting is a gamble in which the farmer commits substantial resources in the form of seeds, labour, fertiliser and other inputs against an expected return some time in the future, where that future varies from a few months for some crops to many years in the case of trees. Between the planting and the harvest, the household then has to live off the surplus, if any, from the previous harvest plus any other income or resources to which they may have access. For the subsistence farmer in particular, it is a gamble where the penalty for losing can be starvation or the loss of their land and permanent impoverishment. The risks of partial or complete crop loss from drought, pests and diseases, frost or flooding may then be substantial. Average global losses to wheat from pests are 33% but would rise to 52% without the use of control measures; those to rice would rise to 83% without controls from the current 52% (Wood *et al.* 2000). Complete crop loss from drought occurs every four to five years in parts of Africa. In addition, for cash crops, there is no guarantee as to the price that will be achieved; if everyone has a good harvest, prices will be low and may not be sufficient to recover the initial investment. Farmers have therefore been described as people who lose either way: from a poor harvest or from a good harvest. In these circumstances, it is rational to plant crops that are resistant to the different threats so that although the average yield is relatively poor, year-to-year variance is minimised. In addition, there is logic in diversifying the crops so as to reduce the risk of total crop failure.

Irrigation then reduces the risks that water will not be available when needed in the growth cycle of the crop; average year-to-year yields will consequently increase and hence, in the case of cash crops, will increase capital availability. In turn, the farmer may then be prepared to risk increasing other inputs, such as fertiliser and pesticides, so as to increase the yield further whilst paddy irrigation can reduce the requirement for labour inputs and also counter-balances some soil problems which would otherwise limit productivity. However, the farmer must also be concerned with the productivity of labour as a scarce, and perhaps the scarce, resource; in turn, planning their cropping pattern, the farmer will be concerned to maximise the return to labour rather than to land (Stomal and Weigel n.d.).

Given good access to markets then the farmer may then be prepared to switch to the production of higher valued cash crops. However, these higher valued crops are, in most countries, vegetables and fruit which spoil considerably more rapidly than grain and legumes so the risks of these crops are higher. Conversely, if there are other constraints on the farmer that are left unchanged, then irrigation alone will often not yield the predicted benefits. In turn, those constraints vary by the type of farmer and the nature of their holding. Over much of the world, subsistence farmers with what are in world terms very small holdings, often less than 1 hectare, dominate the picture. Their responses are different to those of farmers in the developed world who have much greater access to capital and much larger farms. It is also necessary to adopt a whole livelihood approach so that, for example, irrigation may not result in higher agricultural outputs but free up resources for the household to use in other ways (Johnson 1999).

In subsistence-based agriculture, farming, social organisation and institutional structures are also necessarily interwoven. The open fields that characterised Anglo-Saxon farms and the Commons have, for example, been argued to be a consequence of the use of the heavy plough drawn by up to eight oxen (White 1982). The subak in Bali are also as much a social and institutional system as an irrigation system (Bali-plus n.d.); so too are the Huerta of Valencia (Glick 1970) and the acqueias of New Mexico (Brown and Rivera 2000). Changing farming practices by, for example, introducing irrigation consequently has implications for both the social organisation and for the institutional structures; in particular of gender roles. In such changes, women not unfrequently lose out (Zwarteveen 1997), having been disadvantaged to start with (IFPRI n.d.).

17.2 Rural Economies

In developing countries, a large part of the population still depends upon agriculture and the associated industries, and in turn these industries provide a large part of those countries' GDP. The obverse is the case for developed countries. So, agriculture accounts for 40–60% of the GDP of the Philippines, with agribusinesses adding a further 21%, whilst for Argentina the 11% of GDP contributed by agriculture becomes 39% when the contribution of agribusinesses is taken into account (Bathrick 1998). In developed countries, the proportion of GDP contributed by agriculture and the proportion of the population engaged in agriculture is about 4%. In turn, droughts can have a devastating effect on the economies of developing countries, the 1990s' drought in Zimbabwe causing a 60% decline in GDP (World Bank 2001). Whilst the effect of droughts in developed countries on agriculture and the environment is also severe, the effects on urban uses are generally relatively small and so the overall effect of droughts on the national or regional economy is considerably less (USACE 1995).

In developing countries, agriculture is a net contributor to national revenue; whilst there generally are some subsidies, these are outweighed by the tax revenue produced by the agricultural sector. In the developed world, agricultural practices are almost invariably subsidised. Only rarely are the full costs of irrigation borne by the farmers (Garrido 1999); for example, the US General Accounting Office (1994) has analysed to what extent the costs of the water provided to cities, as a result of tradable entitlements being sold by farmers, will need to continue to

Table 17.2 *Forms of subsidy for agriculture*

electricity
fuel
fertiliser
transportation (e.g. subsidies for the construction and/or operation of navigation)
land drainage works
irrigation (capital works and operation/maintenance costs subsidised or cross-subsidised)
export subsidies
production quotas
import quotas/tariffs
crop insurance
payment for fallowing fields
crop price supports
flood alleviation works (i.e. subsidised construction and operation)
low-cost credit including for buildings/roads
soil erosion/desalination and similar works (i.e. subsidies towards the costs of reducing)
agricultural extension services
livestock feed subsidies
tax relief (e.g. exclusion from property taxes)

be subsidised in order for farmers to be prepared to trade abstraction rights. In economic analyses, these subsidy elements need to be stripped out; Table 17.2 lists the forms of direct and indirect subsidies most commonly found in agriculture. In total, these subsidies are very large indeed; 70% of the value of agricultural products in the UK, Germany and Ireland is made up of one form of subsidy or another (Goncalves 2000). The value of irrigation subsidies alone in the USA was estimated by Repetto (1986) as around US$1 billion and a Democratic staff report (1994) analyses seven projects where the cost recovery for irrigation was found to range from 0.1% to 39% so that in turn, the subsidy per m^3 ranged up to US$0.20/$m^3$. A US General Accounting Office study (1996) reveals a similar picture across a larger number of irrigation schemes.

One reason for the extent of these subsidies is that the schemes are inefficient: the value of crops produced is insufficient for the farmers to be able to pay the full economic cost of the irrigation water. In turn, it is likely that in some parts of the world, including much of California, agriculture would cease in the absence of subsidised irrigation. On a global scale, the consequence is that the terms of trade for agricultural products are severely distorted against the developing countries.

In turn, it should be recognised that agricultural policy is rarely about food; instead, it is usually about achieving other objectives. It may be about securing the land through settlement, as arguably was agricultural policy in the USA in the nineteenth century (Howe 1971); it may be about alleviating rural poverty and in turn slowing migration to the cities; it may be about creating and maintaining a class of small-scale yeomen farmers, who are often seen as the backbone of the nation. It may be about achieving a cheap food supply for the urban population, or it may be about creating or rewarding political support. Moreover, few countries are comfortable about relying upon imports to feed their population, any more than they are happy to rely upon imports to meet any other critical requirement such as energy.

Increasingly, a key element of agricultural policy is environmental policy; to preserve those landscapes that have been created by past agricultural activity. For example, in the UK, upland sheep farming is subsidised because such iconic landscapes as the Lake District were created by sheep farming. If sheep farming were to be abandoned, then the open moor lands would naturally revert to shrub and then to forest. Again, the oak cork forests of Portugal are very important habitats, but cork production is threatened by the introduction of plastic 'corks' for wine bottles (Goncalves 2000). In order to protect the positive environmental externalities of oak cork production, either a subsidy to cork production or a charge on plastic corks may be appropriate. Again, in the long run, rice production from the famous tiered rice paddies of Indonesia is unlikely to be able to compete with production in other areas; again, a subsidy of production in such areas may be appropriate to preserve a World Heritage site. Analysing agricultural practices solely in terms of economic efficiency may therefore be to entirely miss the point.

This is particularly the case when considering the reallocation of water away from agricultural uses; it is increasingly commonplace to call for water to be reallocated from agricultural purposes, where its economic value is low, to high value, that is urban, uses. Thus, that water should be reallocated away from wheat production to such higher valued uses as toilet flushing and domestic swimming pools. However, it is necessary to be clear what this proposal actually means: this is that too much food is being produced at too low a price. The effects will then be three-fold: on rural economies, on food prices and national economies.

If water is switched out of agriculture into other uses then some farms will cease to be viable. Villarejo (1996) analysed the effect of the 1987–92 drought in California on an agricultural community. Contrary to expectations, the production of high valued crops fell – probably because the risk of planting such crops in the face of uncertainties about water availability was too high. Some 70% of small family farms closed; in turn, three out of seven wholesale vegetable packing houses closed, total county payroll fell by 14%, retail sales fell by 11% as compared to a countywide average increase of 5%, and the official unemployment rate rose to 41%.

Similarly, Wolfenden *et al.* (2001) analysed the effects of a reduction in irrigation from 342 000 ML to 308 000 ML in a cotton-growing area of Australia. They anticipate a loss of 300 jobs out of the 3000 directly and indirectly associated with cotton with a resulting increase in regional unemployment of 3%. The total impact in the regional economy was estimated as A$15 million with returns on investment falling from 4.7% to 4.4% per annum with a consequent risk that some businesses would fail, with further knock-on effects on employment and income.

As farming is abandoned, the former farmers will seek work elsewhere, typically in towns and cities (Howe *et al.* 1990). This will increase the rate at which urbanisation is occurring in those countries that have not already been urbanised.

It will add to the pressures to create work in urban areas where many countries already find it difficult to achieve a sufficient rate of economic growth to create jobs at the rate at which the population is growing. Such migration also means that existing infrastructure is abandoned and replacement schools, hospitals and roads must be built in the areas to which the population has migrated. This is clearly a much more significant problem for the developing countries which are still starting on the path to urbanisation than in the developed world where rural populations are already low.

For the value of water in agricultural and in urban uses to coincide, agricultural uses and hence agricultural production would have to fall, with lower valued agricultural uses being squeezed out. Therefore, agricultural production would necessarily fall and the prices of agricultural crops would rise (Rosegrant and Ringler 1998). The critical questions then are by how much agricultural water use and production would have to fall, and agricultural prices rise, before a new price equilibrium is established. Rosegrant and Ringler (1998) modelled the effects of a global switch of water away agricultural use into urban and industrial uses of 10–35% by 2020, the percentage varying from country to country. The predicted result is a 68% rise in the price of rice over the period 1993 to 2020, and a 50% rise in the price of wheat. For a switch from low efficiency irrigation systems to high efficiency systems to occur, the same falls in production and increase in market prices are required. How agricultural prices will change as supply falls, the price elasticity of supply, is important. If small changes in supply result in large changes in prices, then there are obvious political implications. This volatility seems to be uncomfortably high. Adam Smith (1986) gives figures for the market price of the best quality wheat for the period from 1595 to 1764, with the exception of the period of the English Civil War. Prices of wheat fluctuated markedly from year to year over that period (Figure 17.2): the maximum year-on-year price rise is 93% and the maximum fall is to 59%. Without attempting to determine the extent to which these variations are the result of political factors, such as the Glorious Revolution and the Jacobite rebellions, or weather conditions, such year-to-year variations in the basic food staple, one that made up the bulk of the population's diet (Braudel 1974), would not now be politically acceptable to any government. Even the five-year rolling mean shows variations of plus 26% to minus 19%. As an example of the hidden hand of the market in operation, it is not encouraging: given an essentially fixed demand, prices varied dramatically in the short-term as a result of changes in supply.

The obvious solution to stabilising prices, given annual variations in supply, is storage, a practice that is currently adopted in many countries with regard to wheat; currently storage capacity is about 25% of annual production and demand. Even so, prices remain quite volatile, notably for rice where the entire rice-growing region is subject to the same climatic and meteorological variation from year to year (Jayne 1993). Essentially there is an asymmetry to society in the

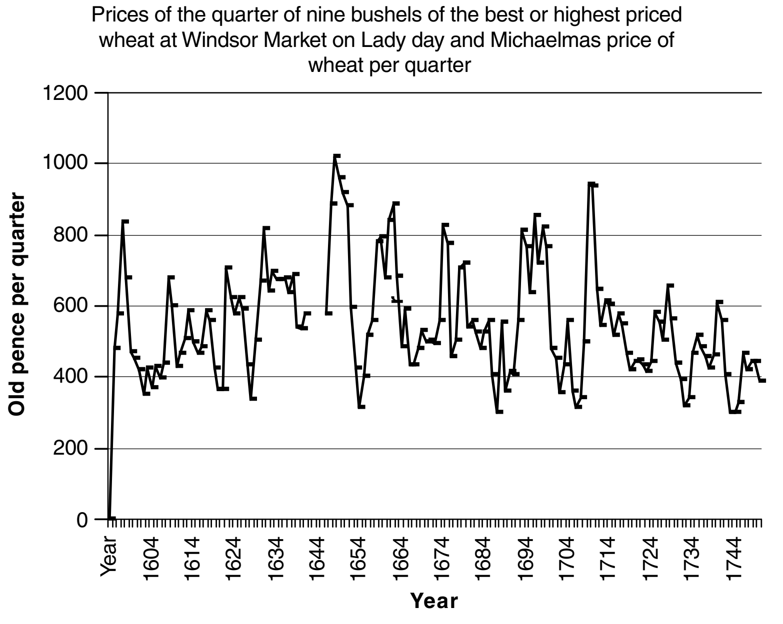

Figure 17.2 *Variations in wheat prices*

payoffs from over- and under-production; it is markedly preferable to have a situation where there is some degree of excess production, even over a long period, than experience a situation where there is under-production, let alone a famine. When the other reasons behind agricultural policies are taken into account, an efficient agricultural policy starts to look singularly unattractive. Given that those people in Asia who live below the poverty line spend around 60% of their total income on cereals which in turn provide over 70% of their total nutrients (Seckler *et al.* 1999), governments in those countries will understandably be highly adverse to volatility in grain prices and concerned to hold down these prices.

So, in agriculture, a competitive market would produce outcomes that are unacceptable and essentially we want market failure; the question is how far it is desirable to move towards another state of market failure than that currently prevailing.

17.3 Agricultural Water Management

In all countries, agriculture takes up the greatest proportion of water demand be this directly in the form of rainfall or indirectly from runoff or groundwater. Essentially, there are three water regimes for agriculture, depending upon whether or not rainfall is sufficient to support crops in terms of quantity, reliability and

Table 17.3 *Precipitation versus potential evapotranspiration requirement*

P/PET ratio	Classification	Implications for agriculture	Rainfall requirements
0.5–0.75	sub-humid zones	humid – rainfed agriculture	>300 mm year in Israel
0.2–0.5 some possible rainfall harvesting – semi-arid 0.03–0.2 rainfall harvesting – arid	semi-arid zones	arid and semi-arid – rainwater harvesting	
<0.03	hyper-arid		<70 mm/year in Israel

Source: Bruins *et al.* 1986.

compatibility with the crop growing cycle (Table 17.3) and, if not, the extent to which the concentration of water in time and space is necessary to support agriculture. In turn, the economic issues in evaluating a shift from one regime to another are fundamentally similar (Section 17.3.4).

Of these three regimes, irrigated agriculture is the most productive, 40% of the world's food being produced from the 17% of arable land that is irrigated. Potentially, irrigated cropland is 3.6 times more productive than non-irrigated cropland and about 36 times more productive than range land (Sundquist 2000).

17.3.1 Rainfed agriculture and supplementary irrigation

Rainfed agriculture requires rainfall that matches or exceeds the crop needs at the different points in the cropping cycle, the soil itself acting as a short-term store for water (Droogers *et al.* 2001). However, rainfall may fail at critical points in the cropping cycle and the timing of the rainfall is obviously uncertain. Supplementary irrigation – defined as the application of a limited amount of water to the crop when rainfall fails to provide sufficient water to increase and stabilise yields (Oweis *et al.* 1999) – may then be used, particularly for high value crops. In England and Wales, in the dry eastern side of the country, supplementary irrigation is used particularly on potatoes and other horticultural crops partly to guarantee the quality of the crop. In addition, the supermarkets and food processors require tight delivery dates for the crops to be met by the farmers. The marginal value of water for these purposes is so high that it can be economic for some farmers to use potable water for irrigation and some do (Rees *et al.* 1993). Weatherhead *et al.* (1994), for example, estimate the crop response to irrigation as varying between £0.21/m^3 for spring field beans and £5.37/m^3 for runner beans in the United Kingdom. Weatherhead *et al.* (1994) calculated crop responses as varying between £3.50/m^3 for raspberries down to £0.10/m^3 for grass for grazing. To these crop response benefits must be added a quality price differential which Morris *et al.* calculated as £1/m^3. Similarly, in Syria, supplementary irrigation increased average rainfed wheat yield from 2.25 tons/ha to 5.9 tons/ha; with increases in dry years from 0.74 tons/ha to 3.83 tons/ha (Oweis *et al.* 1999).

17.3.2 Rainwater harvesting

Water harvesting is defined as the process of concentrating rainfall as runoff from a larger area for use in a neighbouring and smaller area, with the water usually stored in the soil profile of the target area (Oweis *et al.* 1999). Frequently, some storage is added and the system is then one of supplementary irrigation. Rainwater harvesting is most likely to be appropriate where rainfall is reasonably distributed in time (e.g. at least 100 mm in winter rains and 250 mm in summer rains) but inadequate to balance evapotranspiration. Marginal lands with rainfall less than 30 cm a year can be cultivated if controlled but limited additional water is available (Oweis *et al.* 1999); however, the absence of storage complicates the risk analysis (Cohen *et al.* 1995). Some 50% of the world's population live in arid or semi-arid areas and Gilbertson (1986) estimates that 3–5% of these areas may be brought under cultivation by runoff farming.

There are two variants of rainwater harvesting for agriculture; some systems, such as terracing and contour lines of stones (Critchley *et al.* 1991), largely increase the proportion of local rainwater that is captured by reducing the proportion of rainwater that is lost through runoff. If this would still not capture sufficient water then the runoff from a relatively large area can be gathered and used to support a smaller and adjacent area of crops (e.g. Gilbertson 1986). Historically, rainwater harvesting has been a very important method of supplying water for agricultural uses (Lavee *et al.* 1997; Yapa 2001): the Shruj system developed in the Yemen around 6000 years ago (Brunner 2000) and Albarradas of Ecuador are believed to date from at least 4000 years ago (Yapa 2001).

Methods of rainwater harvesting can also conserve soil (Hudson 1987) and there has been a renewed interest in these traditional methods (Agarwal and Narain 1997). However, labour requirements both for construction and maintenance are often high; for example, 1 ha of contour terrace in Kenya is estimated to take 300 person-days to construct and 320 person-hours a year to maintain. Rainwater harvesting has also been a common method of providing for livestock watering. For example, in England, dew ponds were a traditional method of collecting water for these purposes and similar methods are quite widespread in other countries (van Wesemael *et al.* 1998).

For rainwater harvesting to be feasible:

- landscape surfaces must be such that runoff is relatively easily generated by rainfall;
- there must be differences in topography so that runoff can be concentrated; and
- soils in receiving parts must be able to retain and store water.

Increases in yield by a factor of three to four have been demonstrated by experiments in Burkina Faso, Kenya and the Sudan (FAO 1996).

17.3.3 Irrigation

Irrigation works, often on very large scales, characterise these early civilisations on most of the continents and most famously those of Mesopotamia, Egypt and the Indus basin (Postel 1992). The Marib dam in Yemen was constructed around *c*. 600 BC and had a length of 500 metres: effectively this was a very large weir which diverted spate flows into two canals (Hehmeyer 2000). The Dujiangyan project in Sichuan Province in China was constructed around 256 BC as both a flood control and irrigation measure: some 160 000 ha were brought under irrigation by its construction. In Sri Lanka, the kantalai tank, some 16 metres high, was constructed around 280 AD, and King Dhatusena constructed the kalawena tank towards the end of the fifth century AD. With a length of nearly 5 kilometres, and a height of up to 18 metres, this created a reservoir with an area of nearly 20 square kilometres (Mendis 1999). Large-scale dams were similarly being constructed in Iran at least 1300 years ago; for example, the Bahman weir in Fars province. Significant dams were also constructed in North Africa prior to the Roman period (Shaw 1984) and also in South America (Yapa 2001).

The construction of irrigation canals began even earlier and is extremely widespread through the world. Qanats, underground canals running in tunnels that connect to a high point in the water table, are believed to have originated in Persia around 1000 BC. Some 60 000 qanats are still in use in Iran (Lightfoot 2000), as are 11 000 Aflaj in Oman, each irrigating an area of up to 5 square kilometres. The Islamic conquest spread their use across the Middle East (Lightfoot 1997) into North Africa into Spain and from there to Latin America (Beckman *et al*. 1999). The same approach was adopted by the Nasca in Peru from around 600 BC (Yapa 2001). The enormous human effort to construct and to maintain these systems testifies to the gain in productivity that resulted. Droughts, earthquakes, wars, rivers changing course and salinisation of the soil brought down some of these systems (Postel 1992; Williams 1997). However, some irrigation systems have survived for hundreds and in some cases thousands of years, most famously the Huerta of Valencia (Glick 1970) but also the Acequias de Comun of New Mexico (Brown and Rivera 2000) and the water management systems in the Yemen (Hehmeyer 2000).

17.3.4 The benefits of shifting from one regime to another

Provided that the soil is adequate and other inputs are appropriate, then the availability of the required quantities of water at the appropriate times in the growing cycle will increase agricultural productivity in one or more of the following ways:

- increased average yield;
- reduction in year-to-year variability in crop yield;
- reductions in other inputs (e.g. labour for weeding);
- an increase in cropping intensity to more than one crop a year;
- a shift to higher valued crops (e.g. to vegetables or soft fruit);

- an improvement in the quality of the crop;
- greater precision in the time at which the crop can be harvested.

When evaluating the benefits and costs of a potential shift of one regime to another, it is essential to consider the other constraints affecting the decisions of farmers. For example, soil conditions are a major constraint on the crops that can be growth and the potential yield. Thus, Niemi *et al.* (2001) calculate the value of 1 acre foot of water in Oregon as varying from US$9 to US$44 for class V and class 1 soils, respectively.

Whilst the same basic principles apply when evaluating a possible shift from rainfed to supplementary irrigation as from rainfed to rainwater harvesting, and in all other possible shifts, the secondary benefits and costs associated with each shift can be different. In each case, these also need to be considered. For example, rainwater harvesting can reduce soil erosion and reduce the risk of flooding (Yapa 2001); irrigation will make water available for household purposes and may promote groundwater recharge (IWMI-TATA 2002), as may some forms of rainwater harvesting (Agarwal 2001). Conversely, water is often a breeding ground for the insects and other species that carry diseases (Section 14.6).

17.3.4.1 Increases in yield

The increase in yield as a result of irrigation can be significant; in Namibia, the yield of irrigated maize is three times that of rainfed maize; and across Africa as a whole, on average, 1 ha of irrigated land produces 2.2 times the yield of rainfed land (FAO 1996). Across Sub-Saharan Africa, the ratio of the yield from irrigated land to unirrigated land for different crops varies between 1.4 to 5.5 (Figure 17.3). Sanmuganathan *et al.* (2000) give figures of increases in yields through irrigation in India as a factor of between 1.3 and 4.6, and for China of between 1.8 and 6.4. Moreover, the 'green revolution' has in many senses been a water revolution; whilst yields have risen from 2–3 tonnes/ha to 5–6 tonnes/ha (Guerra *et al.* 1998), water productivity has increased by a factor of 3.3 because once the field is adequately irrigated and the crop canopy is closed, evaporation is constant so that improvements in crop yield are not accompanied by an increase in water demand (Seckler 1999).

17.3.4.2 Reduction in year-to-year variability in yields

Whilst the reduction in the probability of partial or complete crop failure is a benefit, the primary benefit from such a reduction is usually the increase in inputs or the switch to a higher valued crop.

17.3.4.3 Reduction in other inputs

Irrigation can have a number of other benefits in addition to adjusting the soil moisture in the root zone of plants. It can have effects on the physical and chemical properties of the soil; reduce soil temperature; substitute for mechanical or

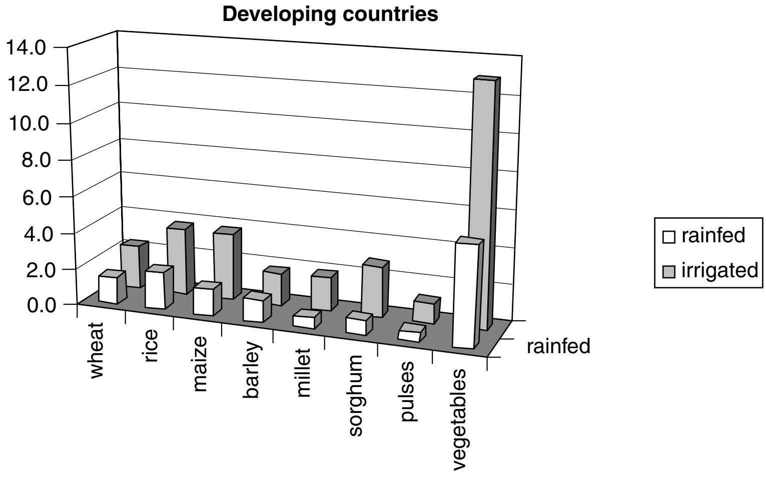

Figure 17.3 *Yields of irrigated and rainfed agriculture. Source: Rosegrant and Perez n.d.*

chemical means of weed control; and substitute for mechanical land preparation before seeding (Smith 1992). These other benefits are particularly true for paddy rice but in turn water is required for these other purposes: 150–250 mm water for land preparation, 50 mm for growing seedlings, plus an ET requirements of 500–1200 mm over 100 days after allowing for losses from seepage and percolation (Guerra *et al*. 1998). Of the water required for land preparation, a high proportion is drained off and during the growing season outflows of water can be 50–80% of the total water input. The paddies themselves provide important local storage that can buffer variations in the availability of irrigation water. Indeed, paddy rice and dryland irrigation are markedly different forms of irrigation. In addition, if water is available for irrigation, it is also available for other purposes, notably household use.

17.3.4.4 Increases in cropping intensity

Given the right temperature conditions, more than one crop a year can be grown given adequate water; in some cases, three crops can be achieved – and rather more in the case of vegetables. However, whilst feasibility studies of irrigation schemes have commonly expected cropping intensities in Asia of 1.8 to 2, the actual achievement has averaged only 1.2 (FAO 1996).

17.3.4.5 Shift to high valued crops

The benefits of irrigation are greatest when conditions allow a shift towards cash crops particularly luxury foods such as soft fruit and vegetables, although potatoes also typically give a high return. This pattern is relatively consistent between countries. Such a switch clearly requires good access to a market in the widest sense; that is, in institutional terms as well as physical access. There is also a gain in output per unit input of water; for example, the water requirement per kg yield varies between 418 kg for citrus fruits through to 1383 kg for bananas and to 2352 kg for wheat in parts of the Middle East (Pohoryles 2000). Yields are also higher for soft fruit and vegetables than for grains and legumes.

17.3.5 Stages in evaluation of changes in regime

The three main stages in evaluating the benefits of a proposed regime change are consequently:

- What is the anticipated cropping pattern with regime as compared to the present pattern?
- How much water will be required for the proposed cropping pattern?
- What is the increased gross margin; the difference between the value of the crop grown and the inputs required?

The first two stages will normally be undertaken by agronomists and social scientists with the economist being involved in the third stage. The first stage is partly a technical and partly a social question; it is usually fairly straightforward to predict what would be the most profitable crops in theory to grow in the particular soil and climate conditions. However, what crops will actually be grown depends upon a range of social and other factors; what might notionally be the most profitable will not be so if it is impossible to get that crop to market. Similarly, a massive expansion in production of what is currently a highly profitable crop will drive the market price downwards. In the second stage, the FAO Penman–Monteith approach (Smith *et al.* 1990) is now typically used to estimate crop water requirements using the crop coefficients given in, for example, Allen *et al.* (1996).

The increase in the gross margin per unit area is the difference in yield times price per unit quantity minus the change in variable costs per unit area plus any changes in fixed costs. Variable costs may increase under the new regime if the anticipated new crop requires additional fertiliser or pesticides; it will almost invariably require an increase in labour costs. Fixed costs may also increase and for this reason it is necessary to consider the effects of irrigation on individual farm holdings.

The analyst is, once an agronomist has assessed what is potentially the changed pattern of agricultural activity in the area, faced with three problems:

- considering whole-farm effects;
- estimating the rate of take-up; and
- evaluating changes in output.

However, because both irrigation and drainage are about changing risks, an important first step is to consider the pattern of water availability that will result from the proposed scheme; the right amount of water at the wrong times in the cropping season will have scant benefits. Hence, a key issue is how will water availability be allocated both spatially and over time? This refers not just to an ordinary year but also to drought years when there will not be enough water for all farmers to satisfy all of their crop requirements. In turn, the obvious questions are how and by whom will these decisions be made? In particular, cropping patterns should be expected to change over time, or cropping patterns would change except that they are constrained by the existing pattern of water allocation.

17.3.5.1 Considering whole-farm effects

A farm is an integrated system which the farmer manages as a whole; however, the area of that farm which may benefit from the changed water management regime may be only a small part of the total farm. A farmer may adopt crop rotations, or there may be interdependencies in the use made of land in different areas; for example, the use of grass for silage for winter feed of animals which are in the summer grazed on higher land. Similarly, fixed costs such as barns and equipment have to be spread over the entire farm and it is unlikely to be worth incurring a high fixed cost if this can only be spread over a small area. A farmer will consequently only make a change to the cropping pattern for land that would benefit from the new water management regime if doing so will result in a higher return from the farm as a whole. In addition, farmers will have adapted to the existing pattern of water management regime and farming may be one of a multiple number of activities which the farmers undertake as part of their adaptation strategy.

Consequently, the focus must be upon the whole-farm effect. Again, in some countries, the two different genders differ in the agricultural activities they undertake. If regime change results in gains to one of those activities which is gender-specific, it may or may not result in benefits to the household as a whole but it will probably have differential effects in terms both of labour and of income on men and women (Rathgeber 1996). Finally, households exist within and are dependent upon a wider community and the effects of the proposed scheme must be assessed in terms of the effects on the wider community.

17.3.5.2 Estimating the rate of take-up

The benefits of the regime change or of land drainage will only occur to the extent that individual farmers adopt new practices or otherwise respond in an efficient manner to the change in the water management regime. Not all farmers will respond at once or indeed at all, so the rate of adaptation or take-up must be estimated. Consequently, it is necessary to assess the rate at which the shift to the predicted new pattern of cropping will take place. As with most forms of innovation it is usual to anticipate an 'S' shaped curve; a slow initial take-up (Bright 1972), followed by a steady rate of take-up, with the last farmers only adapting after a long period, if ever (Morris and Hess 1986). If the rate of take-up is anticipated to be slow then the scheme is less likely to be efficient. Assessing who will take up the predicted change is then critical in assessing the rate of take-up: are some farmers more likely than others to change their farm management practices, and which groups of farmers? Changeover between generations is often a time when the young farmer is prepared to make changes in farm practices which the elder generation did or would not consider (Morris and Hess 1986). At the same time, it is necessary to examine what are the potential barriers to farmers taking up a new cropping pattern. These barriers can include a lack of knowledge, a lack of access to affordable credit, or no access to the market for the crops which are to be produced. The possible responses by the farmers to the proposed change in the water management regime are best understood by talking with the farmers themselves.

The proportion of farmers who are prepared to change will depend in part on the change that they perceive in the risk schedule that they face. In the UK, with relatively large-scale farms, a reduction in the risk of flooding from 1 in 5 to 1 in 10 is usually adjudged to be sufficient for a wide-scale shift in farming practices to occur (Morris and Hess 1986), in part because the other risks of drought, disease, pests and so forth are either low or controlled through pesticides, coupled to a subsidy regime that reduces risks. Thus, land drainage provides a relatively large reduction in the total risk schedule that they face. Other farmers in other countries may be considerably more risk averse or the change brought about by drainage or irrigation may be considerably less in the total risk that they face.

17.3.5.3 Evaluating changes in output

In evaluating the changes in output resulting from the regime change, or land drainage, it is necessary to first correct for own nation distortions in farm gate prices by netting out the effective national subsidies. Where the basis of evaluating the increased yield or change in cropping is to be world prices, it is then necessary to correct for distortions in world prices (Black and Bowers 1984); unfortunately, world prices in many agricultural commodities are thin and world prices are in any case distorted by other countries' subsidisation of their own agriculture. It is also necessary to correct the exchange rate (Squire and van der Tak 1975). One consequence is that the prediction of future movements in the real exchange rate can become critical in assessing the economic efficiency of the scheme (Rayner *et al.* 1984). If the realistic expectation is of a worsening exchange rate against the reference currency, then any project which either results in import substitution or increases exports is more likely to be efficient than if the likelihood in the medium term is of a rising exchange rate.

17.3.6 Externalities of irrigation

The necessary starting point in the evaluation of any new irrigation scheme is: how will the water be collected and transported? The disbenefits of any requirement for a new storage reservoir will require to be evaluated. These disbenefits include possible environmental losses and the displacement of population to make way for the reservoir (WCD 2000). Abstraction from any contained aquifer may also have disbenefits in the form of subsidence of the land above. Pumping in excess of the rate at which that groundwater is renewed is obviously only possible for a limited length of time and raises the question of what will happen to the irrigated area when the groundwater is exhausted. Pumping from unconfined aquifers will usually have environmental consequences as the rivers and wetlands fed from the aquifer dry up. Diverting water may reduce wetlands which typically have a high environmental value.

The transfer of water may have a number of consequences which will depend on the distance over which the water is transferred and whether the water is then mixed with local waters; waters may differ by their temperature, hardness and other factors and the receiving ecosystem may be damaged by the change in the physical-chemical characteristics of the water as well as by the change in flow regime. The linkage of previously unconnected waters may also allow species to move too; there are increasing problems with introduced species and transfer canals, tunnels or pipes may allow these to spread further. Static water is also a good breeding ground for some forms of insects, notably malarial mosquitoes and in Africa, canals and drains serve as breeding grounds for the bilharzia-bearing snails. The canals or pipes will also obstruct both human movement and animal movement including migratory travel.

In developing countries, the use of lands proposed for irrigation is often complex both in socio-economic and environmental terms, and in ways which are not necessarily immediately apparent. Wetlands are often of both high environmental and functional value (e.g. Seyam *et al.* 2001) providing fisheries that are an essential contributor to the local diet. The drainage water from the irrigated areas will often have an enhanced content of salts which may damage the ecosystem of downstream areas, particularly if the drainage water also carries away excess nitrates from fertiliser applications and pesticide runoff.

17.3.6.1 Improvements in the efficiency of an existing irrigation scheme

What is efficiency? Discussions of the efficiency of irrigation combine two elements: loss and productivity. Only some of the water withdrawn actually reaches the plant with the rest being lost through leakage, evaporation and as drainage water. Assessments of the productivity of irrigation water are conditional on the quantity and temporal distribution of all other inputs. In turn, it may thus be better to change the distribution and quantity of other inputs rather than the irrigation regime. Thus, discussions of the efficiency of irrigation are complex

(Kloezen and Garces-Restrepo 1998) and to be useful, multiple measures are necessary, with different decisions requiring different performance indicators. Consequently, various methods of measuring the efficiency of use of water for irrigation have been proposed (e.g. Bos and Nugteren 1990). The proportion of water supplied which is converted into either enhanced crop or a reduction in other inputs can generally be increased but at the cost of increases in capital intensity or in other inputs.

Three possible techniques for improving the efficiency of a scheme are then:

- reducing losses during transfer by, for example, canal lining;
- improving management of irrigation waters by, for example, a shift in application technology; or
- improved water management and cropping by the farmer as the result of an information or educational programme (timing and amounts).

But some of the leakage during transfer may serve to recharge groundwater which is then used for other purposes and the drainage water may be reused by other abstractors or the natural systems downstream. Therefore, a whole catchment approach must be adopted to assessing losses (Chapter 14); what is apparently an inefficient leaky canal may in effect be a very effective way of recharging groundwater (Seckler 1999), as may paddy fields (Seckler *et al.* 1999). In India, Seckler (1999) notes that approximately half of the recharge of the aquifers is from the outflow of irrigation systems.

Sprinkler and drip irrigation are usually argued to be more efficient than the different forms of flood irrigation (Postel 1992). However, the real efficiency measure here is what is lost in evaporation before reaching the plants since runoff flows will be captured by the drainage system and are available for use downstream. It is therefore undesirable to reduce apparent losses through runoff at the cost of increasing evaporation losses. In addition, drip irrigation is not suitable for all crops (Brooks 1996).

Of the water that reaches the plant, some of it is delivered at the wrong times in the wrong amounts to the wrong crops so the productivity of the water may be low as compared to the optimum. That groundwater irrigation is generally found to be twice as efficient as surface water irrigation (Chambers 1988; Estrela *et al.* 1996) is probably a reflection of the greater ability to control when and how much water is delivered through groundwater irrigation: irrigation from groundwater has increased rapidly as real energy costs have fallen so that now 50% of irrigation in India is from tube wells (Crosson and Anderson 1992). Conversely, the travel time for water released from storage is typically about 3 km/hr so that, for example, water released from the High Aswan Dam takes 10 days to reach the delta areas (Keller *et al.* 2000). Better control over the timing of deliveries and application of water can reduce water usage by up to 50%. Where there is uncertainty, farmers may apply more water than necessary to provide a buffer against the next delivery being either late or too small in volume.

This ability to match supply to demand can to some extent to be mirrored by local small-scale reservoirs where these reservoirs are either fed from a main large remote reservoir (Keller *et al.* 2000) or where they collect local rainfall, notably the traditional tank systems of India (Agarwal and Narain 1997) and Sri Lanka (Mendis 1999). Moreover, a major benefit of some large-scale canal irrigation systems is now seen to be the recharge of groundwater through leakage from canals (IWMI-TATA 2002).

Moreover, unless the other inputs to the growing process are also optimised, then the productivity of the water will also be less than could be achieved. Just improving farm management skills via farmers' organisations can improve irrigation efficiency by 10–15% overall and productivity by up to 30% (Xie *et al.* 1993). Opinions differ as to whether it is sensible to make comparisons between areas in terms of the efficiency of water use rather than to compare different irrigation options for one area of land. In general, in developed countries a more efficient outcome is likely to result when capital is substituted for operating costs because capital is relatively cheap and labour and other inputs are relatively expensive. Conversely, in developing countries because capital is expensive, high inputs are usually more efficient than increasing capital intensity. Equally, high capital intensity is associated with high inputs of skilled labour which are also likely to be scarce in the developing countries.

Scale Across the world, the majority of farms are small, especially subsistence farms. However, such farms produce the majority of food in the world; thus, for example, one million small farmers produce 80% of the food production in Africa. In turn, both irrigation systems and possible methods of improving irrigation efficiency must meet the needs of these small farmers; a small farm translating into both a scarcity of capital and systems suitable for small areas of land.

Low-cost groundwater pumps are particularly useful in raising the incomes of near-subsistence farmers. Although treadle operated pumps were reported in China in 1210 AD (Braudel 1974), these were first introduced in the modern period in Bangladesh and are able to irrigate an area of up to 0.24 ha. In Zambia, farmers' incomes increased from US$125 with bucket irrigation to US$850–1700 with treadle pumps; cropping intensities rose by up to 300%. Similarly, in the Niger, where treadle pumps replaced hand pumps, the average irrigated area per farm rose from 0.17 ha to 0.24 ha, and incomes from US$109 to US$312. In Kenya, where irrigation with a bucket was replaced by a treadle pressure pump, cropping intensities rose to 2.7 per year, irrigated areas per farm from 0.1 ha to 0.27 ha and farm income rose from US$80 to US$690 (IPTRID 2000).

Distribution systems are faced with the same problems; traditional flood irrigation requiring little capital investment. There have been attempts to develop small-scale irrigation systems that are affordable (Polak *et al.* 1998) or institutional systems such as co-operatives may enable small-scale farmers to buy and use more efficient equipment.

17.3.7 Agricultural drainage

Both natural rainfall and excessive irrigation can cause crop losses through water logging, as well as possibly other problems such as salinisation (Postel 1992). Some 500 million hectares of arable land are not adequately drained for optimal production (FAO 2000), largely because of the expense: subsurface drainage in the form of tile drains is particularly expensive with figures of US$1500–3000 per hectare being given for Australia.

In most cases, the purpose of agricultural drainage and its benefits are the same as for irrigation and the economic evaluation of these benefits follows the same procedures. Whether irrigation, irrigation and drainage or drainage alone is required depends partly upon the climate and partly upon cropping. Thus, for example, the Fens of eastern England were first reclaimed from the sea and drained (Purseglove 1988) and are now increasingly being irrigated as well. As Table 17.4 shows, the response of crops to drainage shows a very similar pattern to that found for irrigation: the greatest gains are when cropping can switch to horticulture.

17.3.7.1 Flood losses

Flood and recession irrigation is a traditional form of irrigation (e.g. Shaw 1984), and one that is still quite widely practised in some parts of the world (Marchand 1987). Thus, for example, Paul (1984) points out that in Bangladesh rice paddy farming depends upon some flooding, and varieties of rice that are adapted to relatively deep water flooding are used. Hence, it is only the extreme floods that cause problems. Floods may bring other benefits; for example, the addition of silt or blue-green nitrogen-fixing algae which will improve soil fertility (Brammer 1990). In turn, this means that it is necessary to look across several years of

Table 17.4 *Economic benefits of land drainage in the UK*

	Economic net return (£/ha drainage status – 1997/98 prices)		
Land use type	good	bad	very bad
Extensive grass	−73	−81	−103
Intensive grass	320	245	131
Grass/arable rotation	283	215	115
All cereal rotation	280	217	109
Cereal/oil seed rotation	329	263	165
Cereal/root crop rotation	280	217	109
Horticulture	1500	750	109

Source: Dunderdale 1998.

crop figures in order to assess flood losses to crops as yields may increase in the following year as a result of these flood-induced improvements in fertility. Conversely, floods may also deposit sand, as did the 1993 Mississippi flood (Galloway Report 1994), with a consequent reduction in soil fertility.

In addition, crop losses are usually reported as financial losses (Galloway Report 1994) and hence markedly overstate the economic costs of losses; what is lost is the economic value of the crop minus the variable costs that would have been committed even if the flood did not occur. In turn, under subsidy regimes, the real economic value of the crop can be markedly less than the financial value. Equally, it may sometimes be possible for the farmer to plant a different crop after the flood which will give a return that makes up some of the losses to the standing crop during the flood. However, irrespective of the loss to crops, the loss of livestock and particularly of draught animals in floods can still have severe consequences. Equally, to poor farmers, the loss of one crop may be sufficient to destroy their capacity to plant in a subsequent year, particularly if they have had to go into debt to buy the seeds and other inputs for the crop that was lost in the flood. To the farming family who are now destitute it is of little compensation that from a national economic perspective those who take over their land will get a bumper crop next year.

Hess and Morris (1986) provide the following equation to estimate the losses caused by flooding to arable crops:

$$L = Y + (P_r \times RC) - (P_h \times HC) + REM$$

where:

Y is the loss of output (reduction in yield times price);
P_r is the annual probability of the need to reseed;
RC is the cost of reseeding;
P_h is the annual probability of complete harvest loss;
HC is the cost of harvest and inputs avoided because of flooding;
REM are the post-flood clean-up costs.

For the flooding of grassland and other animal feedstuffs, Hess and Morris (1986) then give the following equation:

$$D = GMJ \times RF + C$$

where:

GMJ is the energy from grass lost due to flooding (MJ/ha);
RF is the cost of replacement feed (£/MJ); and
C refers to the other costs incurred.

Care is also needed to distinguish between losses that are the result of poor drainage and flood losses; rises in groundwater levels into the root zone, or

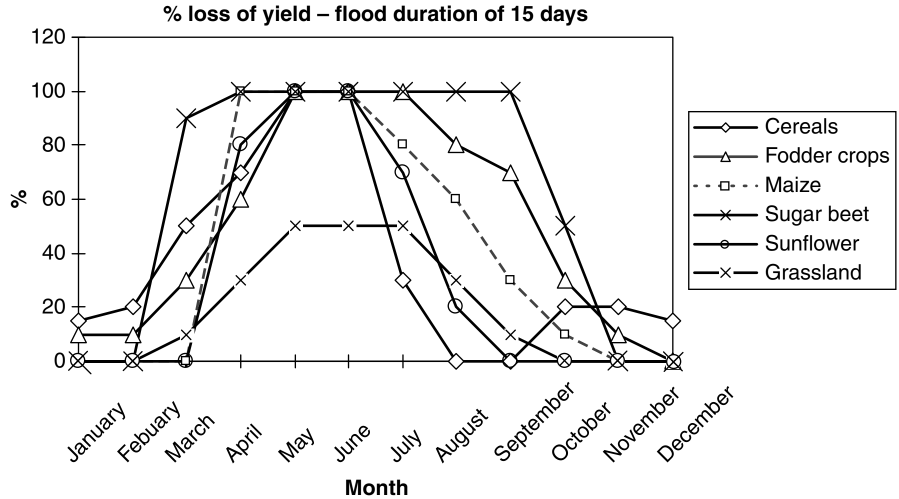

Figure 17.4 *Agricultural losses from flooding in Hungary. Source: Podmaniczky 1999*

standing local rainfall, have often damaged or destroyed most of the value of the standing crop before the land is flooded from the nearby river (Hong and Zhang-Yu 1999). For example, the drainage system, and particularly the pumping system, of a polder will not usually be designed to cope with a rainfall greater than that with a 10- to 20-year return period whilst the polder dikes may be designed to contain river flows with a return period of 50 to 100 years. If local rainfall accompanies high flows in the river, then the crops will have been damaged before the dike fails. A significant fraction of the crop losses in the 1993 Mississippi flood appear to have been losses from local rainfall and drainage problems rather than flood losses (Galloway Report 1994).

The extent of the crop losses due to flooding then depend upon the point in the growing season at which the flood occurs and the duration of the flooding, and to a lesser extent on the depth of flooding. In turn, the critical months for flooding differ between the northern and southern hemispheres (Figures 17.4 and 17.5).

17.4 Charging for Irrigation Water

Having determined what is the cost of the water supplied for irrigation (Chapter 7), the question is then how to recover that cost. The general rule is that the cost of controlling access to a resource and recovering the costs should not exceed the benefits of doing so. Applying marginal cost pricing will be easiest and most likely to be viable when water is supplied by pipeline, by elevated canals or from boreholes and in developed economies where the capital and maintenance costs of water meters are relatively low. Furthermore, transaction

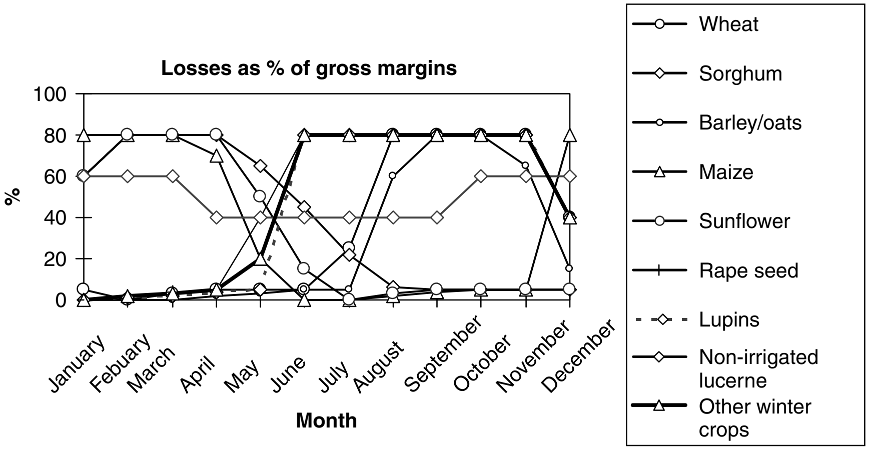

Figure 17.5 *Agricultural losses from flooding in Australia. Source: Higgin 1981*

costs as a function of revenue show economies of scale: the costs of charging a few big users are considerably less than charging many small users for the same total amount of water.

Secondly, it does not follow that excessive use is simply the result of too low a price: salinisation of soil as a result of over-irrigation is an observable problem with a high associated cost; the implication is that the farmers do not know what is the marginal value of water since they are applying water beyond the point where it has a negative marginal value.

In systems when water is simply available in open channels from which it is then moved on to the land which is to be irrigated, it is difficult to measure how much water is being abstracted, the necessary first step to applying marginal cost pricing. In some cases, a marginal cost mechanism is in place in that the water must be physically lifted from the supply canal on to the land using human, animal or mechanical power. Thus, for example, in Egypt, the farmer has an incentive to minimise the use of irrigation water because the labour or other costs of lifting water are significant. In principle, where mechanical or electrical power is used for lifting, taxation on the lifting cost could be used as a surrogate for marginal cost pricing of water, but such a tax would spill over in other, possibly undesirable, directions. Even where volumetric charging is feasible in theory, it will require meters which must be maintained by scarce skilled labour and possibly the import of the meters themselves.

Alternative cost recovery mechanisms are charges per unit area of the farm or taxes based upon the notional value of the improvement in land value or on the notional crops produced (Johansson n.d.). These mechanisms may provide an incentive to the farmer to change the cropping pattern; they do not provide any incentive for the farmer to make the best use of available water.

One way round the problem is the conversion of state-run systems to farmer-run organisations (e.g. Bruns and Atmanto 1992). If farmers as a group are required to pay \$$x$ for a bulk quantity y of water then they have some incentive to spread that cost over a group until the size of that group z is such that the marginal value of the water to the individual farmer is equal to x/z. The group then has an incentive to ensure that water is properly allocated since one farmer can only increase his or her allocation at the cost of the other farmers. The individual farmer also in theory has an incentive to make the best use of the quantity of water for which she or he has paid both in terms of cropping and in application of that water. However, it is not yet entirely clear that water is used more efficiently in water user associations than in conventional state-run irrigation systems (Vermillon 1997).

A possible way of introducing an incentive for farmers to use water efficiently is to require them to provide on-site storage of water. Since this will take up land which could otherwise be used to grow crops, they are then provided with an incentive to make the most efficient use of water and so minimise the land requirement for storage. In England, in recent years, new licences for irrigation have often been limited to winter abstraction, when the rivers are in flood, so farmers have been effectively compelled to build on-farm reservoirs.

17.5 Tradable Entitlements to Abstraction

Tradable entitlements have proved to be a very successful way of reducing the costs of air pollution abatement (Opschoor and Vos 1989). Consequently, it is not surprising that their application to water abstraction has been recommended (e.g. Howe *et al.* 1986), or that they have been tried in some countries (e.g. Pigram *et al.* 1992).

Tradable entitlements to abstraction have been proposed for a number of reasons:

- The existing allocation of entitlements to abstract water is inflexible and incapable of responding to changes in uses and to the relative values of those uses (this is particularly the case where agricultural uses have established an entitlement to abstract and consequently consume the majority of water available, but where the value of this water is relatively low compared to expanding urban uses).
- The theoretical efficiency gain from their use relative to administrative methods.

Whilst some reallocation between agricultural uses is foreseen to result from the introduction of tradable abstraction permits, generally the main reason for proposing their introduction is so that water is transferred from agricultural to urban uses.

The extent to which the first problem has been created depends upon the system of water law that exists; the Prior Appropriation doctrine in the western United

States (Wright 1990) was a remarkably successful means of bringing water into use. However, most of the 'First in Time, First in Right' entitlements created under the doctrine were for agricultural uses and the only way that existed to reallocate water to other uses was to buy the land to which the water entitlement was attached. Hence, some urban areas have been buying farms in order to acquire the entitlement to use the water (Chang and Griffin 1992). Equally, overallocation of water has resulted in environmental damage. So Landry (1998) has made the rather bizarre suggestion that those who believe that rivers should support trout, should buy water entitlements from the farmers who are abstracting unsustainable amounts of water that render the rivers unable to support trout. In countries where other systems of law exist, notably Islamic or Spanish colonial law (Section 8.1.1), effective legal mechanisms exist to reallocate water and the only reason for creating tradable entitlements to abstraction is then the possibility of efficiency gains.

A distinction must also be made between the nature of the resource that supports the abstraction. Groundwater is treated as an open access resource in most countries so, whilst active markets exist in a number of countries for the sale of abstracted groundwater (Shah 1993), these are not examples of a system of tradable entitlements to abstraction. The two other systems of resource are then entitlements to abstract from the run of the river, and abstractions that are supported by reservoirs and distribution systems. In the latter case, the obvious first step is to eliminate subsidies to irrigation; in turn, this should both free up some water for other uses and drive up the efficiency of use. Hence, the key test of tradable entitlements in unsupported abstractions.

17.5.1 Experience with tradable entitlements to abstraction

The country with greatest experience in the use of tradable entitlements is Australia and it is also the country where they seem to have been most successful. Pigram (1999) reports that in the four states involved, trades have involved 5–10% of total water use. However, most of the trades involve a temporary leasing: in the Goulburn-Murray Irrigation district in 1997/98, some 250 000 ML were leased (8% of total water use) and only about 25 000 ML were permanently traded, 1.1% of the total entitlement (Earl and Turner 2000); by 1996, some 20% of irrigators had been involved in some sort of trading. Similarly, the majority of transfers in New South Wales have also been on a temporary basis; for example, in the Macquaries valley, cotton planters drove up the price from A$80 to A$120 for the last watering (Department of Land and Water Conservation 1999). Consequently, in Australia as a whole, the majority of transfers were temporary: over 800 000 ML in 1994/95. Trading is very largely restricted to supported catchments in New South Wales but trading has increased by over thirteen-fold since the 1993–94 season (Department of Land and Water Conservation 1999). As the Department goes on to observe, since government policy is to adjust entitlements downwards to match available resources, the price will rise: consequently, it makes sense to hold on to any entitlements or to lease them rather than to sell them now.

On the down side, only 40% of volumes traded in Victoria resulted in increased or reduced water use so the remainder were of unused entitlements (Earl and Turner 2000). Bjornlund and McKay (2000) also report that a significant proportion of the trades involved sleeper or 'dozer entitlements': ones not currently being used by the seller. In turn, Smith (1998) reports that the effect of such trades was to increase total abstraction in a single year. However, for some time previously, the pattern of development of water use had been one of the activation of sleeper permits (Department of Land and Water Conservation 1998). In turn, the Murray–Darling Basin Ministerial Council announced a cap on diversions from the Basin in order to protect downstream rights and also to reduce the stress on the aquatic environment. This cap was then set at the level for the 1993/94 season for each valley.

However, Bjornlund and McKay (2000) also report that there was a shift of water towards efficient irrigators although this was within existing farming practices. The Department of Land and Water Conservation (1999) reports that 49.3% of water sales in South Australia were from lucerne and grain, with another 13.3% from dairy pastures whilst 26.9% of buyers were vineyards and 38.1% were engaged in horticulture. Thus, water was being traded away from low valued agricultural uses towards high valued uses. A similar pattern was found in Victoria although the trades were largely within the livestock industry but away from meat towards dairy production. In addition, tax provisions are thought to influence the pattern of sales/leases: leasing water on an annual basis can be offset against income tax but the purchase of a permanent entitlement is not tax deductible, whilst the leasing out of water can be offset against expenses for tax purposes whereas a sale might attract capital gains tax. Australian irrigation is also supported by reservoirs and effectively an entitlement is then a share of capacity sharing versus release sharing (Pigram 1999). Although charges for irrigation have been increased, the level of charges does not yet cover the full costs of providing for the storage and the distribution of irrigation water (Musgrave 2000).

The other major experiment in tradable entitlements to abstraction has been in Chile. Quite different views are held about the relative success of this experiment (e.g. Bauer 1998; Briscoe *et al.* 1998). But, in the upper Maipo and Elqui, there have been relatively few transactions, with sales in the Elqui being sales out of agriculture of water not previously used – sleeper rights (Hearne and Easter 1995). Although in 1992, 85% of sales were from agriculture to urban areas, these accounted for only 3% of sales by volume and only provided sufficient water to supply 10 000 customers (Brehm and Castro 1995). As in Australia, the majority of trades were leasing rather than sales (Brehm and Castro 1995). Transactions of the Limari river were relatively frequent but here irrigation is supported by a reservoir and there is a publicly provided infrastructure by which the water can be transferred (Hearne and Easter 1995). Davis and Lund (2000) argue that in the other, short and steep valleys, it is difficult to transfer water. Sales of water entitlements to mining companies are reported to have resulted in increased usage (Bauer 1998).

Two significant failures in the strategy to create tradable entitlements in Chile are, firstly, that there was a failure to establish a clear record of who held what entitlements and the way in which these entitlements were initially distributed (Brehm and Quiroz 1995). Secondly, there is no cost associated with holding an unused entitlement, so there is a tendency to hold on to such entitlements rather than to sell them (Solanes 1999).

Rather more limited experiments have been conducted in the USA (Howe *et al.* 1986) although the Colorado studies may be said to have started the interest in the approach. Outside of Colorado, on the Lower Rio Grande in Texas, sales of sleeper permits away from agriculture are reported (Chang and Griffin 1992). 'Water banks' then offer a way of lubricating the sale or leasing of water entitlements. The Texas Water Development Board water bank, established in 1993, allows the holders of water entitlements to deposit up to half of their allocation to the bank for others to buy or lease; rights placed in bank are protected from cancellation for nonuse for an initial 10 years. In Idaho farmers with surplus entitlements lease more than 100 000 acre-feet annually through water banks (Bowman n.d.).

During the drought of 1991 to 1992, a Drought Water Bank was established in California and this actively sought for purchases, offering a price of US$125 per acre-foot: 369 water transfers were made through the bank, totalling just over 1 million acre-feet of water. Of that amount, some 414 000 acre-feet of water were released from fallowing but 420 000 acre-feet were from groundwater (Department of Water Resources 1993). The experience of that bank illustrates some of the problems in ensuring that what is sold or leased is 'real water' rather than 'paper water' (Seckler 1996), and it was found that each deal had to be evaluated separately in order to ensure that only 'real' water made available by reducing losses or flow to unusable water bodies was actually being purchased. Paper water then included return flows that would otherwise have been used by downstream appropriators, which also revealed an additional problem in that irrigators can measure how much they put on to the fields but have to guess what they lose through evapotranspiration or, alternatively, the quantity of drainage water. The California Department of Water Resources reported that the bank and potential sellers often had different views of these hydrological realities (Department of Water Resources 1993). The problem of paper water transfers is a major one: there must be a suspicion that the transfer of some water entitlements from the Imperial Valley irrigation district in exchange for the lining of some irrigation canals (Postel 1992) was something in the nature of a paper transaction with the real losers being those who were using the groundwater recharged by leakage from the canals.

17.5.2 Transfers out of agriculture

If towns can buy farms in order to acquire that farm's water entitlement, then is there an advantage to separating the water entitlement from the land? In the case of arid land, effectively the entire value of the land for agricultural purposes will be determined by its access to water. More generally, for the farmers to be prepared to sell some or all of their entitlement to water, then, unless they are not currently using all of their entitlement, they have to reduce their use of water. The possibilities are:

1. Fallowing the land.
2. Switching to dryland farming.
3. Shifting to crops that require less water.
4. Increasing the efficiency of irrigation.
5. Retiring from agriculture and converting the land to other uses.
6. Constructing on-site storage so as to shift demand to high flow periods when abstraction entitlements can be more cheaply acquired.
7. Using groundwater instead of surface water if controls, possibly including tradable entitlements, are not also imposed on the use of groundwater.

For the outcome of a system of tradable entitlements to be advantageous, then the circumstances under which farmers sell some or all of their entitlements need to result in a desirable outcome. The conventional assumption would seem to be that the farmer will adopt strategy 2, 3 or 4. But the farmer has other options, some of which are undesirable from the wider perspective. If the farmer is contemplating retiring from farming then attractiveness to the farmer of selling the water entitlement and land separately will depend upon the relative states of the two markets. If prices of agricultural land with or without water are low, but the market for water for urban uses is strong, then it is logical to seek to sell the two separately, provided that the premium for urban uses exceeds the difference in the price of agricultural land with and without an attached water entitlement. If the difference in the value of agricultural land with and without a water entitlement is large, then it should be expected that there will now be strong pressure to convert that land to another use. So, we should expect farms on urban fringes to sell the water and develop the land.

To avoid perverse incentives, then it would be logical to require all developers of land to purchase a water entitlement sufficient to provide the water needs of that development. If this is not done, then it would be open for a farmer to sell the water entitlement, develop the land for urban purposes and then require the municipality to supply that development with water. Under some circumstances, the municipality would be left worse off under this arrangement than before; if the farmer had an entitlement to 50 cm per square metre but the development had a density of 60 people per hectare, each of whom uses 250 l/p/d, the water requirement per hectare of land increases after development.

Finally, the farmer may switch from surface water irrigation to abstracting groundwater. This is what seems to have been the basis of a proportion of the transactions with the water bank set up in California during the 1987–1992 drought (Department of Water Resources 1993). Such a switch is clearly a danger particularly where groundwater is an open access resource and especially when the aquifer is unconfined.

More generally, as Davis and Lund (2000) have pointed out, agricultural and urban supplies are associated with very different levels of risk; the risk of unavailability of supply that is acceptable to a farmer is quite unacceptable for urban uses. Even when irrigation is supported by a reservoir, the design drought for that reservoir is typically a much lower standard than would be required for urban uses.

17.5.3 Tradable entitlements?

For a market approach to be effective, there are a series of conditions that must be satisfied:

- There must be many different and relatively small potential purchasers and sellers of water if there is to be effective competition.
- There must be heterogeneity of demand particularly over time – if the entire demand is from potato growers then there are unlikely to be any gains from trade since all the farmers require water at exactly the same time and all have a very similar scope for using water more efficiently.

The hidden element in the standard definition of the conditions for the perfect competitive market is that whilst the pool of sellers and the pool of buyers are both individually homogeneous, the two populations are different. The primary assumed difference is that one produces and the other consumes. But a market for water abstraction is a market between consumers; by analogy, it is as if loaves of bread were first to be shared out between consumers and then consumers were to be left to trade bread with each other.

In such a market for tradable entitlements, there have to be sufficient differences within the common pool of potential sellers and buyers so that some are prepared to sell in order for others to buy. If the pool is completely uniform, there will be no one prepared to sell and hence nothing to be bought. Unless there is a reason to believe that the pool is heterogeneous, then there is no purpose in introducing a system of tradable entitlements. These are the conditions necessary to create an approximation to a perfectly competitive market and they are likely to limit potential use of tradable entitlements to relatively large rivers, or where there are marked differences in the quality of the soils in different areas, or differences in access to markets. In the latter case, there are likely to be sales of water away from farmers on poor soils and with limited access to markets towards those who can, for example, plant vines or engage in horticulture. Thus, in New South

Wales, the gross margin on water use is A$25/ML for wheat in the Macquarie Valley versus A$1289 for avocados, A$2456 for macadamias and A$2917 for Murcott mandarins, and A$2917 for vines in the Hunter valley (Department of Land and Water Conservation 1999). But critically the higher gross margins are associated with permanent plantings and the demand is for high security water rather than the low security water which is acceptable for wheat farming.

If these conditions are met and a tradable entitlement approach is feasible, then a further series of decisions must be made:

- At any point in the catchment, the individual demand must be low relative to supply in the river at that point otherwise location effects will be significant – for example, if the demand is shifted upstream by a trade then the impacts will be different to that same demand being shifted downstream.
- It has been found necessary to ensure that there is a cost to holding a water right (Solanes 1999) otherwise holding rights is an effective way of blocking the entry of competitors into the market. If water is currently subsidised, then it is more logical to eliminate those subsidies rather than to try a band-aid approach of introducing tradable entitlements.
- If a private property right to water abstraction does not already exist then a decision has to be made as to how tradable entitlements are to be allocated initially. In Chile, when the state monopoly hydroelectric power company was privatised, it was allowed to take with it all its existing water rights. As a result, it is able to exploit its monopoly position (Solanes 1999). A tradable entitlement where there is an active market will necessarily be of a higher value than an existing right. Therefore, those with existing rights can be offered the choice of either keeping their existing fixed right or exchanging it for an entitlement for a lower but tradable amount. Alternatively, the entitlements could be auctioned with the sums raised being used to extinguish existing rights; this option also allows scope for cutting down the total permitted volume of abstraction to what is either realistically available or sustainable. It also avoids giving a further subsidy to agriculture as is the case if farmers are simply awarded a tradable entitlement equal to their current right to abstract.
- Whether environmental requirements are to be top-sliced from the available sustainable flows or environmental requirements are to be met through purchase in the market (Department of Land and Water Conservation 1999; Landry 1998). In the latter case, there is then the question of how such purchases are to be funded and the sum that is to be made available to fund such purchases (Morris *et al.* 1997).
- A decision has to be made as to what a right is to consist of; whether it is to a proportion of the flow at particular times in the year, or whether there are to be layered rights to particular quantities of water if that water is available. Since there will usually be more water available at one time of the year than another, rights will also need to be specified in terms of a quantity in a given month or perhaps season; furthermore, whether this right is as to the amount

that can be abstracted or as to the amount that can be consumed (e.g. net of return flows).

- These rights have to take account of possible changes in the amount of water available either because of changes elsewhere on the catchment that will change runoff, as a result of climate change, or because flows were miscalculated in the first place. Solanes (1999) reports that present applications for water amount to four times total exploitable resources available in Chile.
- A system for both enabling trades to take place and to monitor compliance also has to be established, along with an enforcement regime. This is unlikely to be less costly than a conventional licensing regime, particularly if rights are to the amounts consumed rather than to the amounts abstracted.

Transfer of an entitlement to abstract water from one basin to another is unlikely to be practical and transferring water from one basin to another will tend to create additional externalities. In addition, unless the flows in the river or canal are large then there are practical limits to the amounts that can be transferred up or downstream. A hypothetical irrigation system is shown in Figure 17.6.

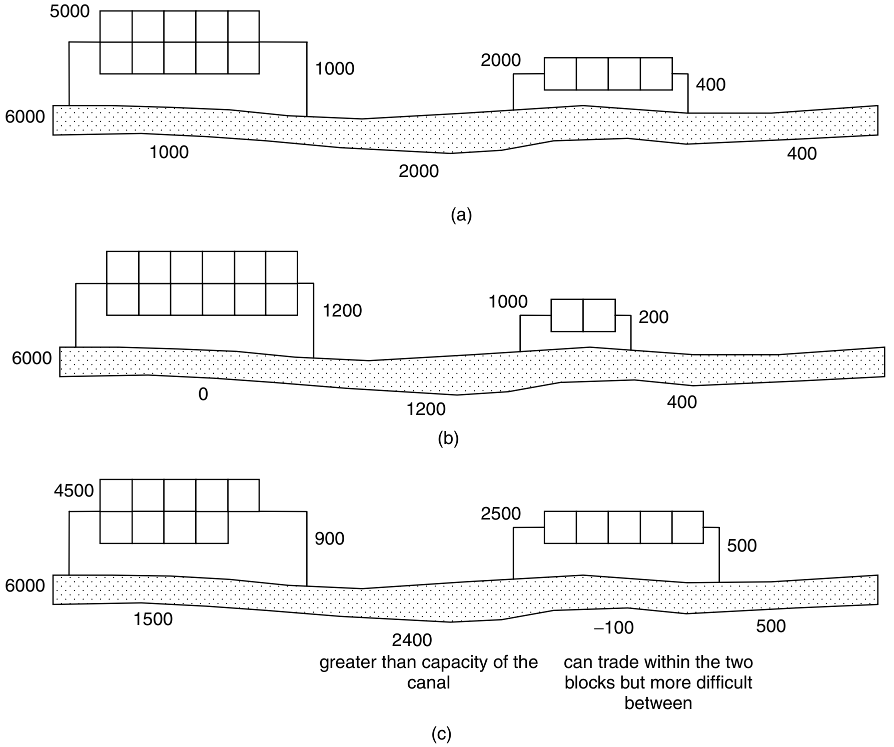

Figure 17.6 *Hypothetical catchment and irrigation*

There are 10 farmers in the upstream irrigation district and four farmers in the downstream district; each farmer abstracts 500 units of water and returns 100 units as drainage water to the irrigation canal. Consequently, out of the 6000 units of water available in the system, total utilisation is 7000 units of water. In Figure 17.6b, two of the farmers in the downstream irrigation area have sold their total entitlement to farmers in the upstream irrigation district. This is the maximum it is possible to sell because only 6000 units of water enter the main irrigation canal. As Figure 17.6c shows, it is not physically possible for a sale to occur from the upstream to downstream block; a cut of 500 units of abstraction to the upstream block only increases the flow to the downstream block by 400 units. Moreover, if the main irrigation canal was only designed to have a capacity of 2000 units then it would be impossible to transfer the additional amount to the downstream area.

If instead of a canal, the main irrigation water distributor is a river, then in the baseline condition it is already very badly degraded; if water entitlements are traded from the downstream area to the upstream area, then further damage is done to the ecosystems dependent upon the flow, with one section of river running completely dry. Since the geomorphological form of a river is a function of its flow, the river channel would be expected to degrade and narrow as a consequence of the lower flows in this section so that the natural capacity of the channel is decreased. In turn, this might result in an increased flood risk in the areas neighbouring those stretches of the river. Either effect might be sufficiently large to overwhelm any apparent gains from trade.

In this hypothetical example, there is limited scope for reallocating water between the two irrigation districts. Transaction costs would be expected to be quite high since it will be necessary to determine whether the transfer involves real and not paper water, to assess the environmental externalities associated with any change, and any side effects such as an increase in flood risk. The marketplace will not be able to take care of these effects because the farmers cannot be expected to have knowledge of the hydrological functioning of the canal or river as a whole. This example illustrates that there can be a conflict between the principle of holistic catchment management so as to maximise the efficiency of use of the catchment as a whole and the approach of piecemeal local optimisation that forms the basis of the tradable permits approach. As the basin approaches closure, the impacts on the functioning of the basin as a whole from one small change will tend to increase. However, it is precisely when the basin is either closed or approaching closure that we need to make improvements in managing it.

These problems do not exist or not to the same extent for trades within the two irrigation districts and so more trades are likely to be possible between the farmers in each of those two districts. Hence this example does provide some clues as to the extent and nature of trades that are likely to take place in the real world.

Case Study 17.1 Tradable Abstraction Entitlements in East Anglia

The Water Resources Act 1963 brought abstractions in England and Wales under a coherent system of control. However, it created two classes of abstractors; those who could demonstrate that they have been abstracting a given quantity of water in the five years prior to 1965 gained a licence of right in perpetuity. There was no provision that the licence would be lost if there was no use made of that abstraction right; however, those licences tied the use of the water to particular parcels of land in the case of licences for irrigation. Licences granted to those who applied to abstract water after 1965 are time limited and a number of conditions may also be applied to those licences. Thus, an inequitable system was created of two different classes of abstractors. Moreover, for some rivers, the abstraction licences allow abstraction of more water than was available (Drake and Sherriff 1987), whilst at the same time, the amounts abstracted are, on average, far less than the amounts licensed. Where those unused abstraction licences, 'sleeper' licences, are licences of right then there would be major problems if the holders of these licences sought to abstract that water.

The Water Resources Act 1991 allows the Environment Agency to introduce restrictions on abstractions during drought years. It also allows the Agency to charge for abstractions; to a base charge rate constant for all forms of abstraction, a series of multipliers are applied that cover the time of year when abstraction occurs, the nature of the source, and the proportion of the abstraction amount that will not be returned to the river. In 1995/96, the basic charge rate in the Anglian region of the Environment Agency was £13.94 per 1000 cubic metres.

Agriculture is not a major user of water in England and Wales, with only supplementary irrigation via spray irrigation being useful in some parts of the country, notably East Anglia – other forms of irrigation (drip, trickle and subirrigation) do not require a licence.

In 1995, the Flood Hazard Research Centre and Silsoe College were commissioned by the Royal Society for the Protection of Birds, an NGO, to conduct a study of the potential impacts of the introduction of tradable abstraction licences. A number of the RSPB's most important reserves are wetlands which could be severely damaged by a reduction in water availability. The Society, whilst broadly favouring the extension of the use of economic instruments, was concerned that the adoption of tradable permits would not result in the activation of some of the sleeper licences.

The area study was in East Anglia and covered *c.* 300 ha RSPB nature reserve at the Nene Washes and 11 861 ha of agricultural land within the Middle Level Commissioners Internal Drainage Board – drainage being essential in the area if the low-lying land is to be put to arable use. The Nene Washes nature reserve is designated a Special Protected Area in accordance with the European Union's Birds Directive; in consequence, the UK is required under European law to ensure that no damage occurs to that site. The agricultural area is one of the richest in the country; the crop pattern at the time of the study being: cereals 54%; sugar beet 22%; potatoes 11%; and grassland 10%. The mean rainfall is 536 mm compared to a PET of 487 mm so supplementary irrigation can be required; this is focused on potatoes, vegetables and soft fruit. The water is taken directly from the river and there is no storage reservoir to maintain flows on that river. The marginal value of that water is very high; for example, £10.20 ha/mm for early potatoes and £42 ha/mm for strawberries (Weatherhead *et al.* 1994). However, of the amount of water licensed for abstraction, only 26 to 57% of that amount is actually abstracted.

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The research plan was first to carry out a series of focus groups with the farmers in the area in order to develop a system of tradable permits that would meet their needs. The intention was then to carry out with the farmers a simulation of a number of annual rounds of trading using that system of tradable permits and individual farm models. However, the results of the focus groups showed that the farmers did not have the knowledge of the current costs and benefits of irrigation for the simulation exercise to be useful. Equally, those focus groups suggested that farmers would only sell tradable rights if they intended to leave agriculture altogether. Box 17.1 lists the issues that were discussed in the focus groups; Box 17.2 summarises the main points that emerged in regard to agriculture and water whilst Box 17.3 outlines the main points made by the farmers concerning tradable abstraction licences.

Box 17.1 Issues addressed in the focus groups

- Should the allowance for the environment be 'top-sliced' or should water for the environment be bid for?
- How should the initial allocation of tradable permits be determined?
- What should the entitlement be under a permit (e.g. amount per month, share of resource)?
- How should the system adapt to future increases or decreases in available supply (e.g. as a result of climate change)?
- Who should administer the scheme?
- Over what area should the permits be tradable?
- Between which classes of abstractors should the permits be tradable?
- Should there be different classes of permit with different guarantees of reliability of supply?
- How should the system be policed?
- Should there also be charges for abstraction?

Box 17.2 Farmers' general views on water and farming

- The existing system is inefficient because abstraction points are tied to particular parcels of land; therefore, farmers often require larger licensed quantities than they actually need.
- The existing system of licensing is difficult to understand, cumbersome, expensive and slow.
- The Navigation Acts dating back to the 1760s impose significant constraints on water abstraction.
- Winter runoff from their land is their water and they ought to be able to keep it for themselves for summer use.
- They see agriculture as being given the lowest priority for water use.

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- The cost of water itself used in irrigation does not feature strongly in financial appraisals of irrigation and is not considered in assessing alternative methods of irrigation: the main costs are pumping and labour.
- An abstraction license adds value to the land.
- Because the farmers are all growing the same crop, they all want water at the same time, especially July and August.

Box 17.3 Farmers' views on tradable abstraction licences

- Tradable permits would mean that water ran out earlier and hence cessation orders would be issued earlier in the season. The threat of cessation makes the value of a tradable permit more difficult to assess.
- Other potential buyers (e.g. the water companies, environmental groups) have more spending power with which farmers would find it difficult to compete. They would not therefore want any trading to be extended outside of the agricultural market.
- Because irrigation is capital intensive, 10 years of certainty is needed to justify investment in irrigation so short-term (annual or seasonal) water leasing is not very helpful.
- The idea of a banded priority system of permits is extremely unattractive because of lack of certainty that water will be available when needed.
- Environmental requirements should be set first by the Environment Agency with water being 'top-sliced' for the environment.
- Permits, like licences, would need to set both daily and annual abstraction limits.
- The cost of water is likely to rise under a tradable permit system.
- Selling water would mean changing the cropping pattern.
- No one will be willing to give up water and therefore tradable permits will not work. Moreover, since water was anticipated to become scarcer in the longer term, they would hold their licences in order to keep their options open for the future.
- Those who would be prepared to sell water would be farmers retiring or leaving the industry and those who invested in on-farm storage and would be prepared to sell any surplus – tradable permits would encourage investment in on-farm storage.
- Any tradable permit system would need policing.

The end conclusion was that freeing up the existing licensing system would achieve most of the potential gains from a tradable permits system. The proposed improvements were to cease to specify the parcel of land to which the water could be applied; to encourage farmers to construct on-farm reservoirs for winter filling; and to allow farmers who had constructed an on-farm storage reservoir to sell water

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to their neighbours. A subsequent, wider study also concluded that there would be few economic benefits from introducing a system of tradable abstraction licences in England and Wales (RPA 2000). Equally, the farmers placed great stress on the need for certainty, whereas the potential gain from a system of tradable permits is that of flexibility and adaptability.

As compared to other countries where tradable permits have been introduced, the notable differences here were:

- Irrigation has not been subsidised nor supported by major infrastructural works and abstraction from rivers instead attracts a significant charge.
- Only supplementary irrigation is necessary and the marginal value of water for that purpose is high compared to its value for domestic or industrial purposes.
- Irrigation is a small proportion of the total demand for water, and in the event of a drought, the first use for which the use of water is restricted.
- The rivers are very small as are the areas across which water could be traded.

The general lesson is that there are no general lessons about the applicability of tradable permits; the solution needs to be tailored to local circumstances and the starting point must be to discuss with the current and potential abstractors what are their needs and requirements.

A review by the government of the system of abstraction licensing resulted in a decision to phase out licences of right, without compensation, so as to bring all licences within a single system of time limited licences with associated conditions (DETR 2000b) and the introduction of strategic abstraction plans for catchments (Environment Agency 2000b).

17.6 Aquaculture

One-fifth of the total value of fish production is from freshwater (Winpenny n.d.) and as wild sea fisheries decline through over-fishing, fish farming is increasing, growth averaging nearly 10% a year since 1984 (Rana 1997). In some areas, freshwater fisheries contribute a significant proportion of the total intake of protein (Brummett and Chikafumbwa 2000) although globally fish provide only a small part of the diet (FAO 1996). The negative impacts of different projects, notably dams, channelisation of rivers, and particularly either the draining or reduction of water supply to wetlands on wild fisheries can be significant. The expansion of shrimp production also frequently involves the conversion of mangroves which in turn play an important role is sustaining wild fisheries. Alternative, the expansion of aquaculture through either combined paddies/fisheries can yield significant economic benefits (MacKay 1995; Halwart 1998), as may the construction or use of ponds or tanks for fisheries, as part of a sustainable livelihood approach (Edwards 2000). The FAO (1997) sets out the framework for the economic appraisal of aquacultural projects.

It is reported that for carp ponds in Germany, discharges of phosphorus and nitrogen are reduced below the levels in the inflow water (Knosche *et al*. 1998), however, intensive fish production systems release quite large amounts of nutrients (European Inland Fisheries Advisory Commission 1998) and the overall inter-relationships between aquaculture and the environment are complex (Barg and Phillip n.d.). However, aquaculture can be more water intensive than irrigation (Boyd and Gross 1998).

Thus fisheries may be proposed as part of an integrated system with arable and other uses, or as a separate and distinct project. In either case, however, the analysis should be undertaken of the change in the system as a whole.

18
Flood Management

In Chapter 14, the importance of treating floods as part of managing variations in river flows was pointed out: in arid regions, the floods are the water resource. Since ecosystems are dependent on the water regime, ideally what we want to do is to maintain the high frequency variations in flows (e.g. 1 to 10 years) but to filter out the extreme flows (Figure 18.1). In practice, this is difficult to do and typically flood alleviation schemes filter out the high and medium frequency events without necessarily having much effect on the extreme events.

The general issues and principles in flood management have been discussed elsewhere (Green, Parker and Tunstall 2000; Green *et al*. 2001). The two most important of these principles are that the objective in flood management is to increase the efficiency of the use of the catchment and not to minimise flood losses; annual flood losses are a misleading indicator of performance (Green, Parker and Tunstall 2000). Secondly, it is necessary to consider how to manage all floods and not just some; it has become common in recent years to design a flood alleviation scheme to some design standard of performance, such as a flood with a predicted return period of 200 years. Instead, it is important to assess what will happen when an extreme flood occurs and how that flood will be managed: in short, to design for failure (Green *et al*. 1993; Green 2002). In the time before formal engineering design, such an approach was generally adopted; in the Netherlands, 'terps', raised mounds of earth, were constructed as places of refuge within the polders. Similarly, in Japan, traditionally dikes have included low points for planned spill areas, *Eturyutei*, and discontinuous sections, *Kasumitei* (Iwasada *et al*. 2000). More recently in such countries as Hungary, dikes have been constructed with demolition chambers in place: in the event of an extreme flood, it will be necessary to deliberately allow some areas to flood in order to protect more important areas. The concept of a design standard of protection is an idea that ought to be abandoned (Green 2002).

The application of benefit–cost analysis is well established in many countries with guidance being given as to the detailed procedures to adopt (e.g. DEFRA 1999; Ministry of Water Resources 1998; River Planning Division 1990; US Water Resources Council 1983). However, the quality of that guidance varies;

Handbook of Water Economics: Principles and Practice. C. Green
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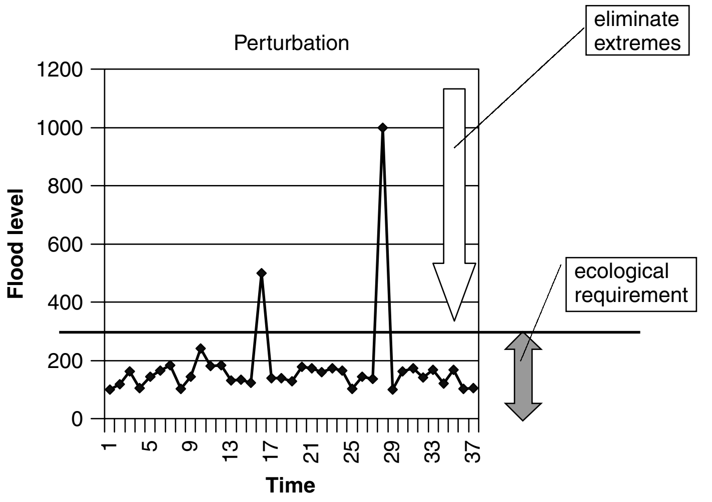

Figure 18.1 *Floods and ecosystem requirements*

for example, that for the USA is very dated and does not require agricultural prices to have the subsidy element removed.

Flood alleviation benefits are the expected value of the reduction in future flood losses; the core of the method is to plot the loss-probability curves under the baseline and do-something options (Figure 18.2): on the x-axis, the exceedance probability of the flood is plotted and the loss from each such flood is plotted against the y-axis. The area between the curves is then the reduction in the expected value of flood losses in the average year at some point in time and this reduction in expected value is then simply discounted back to give the present value. The derivation of the loss-probability curves is thus central to flood alleviation benefit–cost analyses.

If neither the probability of the loss nor the size of the loss changes over time, it is only necessary to do this once. However, flood management is about changing risks and hence the actual analysis will often be more complex; indeed, once some standard data on flood losses has been compiled, the critical part of the analysis is handling the changes in probabilities over time and the differences in probabilities between the baseline and the do-something option. For example, where an existing dike is in a poor state either because of poor initial construction, unsuitable ground conditions or poor maintenance, it is possible that it will fail catastrophically before it is overtopped, this probability of failure in turn depending upon the height of the flood and hence the exceedance probability of that flood. Enlarging and widening that dike will then reduce the probability of failure before overtopping as well as lowering the exceedance probability of the event which will overtop the dike. In general it is necessary to apply a

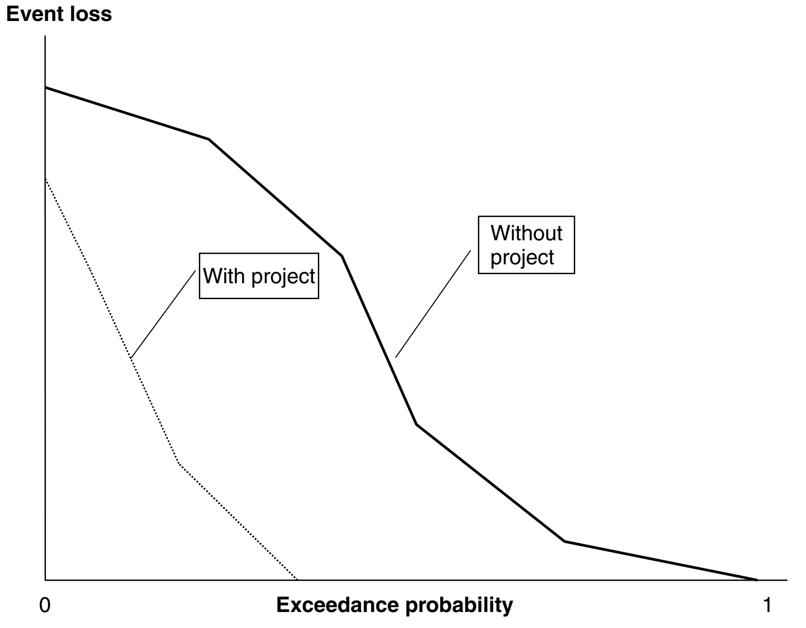

Figure 18.2 *Loss–probability curves*

reliability engineering approach (Kaufmann 1972) to identify the ways in which the intervention strategy may fail and the likelihood that such a failure will occur.

Again, where runoff in the catchment is changing as a result of changes in land use or climate change, then the probability of a flood of a given magnitude and flood loss will change over time. A question in the circumstances is whether a flood alleviation scheme should be undertaken now or later.

The construction of the loss–probability curves is a sampling problem: how many and which flood events will give the best representation of the true curves? Fortunately, we can always define the upper and lower bounds about the curve, and for any section of that curve (DEFRA 1999); the area under each curve being calculated by the trapezium approximation (that is, the area under each curve is the integral of the curve but the functional form of that curve is unknown and indeterminate). In practice, it is losses from the most frequent events that contribute the greatest proportion of the benefits. Figure 18.3 shows the loss–probability curve for a hypothetical project broken down by the type of property affected; but as Figure 18.4 illustrates, it is the losses from the five-year return period event that contribute the largest proportion of the benefits.

Since we need to consider how to manage all floods and not just those up to the design standard of protection, we need also to examine how the proposed scheme will affect the losses from all events. Depending upon the nature of the scheme,

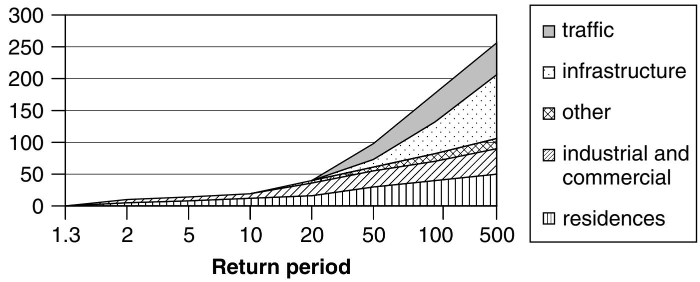

Figure 18.3 *Contributions to event losses*

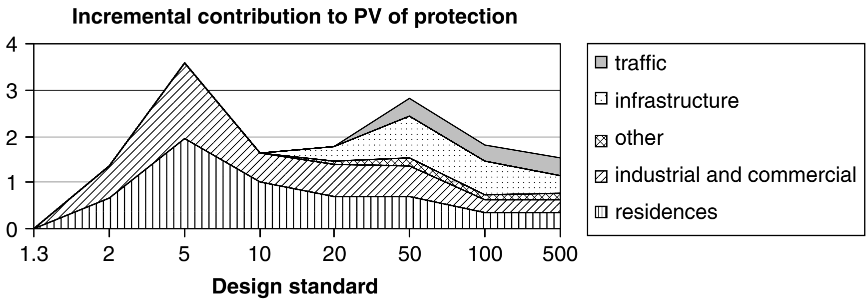

Figure 18.4 *Contributions to present value of benefits*

the losses from these events may also be reduced: for example, if a bypass channel is constructed then the losses from all flood events will be less than they would otherwise be because there will always be less water out of bank. Conversely, it is possible if a dike is constructed that losses when that dike fails will be greater than they would otherwise have been because of the increased velocity of the flood flow (Green, Parker and Tunstall 2000). These above design standard benefits (DEFRA 1999) should be included in the benefit–cost analysis.

The magnitude of the flood losses from a particular event are partly determined by its characteristics; the depth, duration, velocity and loads carried and deposited by the flood (Green *et al.* 1994). In general, the most important determinants of flood losses are the depth of flooding and the duration of the flood; however, this may be a response to the limitations of hydraulic models which in the past did not predict velocities. Standard depth-damage curves are available in a number of countries (Table 18.1) and the methods of deriving such curves are discussed in Green *et al.* (1994). In some countries where data is available as to the value of assets at risk, these curves are expressed as losses as a proportion of the value at risk. For instance, the US and Japanese curves have been developed in this way. The practical problem with such curves is that the geographical and administrative

Table 18.1 *Depth-damage curves (loss as proportion of loss at 1 metre depth)*

Contents	Depth (metres)											
	−0.3	**0**	**0.3**	**0.5**	**0.6**	**0.9**	**1.2**	**1.5**	**1.8**	**2.1**	**2.4**	**2.7**
UK – FLAIR	0.00	0.00	0.77	0.92	1	1.16	1.24	1.27	1.29	1.29	1.29	1.29
UK – survey	0.00	0.31	0.86	0.95	1	1.21	1.39	1.55	1.69			
USA	0.00	0.00	0.55	0.85	1	1.55	2.00	2.55	3.00	3.45	4.00	4.55
USA – one storey, no basement (as % of structural value)	0.13	0.45	0.74	0.91	1	1.23	1.44	1.61	1.76	1.89	1.99	2.08
USA – 2 or more storeys, no basement (as % of structural value)	0.08	0.41	0.71	0.90	1	1.27	1.52	1.75	1.96	2.16	2.33	2.48
USA – split level, no basement (as % structural value)	0.29	0.39	0.63	0.88	1	1.48	2.04	2.68	3.36	4.07	4.76	5.45
Japan	−0.53	0.00	0.51	0.84	1	1.46	1.90	2.30	2.67	3.01	3.31	3.58
Bangladesh			0.61	0.87	1	1.32	1.62	1.88	2.14	2.38	2.62	
Australia			0.55	0.86	1	1.41	1.81	2.19	2.56	2.91	3.27	3.61
Taihu Basin, China	−0.10	0.26	0.63	0.88	1	1.37	1.74	2.10	2.47	2.84	3.21	3.58
Germany	0.31	0.46	0.68	0.88	1	1.47	2.16	3.18	4.68	6.88	10.13	14.89

areas for which data as to value of assets exists rarely coincide with the areas that are flooded. Moreover, a proportion of that value will be above any plausible flood depth and adjustments will need to be made for multistorey buildings.

Alternatively, the curves express losses per building or per unit area of a particular building type. In this case, it is necessary to determine the number or area of buildings of each type that are at risk. Satellite data and GIS systems are increasingly being used in flood alleviation benefit–cost analyses but land use data in such forms (e.g. CORINNE) distinguishes much more clearly between rural land uses than amongst urban ones. For example, the ground floors of buildings in central urban areas often include mixtures of residential, commercial and other uses, including small industrial uses; the satellite data is likely simply to classify large areas as dense urban usage. Nor in central urban areas is data likely to differentiate between, for example, department stores and offices or such critical installations as major electricity substations.

An issue in either case is to identify uses below ground level: the most obvious example is underground car parks which, if occupied, result in a very high loss. Department stores and shopping centres may include shopping and related areas below ground level; Les Halles in Paris is the most obvious example. More importantly, underground spaces pose a very severe threat to life; for example, in Hong Kong, there are cinemas in which the auditorium is below ground level.

The depth of flooding in a building is then the difference between the level of the flood and the ground level. How important it is to be accurate in assessing the depth of flooding then depends upon the depth of flooding anticipated: for large areas currently protected by a dike which would flood to a depth of 3 or 4 m if that dike were to fail, there is little point in being precise to more than the nearest metre. Conversely, where flooding is only expected to a depth of around 60 cm, particularly when a project protecting a relatively small area is being assessed, then differences of 10 cm can make a considerable difference to the estimate of the project's benefits. Ground levels can now be measured quite accurately and relatively cheaply by GPS and other techniques such as LIDAR. However, the floor levels of buildings are seldom actually those of the ground outside and either the floor levels of individual properties need to be assessed or some general adjustment factor incorporated (e.g. assuming that the floor level is the ground level plus 20 cm). This leaves the flood level to be estimated; simple hydraulic models predict only the flood level in the river itself in which case the analysts will find themselves constructing what is in effect an overland flow model in order to predict the depth of flooding in particular locations. Increasingly hydraulic models also include predictions of overland flow, the movement and depth of water outside of the main river channel. In either case, it is necessary to groundtruth the data as far as possible, particularly for the most frequent events.

The duration of the flood is particularly important when considering indirect losses, such as the loss of industrial production, when flooding lasts for several weeks or months. In principle, since the chemical and physical mechanisms that cause damage to buildings and their contents are time dependent, direct damages should also depend upon the duration of the flood. However, understanding of the relationship between the duration of flooding and physical damages is somewhat limited; but in the case of crop losses, the losses are dependent upon both the duration of flooding as well as the time of the year when flooding occurs (Figure 17.4). Commonly, crops will have been damaged by local waterlogging before they are flooded (Section 17.3.7); therefore, only any additional losses caused by flooding should be counted when assessing the benefits of a flood alleviation scheme as opposed to a drainage scheme.

High velocity flows pose a very significant threat to life, particularly when the local combination of velocity and depth is sufficient to cause buildings to collapse. Data on these conditions is somewhat limited (Table 18.2) and there are problems with scour around columns, the 'rough' nature of urban areas (e.g. buildings) which will create variations in water velocity, and the rocks, trees and other loads carried by the flood water. Where it is considered that velocities may be high, the focus must be on reducing the risk to life rather than estimating more accurately the additional damages that will occur to buildings.

In some areas, the load of sediment carried and deposited by the flood waters can be significant; the Japanese depth-damage curves (Dutta 2002) include an allowance for the additional losses caused by this material. Commonly, the flood waters will also be contaminated with sewage, oil and petrol that have escaped from underground storage tanks, and other materials.

The scale of flooding is an important consideration in the analysis; at either end of the scale, data will be sparse and collecting more detailed data is expensive. For very large areas (e.g. the Netherlands or the Yangtze), it is necessary to make some approximations in order to match the availability of the data. A number of different computer models have been developed to carry out such broad-scale assessments (Klaus *et al*. 1994). Similarly, at very small scales, such as assessing the benefits of alleviating a local problem caused by surcharging from a sewer, relatively small-scale details (e.g. the height of the curbs) influence

Table 18.2 *Conditions for serious risk to life*

	Damage parameter $D \times v$ (m^2/sec)		
	Low	Medium	High
Children	<0.1	0.1–0.25	>0.25
Adults	<0.3	0.3–0.70	>0.70
Personal cars	<0.9	0.9–1.50	>1.50
Lightly constructed houses	1.3	1.3–2.50	>2.50
Well-constructed wooden houses	<2.0; v > 2.0 m/s	2.0–5.0; v > 2.0 m/s	>5.00
Brick houses	<3.0; v > 2.0 m/s	3.0–7.0; v > 2.0 m/s	>7.00

Source: Reiter 2000.

the amount of local ponding that can occur before properties are flooded, and the capacity of the road to carry the surcharged volumes away. Measurement of all the necessary details to build an accurate overland flow model would be excessively expensive and simplifications are again necessary; for example, Green *et al.* (1989a) prepared simple look-up tables of the benefits of reducing the risk of sewage flooding to different types of property.

In reality, flood alleviation schemes are constructed primarily in order to reduce the suffering caused to people rather than to reduce the damages to property. It has been found that to those who suffer them, the stress, health damage, disruption and other 'intangible' impacts of floods can be far more serious than the losses they experience in terms of damages to their home and its contents (Green and Penning-Rowsell 1986, 1989). Attempts have been made to evaluate those losses in economic terms (Allee *et al.* 1980) but to do so means first being able to predict how the severity of these losses vary according to the population affected and the characteristics of the flood, with the nature of their home itself being a possible mediating factor. So far, it has not been possible to establish clear relationships between these different factors in a way that would enable reliable and valid predictions to be made (Green *et al.* 1994).

Again, floods can cause significant loss of life but the conditional probability of death in a flood varies from some small chance, probably around 1 in 10 000, up to a high risk of the order of 1 in 5 (Graham 1999). It is undesirable to seek to put a 'value on life' in the economic assessment of a flood alleviation scheme but it is necessary to try to estimate, at least in relative terms, what is the relative risk to life. There are a number of ways in which people die in floods (New South Wales Government 1986), the most common in the USA being attempting to travel by foot or in a vehicle through flood water (Center for Communicable Diseases 2000). The three conditions likely to pose the greatest conditional risk of death should a flood occur are:

- underground areas (including metro systems and underground car parks);
- small, steep and consequently flashy catchments; and
- behind natural or artificial defence lines and below natural or artificial dams if those structures then fail.

18.1 The Likelihood of Failure

If we are to manage all floods, it is critical to assess how likely is each intervention strategy to fail and what are the consequences of such a failure. The first question is how likely is it to work in the first place; second, how will it perform in 'above design' standard situations, what does this section of the loss–probability curve look like?

It is commonplace, if rather misleading, to distinguish between 'structural' and 'non-structural' options; it is misleading because the latter category includes actions, like flood-proofing and house raising, that are structural in nature. The purpose of the original terminology was to introduce new intervention strategies in addition to those commonly adopted by engineers. A more general classification is then between physical and institutional changes and as to the point of intervention in the flood sequence: before, during and after the flood. The principles of reliability engineering need to be applied not just to physical interventions (e.g. KGS Group 1999) but also to institutional interventions. The cynic might claim that in the past it has proved easier to undertake physical interventions that have worked rather than institutions that are effective; equally, that concrete has proved rather more robust when inadequately maintained than have institutions.

18.1.1 Flood warnings

Flood warnings may be provided in order to:

- reduce the risk to life;
- support the management of the hydraulic system so as to reduce the extent of flooding; or
- enable the population to reduce their losses.

The benefits of flood warnings vary according to the purpose of the warnings and the appropriate purpose of flood warnings will often differ between catchments. The ‘do something’ option may, for example, include improvements in flood modelling, in dissemination systems, telemetering rain gauges or installing weather radar. The gain over the existing system may then lie in one or more of the following improvements: in lead time (the length of time between the receipt of the warning and the arrival of the flood); reliability (the likelihood that a warning is issued prior to a flood and that a warning is followed by a flood); precision (the characterisation of the flood in terms of depth, extent and other characteristics); and accuracy (how closely the flood characteristics are predicted).

18.1.1.1 Risk to life

The fundamental reason for providing flood warnings is to reduce the risk to life if a flood occurs. The conditional risk to life given a flood varies markedly from context to context (Graham 1999). The primary problem is then to calculate the conditional risk of death or injury without and with the proposed flood warning system. In then deciding whether or not to enhance the flood warning system, it is more helpful to consider what to say at a disaster inquiry than to rely upon a ‘value of life’: to be able to say that all reasonable options were considered after the risk was assessed.

18.1.1.2 Improvements in the performance of structures

Flood forecasts are important to operating storage and flow controls so as to maximise their effect on reducing the extent of flooding. They also give time for emergency crews to be called out and emergency works to be undertaken to strengthen or raise dikes. The benefit of the flood forecast is then given by the difference between the performance of the system with warnings and the performance of the system without warnings. This can be calculated in the usual way from the loss-probability curve and might be expected to be substantial in some cases.

18.1.1.3 Enabling the population to reduce their losses

People can reduce their losses in one of three ways:

- moving animals and property either out of the flood risk area; or
- moving upwards (uphill or upstairs); or
- flood-proofing their property.

Which behaviour will be most effective depends upon the nature of the catchment; where flooding will be several metres deep, then evacuation will be necessary and the reductions in losses will depend upon what can be removed from the area. Where flooding will less than 2 m, and buildings will not collapse during the flood, then losses can be reduced by carrying possessions upstairs or lifting them above the anticipated depth of flooding. In shallow flooding, less than a metre deep, then it may be possible to flood-proof the property preventing any water entering the building. The reductions in losses then depend upon the means adopted and the success of the method adopted.

18.1.1.4 Assessing reliability

CNS (1991) presented a simple model for estimating the likely benefits of flood warnings in terms of likely damage reducing action taken:

$$P_f P_d P_i P_a P_c$$

where:

P_f is the probability that an accurate forecast is made and converted into a warning;
P_d is the probability that the warning is disseminated;
P_i is the probability that a member of the individual household will be available to be warned;
P_a is the probability that the individual household is physically able to respond to the warning; and
P_c is the probability that the individual knows how to respond effectively.

The benefits of the proposed system are given by the product of the above equation for the existing system minus the product of the equation for the proposed system, times the reduction in flood losses through the action adopted on warning. Where taking action on a warning which is not followed by a flood incurs costs (C_n) then the change in the expected value of these losses must be added to the above results:

$$[(P_{f0}P_{d0}P_{i0}P_{a0}P_{c0}) - (P_{f1}P_{d1}P_{i1}P_{a1}P_{c1})]L_r + (P_{0n} - P_{1n})C_n$$

where P_{0n} and P_{1n} are the probabilities that the warning will not be followed by a flood with the present system and the proposed system, and L_r are the losses expected from a flood. The results of this equation are then aggregated over the properties at risk.

Household time budgets can be used to estimate the P_i coefficient (e.g. Anderson *et al.* 1994); a warning issued when there is no one there to receive it will be ineffective and it is difficult to give an effective warning during the sleeping hours. The P_a coefficient can be approximated from national statistics on disability and chronic ill health. In the UK, 18% of the population have been assessed as having a moderate or serious disability, with 4% of men and 5% of women having a serious disability (Department of Health 1997). Of those aged over 85, more than 70% of both men and women have a disability. The relevant coefficient depends in part on the nature of the action that it is intended those warned will undertake on warning; a higher proportion of the population will be able to evacuate unaided than will be able to lift household goods above expected flood levels. In addition, the likelihood of a person suffering a disability is related to their socio-economic conditions. Together, the P_i and P_a coefficients set the upper limit on the potential effectiveness of a flood warning system but only the P_a coefficient is fixed.

Coefficients P_f, P_d and P_i should be expected to vary as a function of the time available. Sorensen (1988) has estimated, for example, the proportions of the population who had evacuated an area against the elapse of time. The standard techniques of redundancy and diversity of communication channels ought, in principle, to increase P_d. However, the empirical evidence is that since this largely depends upon institutional factors, this probability falls over time if the system is not rehearsed; warning systems work best when they are most often used. Overall, the reliability of a flood warning system is likely to be low; a result found in practice (Parker 1999; Penning-Rowsell *et al.* 2000, Smith 1986, Torterotot 1992). A similar approach needs to be applied when considering other intervention strategies.

Economies of scale are very marked in flood management hence flood-proofing (DTLR 2002; USACE 1998) is only more efficient than the traditional structural solutions when the intensity of development is low. For example, in the UK the cost of flood-proofing a property is estimated to be around £2000 per room or £10 000 per dwelling (Johnson 2002) whereas when the author analysed the results of 35 flood alleviation benefit–cost analyses across the UK, the average benefit per property was £8000.

Case Study 18.1 Yangtze Dike Strengthening and Raising Project

The Yangtze is one of the two main rivers in China. It is has a very flat gradient, the base of the Three Gorges Dam being only 75 m above datum. Although the average fall is 4 cm/km, maximum depths can exceed 40 m and 100 000-tonne ships can navigate up to Wuhan. It drains an area of 1 000 000 km^2, a peak flow of 110 000 m^3/sec being recorded in 1870. The Yangtze has been characterised as being a series of linked lakes rather than being a river; these lakes have been important for flood storage in the past but their capacity has been reduced by reclamation in response to the pressure for land (Green 2001a).

The flood season is from July to September and floods are the result of rainfall, the rain fronts moving from east to west. Whilst it follows that the coincidence of flooding from the tributaries has a significant effect on the flood peak on the main river, flood flows are dominated in the middle section by flows from the main stem. Floods are, however, characterised by multiple peaks; eight in the 1998 flood (Daoxi and Siping 1999).

China is very short of arable land (an average of 0.10 ha per capita compared to a world average of 0.24), and the potential of irrigated land to produce multiple crops has long been important. So, between the ninth and thirteenth centuries, the balance of the population shifted from rainfed agriculture in the north to irrigated, multicropping agriculture in the south. Consequently, the Yangtze valley is densely populated with 42 million people living on the flood plain of the Yangtze. Rural population densities are high and small-scale industrial enterprises are widespread in those areas. In turn, whilst retreating the line of flood defences and allowing part of the flood plain to revert to wetlands is an option that is often appropriate in developed countries (Zockler 2000), this is clearly inappropriate in China's current circumstances.

Administratively, central government takes a very low proportion (12%) of GDP in tax revenue, and the undertaking of public works relies significantly upon specific Provincial and County hypothecated taxes.

Yangtze Flood Management Plan

A comprehensive flood management policy for the Yangtze (Green, Parker and Tunstall 2000) has been prepared, including afforestation, flood warnings, flood refuges, detention basins and live storage in the meanders (for example, there is a 50 km meander on the Yangtze in which the live storage is approximately 2 billion cubic metres), main and secondary dikes, and flood fighting. The first detention basins were designated in 1954 and the operation rules for the existing hydroelectric dams on the tributaries are being altered to include flood storage. The Three Gorges Project (TGP) will add a further 22 billion m^3 of storage (Hong Qingyu and Luo Zhang-Yu 1999) to take off the peak of most floods (the 60-day flow in Hankou in 1998 was 188 billion m^3). The main dikes along the river are, however, of a low defence standard (generally providing protection against only the 10–15 year return period flood). The construction standard is also poor and the dikes are likely to fail through seepage or leakage or for other reasons before they are overtopped. As part of that much larger flood management plan, the Government of China is strengthening and raising the main dikes, notably in Hubei and Hunan provinces.

The strategy for responding to a flood is also complex. At present, the dikes will cope with a relatively small flood but as a flood develops progressively more

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resources are mobilised for flood fighting, there being a highly developed system for flood fighting, including stockpiles of materials on the landside berm of the dikes. Initially, these resources are required to support emergency reinforcement of weak points in the dikes, such as sand boils, and to close any breaches that occur. If the flood then threatens to exceed the height of the dike then emergency measures are taken to raise the height of the dike. At this point, the designated detention basins will be utilised; these provide 47 billion m^3 of storage. The reluctance to use these basins is because of the costs of using them; 4.2 million people live in these basins and the costs of evacuating and rehousing this population, together with the economic losses to agriculture and industry within the basins would be substantial (fixed asset values in the basins in Hubei were estimated as 30 billion RMB). But the low design standard of protection offered by the existing dikes means that the use of the detention basins must be contemplated even in the event of relatively frequent floods.

With the completion of the Three Gorges Project, this strategy will change; the dikes in conjunction with the Three Gorges Project will provide protection up to the 100–200-year return period flood and the use of the detention basins will take the standard of protection beyond the 500-year return period event.

Analysis

Because a major component of the project is dike strengthening, it was necessary to use estimates of the probability of the existing and new dikes failing before they were overtopped. Thus, the probability of a dike failing from a flood of a given return period is a combination of the probability that it will fail or be overtopped. As there is remarkably little information world wide on the probabilities of dike failure (Wolff 1997), the engineers had to use engineering judgements for these failure probabilities. These probabilities were then used as the thresholds at which progressively greater efforts at flood fighting would begin and then the use of the detention basins would be initiated. In addition, two separate analyses had to be undertaken: one covering the early years before Three Gorges is operational and the second covering the latter period when the availability of Three Gorges will substantially reduce the benefits of the dike raising and strengthening. For example, for one dike section, the present value of the benefits for the period prior to the commissioning of TGP is 1.9 billion RMB; the present value of the benefits of the dike works over the remaining period of their life is 0.35 billion RMB.

It is a requirement of the National Codes (Ministry of Water Resources 1998), that sample surveys of flood losses for different land uses be undertaken after every flood. This data is then used to calculate losses per mu (*c*.0.06 hectares) in rural areas and loss per capita in urban areas. Depth-damage curves have not been calculated but across much of the flood plain, either there is a flood to 3–4 metres or there is not; once a breach occurs, neither the extent nor the depth of flooding varies markedly with the return period of the flood. These estimates of loss per mu and loss per capita were used to calculate the event losses, having been cross-checked against other available data such as the levels of compensation set out in the Resettlement Action Plan, a summary of flood losses in China in the 1980s, and the losses as a proportion of the assets at risk found in other countries that have good loss data.

A second potential benefit is that a reduction in operating and maintenance costs should be expected for the renovated and new dikes over the existing dikes. This

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benefit could not be estimated for a number of reasons. Firstly, the National Code covering O&M expenditure (Ministry of Water Resources 1995) requires that the allowance for O&M be taken as 5% of the capital cost; this itself is problematic. Detailed, costed O&M schedules had not been prepared but rather an allowance based on this Code requirement had been used instead as the estimate of the O&M costs for the new dikes. Current O&M expenditure is also inadequate to maintain the present standards offered by the existing dikes, the maintenance engineer in one county estimating that he had only 50% of the budget he needed. Since neither figure was reliable, the benefits of reduced O&M expenditure had to be left as an intangible. Whilst changes in O&M expenditure are expected to be an economic benefit, funding adequate levels of maintenance in the future may be a real problem.

The requirements for bank protection caused some concern. At one bend, an estimated 133 m^3 of rip rap have been placed over the last 50 years per linear metre of embankment. Therefore, the time interval at which bank protection will need to be renewed was a major uncertainty.

Robustness Analysis

The high proportion of capital costs taken up by bank protection, and the uncertainty concerning the life expectancy of those works, means that reducing the life expectancy of those works was an obvious candidate for the robustness analysis. More generally, the results of an economic analysis are known to be sensitive to those streams of benefits and costs that either occur early in the project's life or events that occur frequently. In this case, the large reduction in benefits following the completion of the TGP means that the benefits should be very sensitive to delays in completion of the project. The results of the robustness analysis (Table 18.3) showed that the conclusion that the project is to be preferred to the baseline option is robust to uncertainties. At a 12% discount rate, the uncertainties concerning the life expectancy of the bank protection works proved not to have that great an effect on the benefit–cost ratio, even in the area where they constituted a large part of the capital costs – in part because resettlement and other works contributed a significant fraction of total project costs.

Table 18.3 *Results of the main robustness tests for Hubei and Hunan Provinces: variations in the benefit–cost ratio*

Case	Hubei			Hunan
	Jianan section	Wuhan section	Babu section	
Base	11.0	4.9	10.2	2.7
Delay benefits by 2 years	8.4	3.0	5.9	1.8
Probability of failure by existing dikes is lower	1.7	2.3	6.3	1.5
New dikes are not properly maintained	9.1	5.0	9.4	2.3
Bank protection works required every 5 years	8.0	4.9	10.1	1.2

19
Hydropower

Utilising the potential energy in a river is one of the oldest energy conversion strategies known, traditionally having been used for hulling rice, grinding wheat and cutting wood, and then the early large industrial plants. With the invention of electricity, hydropower was then an obvious extension of these uses. Now, in 65 countries, hydropower produces more than 50% of total electricity production, whilst in 24 countries more than 90% of electricity is produced by hydropower; over 18.4% of the world's electricity is produced by hydropower (IEA 2000).

Electricity, however, does not provide a large part of the world's energy requirements and much of that electricity is generated using fossil fuels. It is more useful therefore to frame choices involving hydropower in the context of a matrix of energy source (e.g. fossil fuels, hydropower) versus the components of consumption. The pattern shown by this matrix varies markedly between countries. Thus, in rural areas in developing countries, households consume 90% of total energy consumption, almost all of that for cooking for which they rely upon fuel wood and dung (World Bank 1996b). Conversely, in developed countries, a significant fraction of total energy demand is taken up by transport, almost all of which is dependent on oil. In the UK, in 1998, the largest fraction of energy demand was from transport (34%), as opposed to domestic uses (29%), industrial (22%) and commercial/public services (13%) (Royal Commission on Environmental Pollution 2000). Thus, there are marked variations between countries in the per capita use of energy, the source of that energy, and use of that energy. The conversion efficiencies also differ markedly between countries (Jochem 2000).

There are two main forms of hydropower:

- run of river projects (e.g. Niagara Falls) where there is little or no storage; and
- reservoir based systems.

Since the former is wholly reliant on the momentary stream flow they rely upon relatively constant river flows, those found in temperate climates. In arid climates, storage is necessary if the supply of electricity is to be reliable. However, reservoirs are very contentious both in terms of their environmental impact (Acreman *et al*. 1999) and the issues of resettlement. In turn, in developed countries, two

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further issues that can require economic analysis are (a) changes in the operating rules and hence the patterns of discharges from the reservoir, and (b) the decommissioning of dams. In the USA, some 587 dams have been removed since 1990 (Pritchard 2001).

19.1 Economic Issues

Conceptually, the assessment of enhancements in electricity supply is very similar to water supply (Section 14.6):

- the benefits of first time electricity; and then
- the incremental benefits of enhancements in the quality, including the quantity, of the service provided.

The former need to be assessed in the broader context of development policy, particularly of rural development policy. In the analysis of the latter, it is essential to consider the electricity supply system as a whole, particularly the interactions between different forms of generation.

Secondly, as with water management, the problem is to match variations in supply and demand but as compared to water, supply can be adjusted through changes in generation capacity. However, demand varies over much shorter time periods as compared to water and whilst there can be considerable inertia in the water distribution system that buffers changes in demand, for electricity, supply must respond instantaneously.

Again, as with water, demand forecasting is a critical issue in energy management. Thus, the potential importance of hydropower depends upon the current and possible future form of the supply–demand matrix. In particular, whilst the Kyoto Agreement calls for some real cuts in greenhouse gas emissions, much greater cuts are necessary to stabilise the climate (Royal Commission on Environmental Pollution 2000), a switch to a hydrogen economy for vehicles or to directly electrically powered vehicles being two options. The former requires electricity to split water into oxygen and hydrogen, so the effect is an increase in the demand for electricity whilst avoiding an increase in greenhouse gas emissions from generating that electricity.

In developing countries, with large areas of the country, especially rural areas, lacking any electricity supply at all, the benefits of first time electricity supply are a major issue. At present, 3% of the population of Nepal are connected to an electricity supply and it is estimated that it will be another 30 years before the whole of Nepal is provided with electricity supply (Eberhard *et al.* 2000). Thus, the problem is likely to be whether to provide a local electricity supply and by what means. Electricity supply systems are likely to be local, lacking the geographical large-scale distribution grids that characterise the developed countries where large-scale plants supply demand centres hundreds of kilometres away.

Hence, another issue is whether to provide an electricity supply by extending the existing grid systems or to provide local, separate sources of generation and distribution. The first offers potential economies of scale but those economies occur through large installations; the latter offers more scope for community involvement and control. Those areas that are served are likely to suffer blackouts and brownouts, fluctuations in voltage and other problems in the quality of the service provided, the question then being whether and which improvements in service can be justified.

In developed countries, service is usually near universal, with high levels of consumption, and the issue is commonly one of whether to expand generation capacity to meet predicted increases in demand and, if so, by what mix of generation capacity. Here, there is a clear question of whether supply expansion is likely to be more efficient than demand management. Where supply expansion is appropriate, then existing grids allow a wide range of generating options to be considered including those located at a long distance from the sources of demand. In addition, these grids increase redundancy and diversity and so enhance the reliability of the system as well as allowing some economies of scale. Issues such as the most efficient means of supplying base load and peak load generating capacity then become important, with high standards of security of supply also being expected in developed countries. In developing countries, a sudden increase in demand is likely to result in a brownout, a response that will not be acceptable in a developed country. Ensuring the quality of supply then requires analysis of the interactions between the different forms of generation capacity, of the dynamic response of the system. In this regard, hydropower has a number of advantages in terms of the control of voltage and frequency, and to maintain a spinning reserve capable of very rapid response to increases in demand.

19.2 The Benefits of First Time Electricity Supply

As with water, women are the primary direct and indirect beneficiaries of the provision of first time electricity supply and some two billion people currently have no access to electricity (Eberhard *et al*. 2000). The benefits then lie in the substitution of electricity for other energy sources (e.g. kerosene and candles for lighting) where the alternatives often have significant health risks associated with them, as well as possibly higher costs. The economic evaluation of these benefits may then be undertaken by assessing the reductions in the costs of buying existing energy supplies, together with an estimate of a reduction in the health risks associated with those existing energy supplies. However, a significant fraction of the demand is for new uses, e.g. watching television (World Bank 1996b) and a willingness to pay study, subject to the usual reservation that women may have, at best, only limited access to the household's cash resources, is necessary to evaluate such benefits.

Although women may spend one-fifth of their working day collecting fuel wood for cooking (Eberhard *et al*. 2000), electricity will not normally be a viable alternative at least initially because of the high power requirements for cooking. Improvements in the utilisation of biomass are likely to be a better option for cooking in the short term although the combustion of wood and other biomass can produce carcinogens and other pollutants.

Small-scale hydropower is an option that can be appropriate in rural communities. For example, in Ethiopia, the lack of wind rules out wind power whilst solar power is prohibitively expensive (Shewarega 1999); it also requires a high level of technology and skills, a problem that also rules it out in rural areas in Pakistan (LEAD – Pakistan n.d.). For example, 1 m drops and very simple technology have been used to provide 50 W power supplies in Laos (ourworld n.d.).

19.3 Enhancing the Standard of Service

Where there is some basic electricity supply, then the choice is between improvements in the quantity, or quality, of the service (e.g. improved reliability, reduction in interruptions etc.) and demand management. Where an increase in the resource is justified then the choice lies between alternative generation options. The higher the current level of consumption, the more likely it is that demand management will be more efficient than increasing generation capacity, and one problem reported with market reforms of electricity services is a serious reduction in the incentives to electricity suppliers to support demand management (World Bank 1996b). However, in the economic analysis, the demand management option should be considered even when current institutional arrangements do not permit its use: the achievement of efficiency then requires those institutional arrangements to be changed.

Amongst the demand management options to be considered may be reductions in losses in the transmission and distribution system: for example, in India, 35% of electricity is lost in this way (Eberhard *et al*. 2000). As with water usage, demand is to a large part determined by technology (e.g. the replacement of tungsten light bulbs by high efficiency fluorescent bulbs).

The quality of service, including reliability, is a function of the characteristics of the system as a whole, and both redundancy and diversity may be important. The characteristics of the system are then partially determined by the mix of generation options adopted; different generation options may be appropriate to provide base load and peak load capacity. Therefore, decisions concerning increases in generating capacity need to be taken in the context of system performance. An important quality criterion is the reliability of supply and a decision must be made as to what reliability of supply is appropriate for each category of consumer. Reliability is in part a function of the degree of redundancy in the distribution network but is also a function of the relationship between generating capacity and demand. A number of studies have therefore been undertaken to determine the economic losses associated with interruptions in electricity supply (Primen 2001; Eto *et al*. 2001) in order to try to determine the optimum levels of reliability for different consumers.

In turn, when considering increasing generation capacity the issue is really one of the reliability of supply; what margin of supply over anticipated demand to provide in order to take account of plants being out of action because of unscheduled maintenance, sudden extreme peaks in demand, and other issues. The problem becomes more complex when different generating sources are themselves subject to variations in their availability (e.g. droughts reduce the availability of hydropower, lack of wind reduces the output from wind farms and so forth). It is the performance of the system rather than its parts that is important.

An advantage therefore of regional grids is the potential to increase reliability or reduce the margin of supply: the excess of generating capacity over anticipated demand. Thus, providing a higher degree of interconnectivity can be an alternative to increasing generating capacity, particularly where demand peaks are out of synchronisation in the different areas. The obvious limitation of a local network reliant upon a single generating source is that the standard of service is wholly reliant upon that single source. Interconnectivity also allows for advantage to be taken of economies of scale.

As with water, a capital intensive industry, demand forecasting is critical and the same techniques discussed in Section 14.5 can be used. However, an important issue here is the possibilities of substitution between energy sources and normally the environmentally preferred option will be away from other energy sources towards electricity. Thus, in the long term, at one level a switch from a reliance on fuel wood or kerosene for cooking to electricity is likely to be desirable whilst a switch away from petrol or diesel powered vehicles is also likely to be necessary if climate change is not to run out of control. In energy management, rather than simply chasing the future, it is likely to be necessary to choose the future and then set out to achieve that future.

20
Navigation

Transport is a frictional cost in an economy: transport consumes resources which could otherwise be put to productive purposes and in the ideal economy, transport costs would be zero. The proportion of economic output that is wasted in transport is obviously largely determined by location, population density and topography: thus, whilst 15% of the GDP of Wyoming is taken up by transport and 14% of that of Montana, for New York state only 8% of the state's GDP is wasted in transport costs. Reducing the costs of transport where possible frees up resources, especially energy, for productive uses. Equally, resources and consumption goods in transit are not being put to any productive use; again, reducing time spent in transit and in store increases overall economic efficiency.

Historically, inland waterways were the primary means of transport in many countries literally because frictional losses and hence energy consumption were lower than transport along the ground. Where the natural watercourses were unsuitable for transport, canals were constructed in early periods or the natural watercourses 'improved' by the construction of locks or the widening or deepening of the channel. Thus, the Grand Canal in China was constructed more than 1000 years ago to transport grain from the Yangtze delta to the north and Beijing. Up to 200 metres wide and approximately 1000 kilometres long, it remains a key transport link, as inland waterways continue to be in many countries. Thus, 47% tonne/kilometres of freight in China are transported by water as is 54% in the Netherlands, 20% in Germany and 15% in the USA. In other countries such as Bangladesh, the proportion of freight moved by water is probably even higher.

Compared to other modes such as trains and road transport, water-borne traffic is slower and primarily suited to bulk freight movements of low unit-value goods. In terms of energy efficiency, it is markedly superior to trucks and only somewhat inferior to rail, water-borne traffic averaging 411 btu/ton/mile as compared to 371 btu/ton/mile for rail and 4359 btu/ton/mile for trucks (Department of Transportation 2001). In cost terms, there are very marked economies of scale with increasing ship size (Table 20.1). The size of the vessel also influences the maximum traffic density per unit length of watercourse and hence the capacity of the navigation route.

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Table 20.1 *Economies of scale in navigation costs*

Vessel size (dwt)	Vessel operating cost (US cent/ton-km)		
	Low	Base	High
50	10.78	13.54	16.25
100	7.91	9.31	10.43
300	4.35	5.12	5.74
500	2.38	2.89	3.14
1000	1.23	1.46	1.62
3000	1.00	1.17	1.31

Source: World Bank n.d.

There are two types of project that may require assessment:

- new canals; or
- improvements to existing routes (e.g. deepening or widening the channel, enlarging locks or increasing the reliability of water supply, reducing tran-shipment times).

As usual, it is necessary to predict both the number of beneficiaries and to calculate the unit benefit. Here the number of beneficiaries is given by the quantity of freight moved and predicting the future volume of traffic is crucial. This has four elements:

- the existing volume of freight;
- shifts of freight from (or to) other transport modes and routes;
- induced traffic: lower costs generating additional volumes of traffic;
- that generated through economic growth.

The primary benefit is likely to arise from freight either being attracted away from other transport modes, particularly from road transport, or retained for water transport when otherwise it would be shifted to another transport mode. As noted later, relative costs are not the only determinant of the choice of transport mode.

Improvements in transport should be expected to induce a growth in traffic; for example, farmers are restricted to subsistence farming unless adequate transport links connect them to the markets in urban areas. In such cases, it may be preferable to make an overall assessment in terms of rural development rather than to focus narrowly on transport improvements.

Economic growth should be expected to result in increased demand for transport and indeed economic growth is itself partially dependent upon adequate transport linkages. However, economic growth is likely to result in changes in the proportion of total freight movements made up of different resources and goods. In particular, a fall in the proportion of low unit-value goods and an increase in the proportion of high unit-value goods in the total volume of freight transported is likely. The result is probably a growth in demand for other transport modes relative to waterways in the future. In addition, the movement of bulk foodstuffs, notably grain, is a major source of traffic for waterways. In most developed countries in particular, grain production is heavily subsidised directly and indirectly through, for example, irrigation being provided at below cost (Section 17.2). When considering the transport of grain, the real economic value of grain should be used since otherwise the result is subsidised navigation being used to transport subsidised grain. But in addition, the extension of WTO rules to agricultural production and consequently a rise in the prices of grain as subsidies are eliminated is likely to result in a fall in demand and hence a reduction in demand for transport in developed countries and especially in North America and Europe. Equally, in principle, the WTO rules will affect the subsidies provided to the construction and operation of waterways and ports to transport grain. For example, the predictions of demand used in the assessment of the Upper Mississippi–Illinois river navigation project (Berry *et al.* 2000; Sweeney 2000) appear to have taken no account of the possible changes in world trade rules and the resulting fall in US grain production for export.

There are significant negative externalities associated with all forms of transport most obviously with the energy consumed and the resultant greenhouse gas emissions. The nature and extent of other externalities then varies according to the mode of transport. Hence in assessing possible navigation improvements, it is more than usually important to consider the alternative: what mode of transport will otherwise be adopted and the resulting externalities. Navigation improvements to an existing watercourse are likely to result in a major reduction in its ecological value; the wash from vessels results in bank erosion which in turn leads to hard bank protection measures being constructed and the effective conversion of a natural river into a canal. Deepening, widening and straightening the channel necessarily results in loss of shallow water habitats. These effects are obviously more severe when the river is currently in a nearly natural condition (Dembek 2000). Spillage of fuel and the discharge of sewerage from vessels may significantly degrade water quality. Particularly where navigation improvements result in intercontinental ship movements, there is a significant problem with introduced species (Carlton 2001). Nevertheless, the externalities associated with water-borne traffic may be less in a particular instance than those associated with the alternatives.

The potential benefits of navigation improvements are:

- savings in transport resource costs;
- reductions in transfer times and waiting times;
- reductions in travel time including reductions in congestion;
- reductions in packaging costs;
- reductions in losses in transit;
- increase in reliability of delivery.

In evaluating these benefits it is necessary to consider complete journeys and not simply that part of the freight movement that could be undertaken on the proposed navigation improvement. Trans-shipment costs can be substantial and additional costs may outweigh any reductions in movement costs. In turn, there can consequently be significant benefits in completing a route to avoid trans-shipment being necessary. In addition, with the exception of pipelines, movements on all transport modes require an outward and inward journey with the costs largely being fixed irrespective of whether the vessel, train or vehicle is fully loaded.

Enlarging or deepening the channel so that larger vessels can be used is the most likely means whereby transport costs can be reduced both relative to those of existing water transport and compared to those of alternative modes. In most countries, no mode of transport bears the full economic cost: the income from tolls or vehicle taxes is not usually sufficient to pay for the full cost and O&M costs of road construction; railways are commonly subsidised and construction costs borne by government; and in each case, the charges or taxes levied are commonly insufficient to cover the full externalities associated with that mode of transport. Similarly, the extent of cost recovery is usually low for waterways, rates of 20% in the USA and 2% in the Netherlands being two major examples. Therefore, it is important to compare the real resource costs of the different modes of transport and also, for economic sustainability, to compare the fiscal costs to government of alternative transport modes.

Loading and unloading can be both expensive in terms of the delays in moving goods, in the idle time of the vessels, and also as an activity itself. There can be economies of scale in loading and unloading costs as a function of the size of the load. The daily cost of resources or goods in transit should also be calculated and included in the comparison of transport costs across the different modes. Water-borne transport will generally be slower than road or rail movements and water-borne transport is most usually competitive for bulk, low unit-cost goods where the value of the load does not justify the use of a higher-cost, faster mode of transport. At the same time, goods in transit provide a degree of mobile storage and a reduction in transport time may then result in requirements for increased storage capacity at one or both ends of the journey. Locks are a notable cause of delays in transport and either improvements in lock handling or increases in lock size so that a larger number of vessels can be raised or lowered in one lock cycle may therefore yield significant benefits. One of the results of queuing theory (Hillier and Lieberman 1967) is that queues can increase exponentially, being infinite in the limit. Hence delays at locks may set the limiting capacity of the navigation. But there may be relatively cheap methods of increasing the throughput of a lock system rather than enlarging the lock (Sweeney 2000).

Economies of scale can also apply to packaging whilst there are typically some losses to goods being transported both during transport and also in trans-shipment. For some resources, notably food stuffs, the rate of loss through natural deterioration is partly a function of the elapsed time. In all forms of transport, the reliability of delivery dates can be a significant determinant of the choice of transport mode: a lower transport cost may not be sufficient to induce the use of water-borne transport if the time taken to transfer the goods varies over time: for example, low flows during droughts may halt all shipping movements. Variability in journey time requires that goods are dispatched earlier so as to increase the probability that they arrive on time and in turn this requires that storage is provided at the destination in order to buffer variations in deliveries. The vessels themselves will be utilised for a lower proportion of the time and this in turn increases unit costs.

The primary benefit is likely to arise in the second way with freight either being attracted away from other transport modes, particularly from road transport, or retained for water transport when otherwise it would be shifted to another transport mode. As noted, relative costs are not the only determinant of the choice of transport mode.

21
Environment

The state of the river environment and the connected river corridor is a function of the flow regime, and with that regime, the process of erosion, transportation and deposition of sediment, together with the quality of the water. In summary, the environment is then a joint product of the flow regime, channel form and water quality as well as the wider environmental context of the river. It follows that it does not matter what is the reason that a change occurs, the benefits of achieving a preferable environmental state are the same whether that state will be achieved by a shift to a more desirable flow regime, a reduction in pollution or conversion to a more natural river form. In short, the nature of the benefits and the means of evaluating those benefits are the same whether the project under consideration is the alleviation of low flows, a reduction in the pollution load from point or non-point sources, or through river restoration. Equally, it can turn out that the real problem is not that which was originally believed; this is one of the lessons from the Groovtlei case study (Case Study 21.2).

Equally, almost any intervention to support other functions, such as navigation, hydropower generation, flood management or abstraction will have as part of its cost one or more impacts on the environment as these change the flow regime, the quality regime or the form of the river. So, too, can attempts to improve the river by, for example, augmenting the flow from groundwater at a lower ambient temperature (Cowx 1998).

Ecosystems and the linkages between them form very complex systems. Moreover, whilst rivers are dynamic systems, ecosystems are only able to cope with specific dynamic ranges of conditions. For example, Figure 21.1 summarises the factors and the interconnections between them that affect the life cycle of the brown trout. In turn, this complexity makes assessing the impact of a change difficult. For example, climate change will affect the runoff and the flow regime which in turn will affect the channel structure as well the depth and velocity of flow (Arnell *et al*. 1994). Temperature will also change and this in turn will affect the level of dissolved oxygen.

Hence, short-term changes, such as a pollution pulse, flood or period of low flow may cause damage from which the river does not naturally recover for a long period of time. Therefore, as has been seen earlier (Chapter 14), the problem is to

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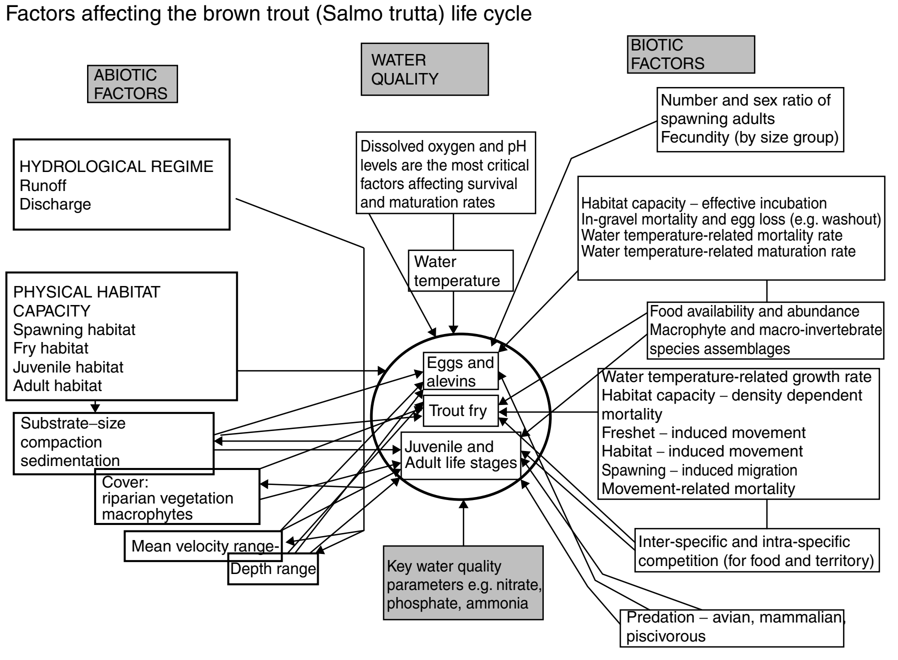

Figure 21.1 *Factors influencing the success of a trout fishery. Source: Burrows 2001*

manage the frequency distribution of perturbations. Some of these perturbations are deliberate (e.g. overflows from sewerage networks during thunderstorms); others are accidental (e.g. escape of slurry from a farm, the misconnection of pipe during the cleaning of a factory, or a fire at a chemical storage warehouse). It is therefore necessary to carry out a full risk assessment before undertaking any specific works otherwise the works may have little real effect. If the state of the river environment is controlled by the runoff of pesticides and fertilisers from agricultural land, then the benefits of improving sewage treatment are likely to be marginal. Equally, it is important to consider whether these changes will extend into the coastal zone. For example, the canalisation of river channels in Spain has resulted in sediment being carried out to sea; in turn, this is considered to have damaged the offshore beds of sea-grass (Fos 1997). Conversely, the flash floods in the Sinai desert carry off heavy loads of sediment which are deposited on the offshore coral reefs, damaging those reefs (Ras Gharib *et al.* 1997).

Figure 21.2 summarises the main benefits, in the case of an improvement, and costs where the river environment will be harmed. Those that are applicable in a particular case depend upon the nature of the river; if the river is small, then there is unlikely to be any scope for commercial fisheries or boating for pleasure. The standard rule applies: since the benefits (or costs) are given by a unit value times the number of beneficiaries, the starting point is to make

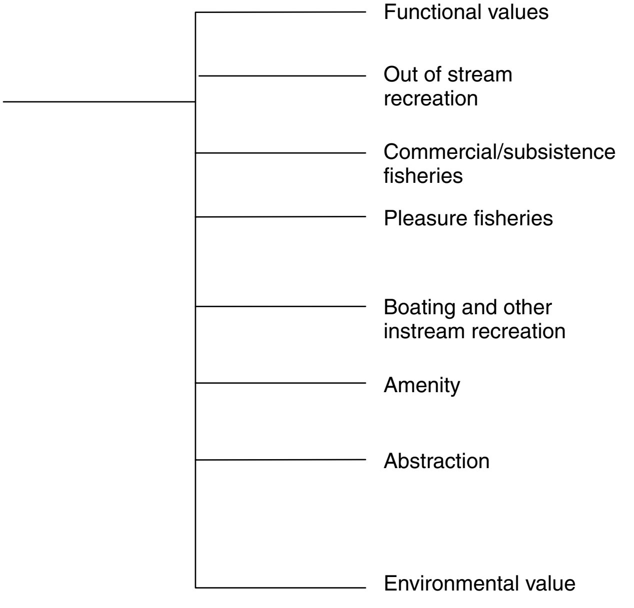

Figure 21.2 *Benefits/costs related to environmental changes*

some assessment of the likely number of beneficiaries and then to concentrate on refining the estimates for those with the largest number of potential beneficiaries. The number of beneficiaries in each category will generally vary to a much greater extent than the unit value; it is not unusual to find, for example, that whilst there are only 2500 canoe trips each year on the stretch of river, there are 500 000 visits by people walking along or picnicking on the river banks. With the exception of commercial and subsistence fisheries which were discussed in Section 17.6, the problems of evaluating these different streams of benefits or costs are outlined below.

An early methodology, together with standard data, to evaluate the benefits of sewerage schemes was produced by Green *et al*. (1989a). More recently, general discussions of the appropriate methodology have also been prepared by van Beukering *et al*. (1998) and Russell *et al*. (2001). The UK appears to be unusual in that benefit–cost analyses are required for all improvement projects and that a standard methodology, together with standard data, has been produced for that purpose (WRc/OXERA/FHRC 1996).

21.1 Functional Value

De Groot (1987) pointed out the general importance of functional value and the functional values of wetlands in particular are well established (e.g. Maltby

1986). The functional values in a particular case need, however, to be established; for example, W S Atkins (1992) identified a benefit of watercourses as being to form barriers for livestock, and their use as a source of water for livestock is self-evident. However, the emphasis needs to be upon exploring the particular functional importance in the particular circumstances. Especially in partially subsistence economies, functional relationships may not be self-evident and require careful investigation before they can be identified. In general, the evaluation technique that is then most appropriate to their evaluation is the least-cost alternative approach (Section 12.2.1).

21.2 Recreational Uses

The basic theory to evaluating all recreational uses is the same; if a site is improved then there will be two streams of benefit:

- Those who visit that site already will gain more enjoyment from that visit.
- In turn, unless a charge is introduced that is exactly equal to that increase in enjoyment, then they will tend to visit more often. In addition, some new visitors will be attracted to the site and away from some existing activity, such as visiting some other site.

Clearly, in the extreme situation, there may be no visits made at all to the site at present, and all visits will be new. Hence, to put a value on the recreational gain to the site, it is necessary to estimate:

- the increase in enjoyment;
- the number of additional visits by existing visitors and the net gain per visit; and
- the number of visits by new visitors and the net gain per visit.

These three values can be different. It also needs to be recognised that it is possible to be spectacularly wrong in the assessments of the number of visits that will be made to the site. For example, when Euro Disney opened outside Paris, the number of visitors and the resulting revenue were far below projections, so much so that it had to be refinanced.

21.2.1 Out-of-stream recreation

Out-of-stream recreation, such as walking or picnicking, in developed countries is important simply because so many visits are made to river corridors; in some cases, the number of visits can exceed 500 000 a year. A relatively low value per individual visit thus generates a substantial annual benefit and a correspondingly large present value.

21.2.1.1 What do people want?

The value of a visit to a river corridor and the effect of some proposed change clearly depends upon what people would like to experience when visiting that river corridor and how the river matches up to those desires both now and after the change. Hence it is necessary to discover what are the attributes that make rivers desirable as a place to visit. For the UK, we now know a great deal (e.g. Tunstall *et al.* 1997) but those characteristics that are important are likely to be very much influenced by the size of the rivers in the UK. It should not therefore be assumed that the same attributes are important in other countries. Overall, what people want of rivers in the UK (Green and Tunstall 1996) is something that looks like what they believe is a natural river, but they also want easy access, including dry paths and car parking, and toilets. At the same time, most people do not want many other people to be there. However, there is a significant degree of market segmentation, those with children wanting attributes that others do not want – things for children to do.

As a result of this market segmentation, the preferences of the different groups of informal recreaters are in conflict; as similarly are those of anglers and boaters (European Inland Fisheries Advisory Commission 1998; O'Riordan and Paget 1978). Equally, those who simply want to go for a walk or a picnic by a river do not want anglers to be there. The results shown in Figure 21.3 are quite typical: making provision for angling would reduce rather than enhance the enjoyment of the majority of those who visit the river, as would pubs and cafes. However, there is no conflict between the desires of those seeking informal recreation and the ecological value of the river corridor. What people want is precisely what they believe constitutes a rich and diverse ecosystem. But this will not always be the case. Figure 21.3 also illustrates the nature of the river environment as a joint product; the respondents want fish, they want to see many water insects, and they want to see more water plants: in this particular river, which is small and suffering from low flows, the only way that these species will be able to colonise the river is if flows are allowed to increase. In addition to the kind of overall studies just described, there are many more specific studies on water quality (e.g. Burrows and House 1989; Ditton and Goodale 1973; Tunstall *et al.* 1997), and sewage debris (House and Herring 1995; Smith *et al.* 1995). Similar studies are required before seeking to evaluate changes to lakes or reservoirs, or to canals.

21.2.1.2 Valuing a recreational visit

There have been a great many studies that have sought to put an economic value on informal recreation by rivers and canals, mainly through the travel cost method (e.g. Harrison and Stabler 1981) and contingent valuation (e.g. Green and Tunstall 1991b; Stabler and Ash 1978). More complete listings of what is now a very large body of work are given in two databases available on the web www.evri.ec.gc.ca/evri/ and http://www2.epa.nsw.gov.au/envalue/StudyCnt.asp, as well as in texts such as

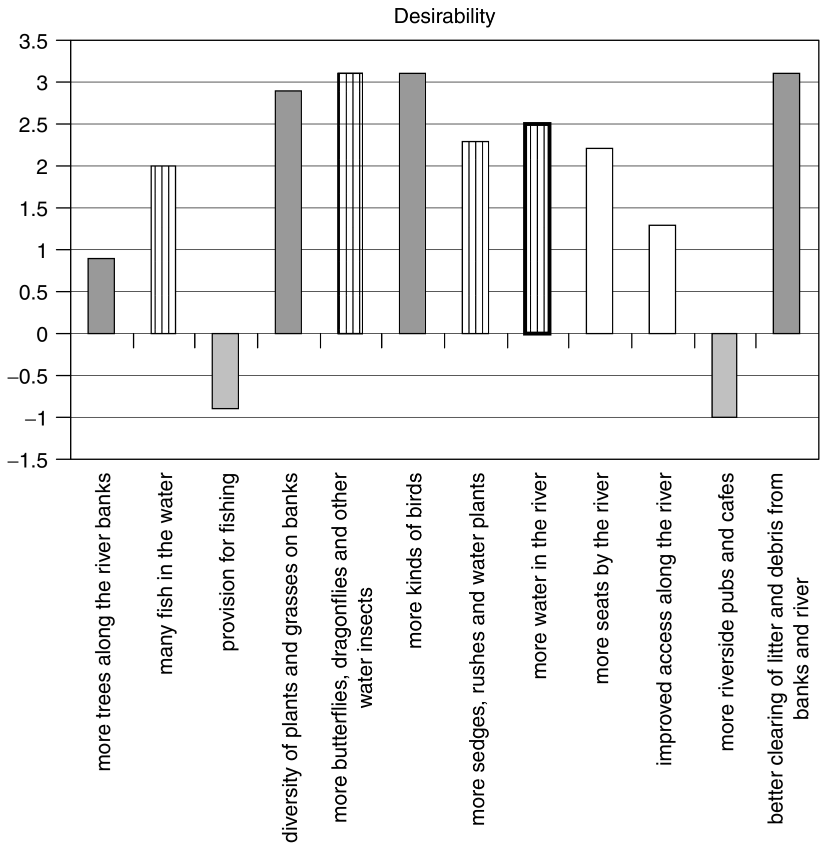

Figure 21.3 *Desired improvements to the river as a place to visit – River Wey residents' survey*

Russell *et al.* (2001), Navrud (1992) and van Beukering *et al.* (1998). Meta-analyses of this work have been undertaken by Walsh *et al.* (1989).

In many places, access to the river corridor is free and, in addition, in Europe in particular, a significant fraction of visits are made on foot. The latter condition means that the travel cost method is not applicable because no resource costs are incurred in making the visit. One approach to valuing the recreational enjoyment given by the site would be to ask visitors what entry charge they would be prepared to pay to use the site now and after the change in conditions.

There are four problems with this approach:

- Since there is no charge for entry at present, respondents have no experience in placing a monetary value on the enjoyment given by a visit. Valuing enjoyment and differentiating this value from the values of other leisure activities is not a task that is necessarily easy – not least because so many leisure activities are not priced.

- An entry charge ought to reduce the frequency with which visits are made to the site (Stabler and Ash 1978). In practice, the reductions in the frequency with which visits are made can be substantial. For example, Savage (2001) reports that the Sydney Museum of Contemporary Art more than doubled visitor numbers when it dropped entry charges. Conversely, when the Australian Museum, the Powerhouse Museum and the Museum of Victoria introduced charges, visitor numbers dropped 50–80%, whilst visitor numbers at the Science Museum fell by 55% and 35% at the Victoria and Albert Museum in London when charges were introduced.
- Introducing an entry charge redefines social relations, and the respondents may regard the changes in social relations as being more important than the monetary value. For example, in one study, respondents said that they choose an amount which would keep undesirables out of the site (Simmonds 1976). More generally, it has not been established that the identity assumed by economists between value and willingness to pay is widely shared by the population as a whole.
- The entry charge is generally in any case hypothetical and only intended as a way of deriving an economic value. It is difficult to explain to respondents that there is no intention of introducing an entry charge, and that it is being used solely as a way of deriving an economic value, without it sounding both silly and contrived. Where there is an entry charge at present – for example, a day licence for angling – this argument no longer holds. But, if an entry charge is used to elicit values, then the methodology developed by Stabler and Ash (1978) must be used: this requires the respondents to state both an entry charge and the frequency of visiting at this charge, and also that entry charge at which the frequency of visiting would fall to zero.

An alternative approach that was developed to get around these problems is the 'value of enjoyment' method (Penning-Rowsell *et al.* 1992). This attacks the first problem by asking people to identify an activity that gives the same subjective amount of enjoyment as a visit to the site in question. For example, a visit to a river may give them the same enjoyment as a visit to a local park or to museum. If this alternative involves costs then this gives the respondents a basis upon which to anchor their estimate of the value of the visit to the river.

The obvious criticism of this approach is that there is no explicit income constraint. However, when the values placed upon the enjoyment per visit are small, so should be any distortion that occurs by not imposing an income constraint. In addition, there are two checks that can be made, one external and one internal. The external check is that the value of any visit must at least equal the value of the time spent at the site where values of time have been calculated for use in transport studies (e.g. DTLR 2000). On this basis, the values obtained by the value of enjoyment method might be considered to be low. Secondly, in each study, respondents were also asked to rate the enjoyment that they obtained from the visit on a 0–10 scale; the relationship between the mean values obtained. When the two are compared across the 21 river and coastal sites for which we have data, the results are not discouraging but more data is required before a meta-analysis can be undertaken.

21.2.2 Instream recreation

The same principles that apply to valuing outstream recreation can be used to value instream recreation such as swimming and boating. However, there are two added complications. Firstly, instream uses tend to conflict with ecological values and also to conflict with outstream uses for small-scale watercourses. Secondly, when considering water quality improvement, different parameters determine the suitability for swimming and water contact activities than determine its capacity to support a diverse ecosystem. Whereas for the latter purposes, it is the removal of nutrients and the reduction of the oxygen demand of the waste stream that is important, for water contact activities, the problem is usually to reduce the quantities of disease vectors (viruses, bacteria, protozoa and helminths). This is a more difficult and expensive task, and where conditions are suitable, maturation ponds are likely to be more effective than conventional treatment (WHO 1987). Even then runoff from naturally occurring animal waste or the presence of leptospirosis may still limit the suitability of the waters for contact activities.

Probably more economic evaluations have been carried out of recreational fisheries than of any benefit dependent upon the environment, particularly in North America. Many of these evaluations have been carried out using the travel cost method (Loomis *et al.* 1986) but a significant number have also been undertaken by the contingent valuation method (e.g. Loomis *et al.* 1986). At least one meta-analysis has also been undertaken (Sturtevant *et al.* 1995).

21.2.2.1 What do anglers want?

Quite marked market segmentation often exists between anglers (Holland and Ditton 1992) with preferences for the fishing experience being different between the different market segments (Hudgins 1984). Similarly, there appear to be some differences between countries in the nature of the fishing experience and also as to who goes fishing.

This segmentation has two consequences:

- There can be differences between the segments in terms of what improvements will increase their enjoyment when angling, and hence their choice of sites.
- It restricts the degree to which any one site is a substitute for any other. In turn, the nature of the fishing experience that can be offered at a site is defined by the characteristics of that site; the most radical change that is made to change what can be offered at a site is introducing alien species.

In the UK, the simplest differentiation is between salmonid and coarse fisheries, the obvious difference between the two being that coarse fisheries are take and return fisheries. In coarse fisheries it is also necessary to differentiate between still and flowing water fisheries. Very few still water anglers wish to fish in flowing waters; and there are also only a relatively few number of anglers who would like to change between coarse and salmonid fishing or vice versa (Figure 21.4). In addition, there are very marked differences between those who prefer still waters and those who prefer running waters in terms of what features they look for in a fishing site (Green, Newsome and Stephen 2000). In turn, there are differences in terms of what still water, other coarse anglers, and game anglers want from a fishing day (Table 21.1), what they therefore look for in a site, and how far they are prepared to travel in order to reach a site (Table 21.2). These results are taken from an interview survey of anglers taken in order to generate the data given in the FWR manual (WRc/OXERA/FHRC 1996). In part these differences are simply a reflection of reality; it is easier to provide good footpaths beside the lowland rivers that support coarse angling as opposed to

		species would like to catch										
	%	bream	carp	perch	roach	rudd	tench	brown trout	rainbow trout	salmon	sea trout	Number of cases
species caught	bream	28	36	14	27	7	22	8	9	4	2	258
	carp	19	48	12	20	5	20	8	9	4	1	277
	perch	23	34	17	26	7	23	9	10	4	2	273
	roach	24	34	14	27	6	23	8	9	4	2	309
	rudd	22	34	16	28	8	24	8	8	5	3	195
	tench	22	37	12	23	5	27	6	7	3	2	264
	brown trout	6	13	7	9	3	7	35	30	23	10	221
	rainbow trout	8	13	9	9	3	8	33	39	21	11	194
	salmon	1	8	0	4	0	1	26	21	38	24	78
	sea trout	4	8	1	3	0	1	27	22	45	29	73
	Number of cases	157	266	103	176	43	156	168	163	152	85	

Figure 21.4 *Preferred species*

Table 21.1 *Importance of factors in making a day's fishing enjoyable: game v. coarse anglers*

	Game	Coarse
Freedom	8.7	8.4
Peace and quiet	8.7	8.5
Relaxation	8.6	8.5
Wildlife	8.2	7.8
Challenge	8.3	7.9
Achievement	6.5	7.1
Meeting other anglers	5.5	5.7
Quantity	4.0	5.4
Size	4.6	5.2
Competition	2.9	4.0

Note: Shaded cells show differences that are statistically significant at the 5% level.

Table 21.2 *Travel to usual site*

	Distance to usual site (miles)	Time to usual site (minutes)	Travel cost to usual site (£)	Number of days
Coarse	16.9	28	3.10	27
Still water	13.5	22	3.36	30
Running water	21.2	33	2.94	25
Trout	24.2	29	5.17	46
Salmon	41.0	41	9.45	39

Note: excludes travel times over 270 minutes.

Table 21.3 *Coarse fishing: quality of fishery*

Quality class	Assumed average biomass of coarse fish	Description
C1	>2000 g/100 m^2	Large number of fish, some of them specimen, from a wide variety of species
C2	600 to 2000 g/100 m^2	Moderate number of fish, but no specimen fish, from quite a wide variety of species
C3	<600 g/100 m^2	Few, small fish from a limited range of species

Table 21.4 *Salmon and sea trout: quality of fishery*

Quality class	Migratory	Non-migratory
S1	1 in 10 chance of catching a salmon for each day's fishing by an average angler	1 in 2 chance of catching a sea trout for each day's fishing by an average angler
S2	1 in 40 chance of catching a salmon for each day's fishing by an average angler	1 in 5 chance of catching a sea trout for each day's fishing by an average angler

the upper land rivers that provide the fast flowing rivers necessary to support salmonid angling.

The most obvious difference between coarse and salmonid anglers is in what constitutes a good site in terms of the fish there to be caught. To derive such measures of the quality of fishing provided by rivers, different angling groups were consulted. In the UK, coarse anglers expect to catch one or more fish during any visit; what is important is the size and species present (Table 21.3). Trout anglers look for wild fish of a good size but for salmon anglers, a good site is one where the chance of catching a fish is as high as 1 in 10 (Table 21.4).

In valuing both a new site and an improvement to an existing site, market segmentation must be taken into account but where anglers are used to paying for a one-day ticket, this provides a straightforward way of determining the value

Table 21.5 *Benefits of angling*

	Amount (£ 1993)	Days would fish per year
River Ver – House *et al.* (1994)	5.10	10.5
River Misbourne – House *et al.* (1994)	8.18	9.2
Stabler and Ash (1978)	6.10	n/a
Smith and Kavanagh (1969)	13.90	n/a

placed on the site. There are some complications when anglers pay for an annual fishing licence which includes access to the existing site, or where that site is owned by an angling club and access is limited to club members. However, the major problem is in predicting the change in the number of visits that will be made, particularly when, as seems to be the case in Europe, the participation rate for angling is falling.

Table 21.5 summarises the results from the study by House *et al*. (1994), where alleviating the low flows in two separate rivers would allow the river to return to being a fishery, together with the results of two earlier UK studies. For comparison, the then price of a one-day ticket for coarse fishing was in the range of £2 to £6, and that for trout fishing between £15 to £25 so the values appear to be plausible.

21.3 Amenity

Living near a body of water may increase the enjoyment of those living there; in turn, that increase in enjoyment should be reflected in an increase in the value of those properties. Thus, the Office of Water (1995) cites figures showing that such proximity to water can increase the price of housing by up to 28%. Green and Tunstall (1992) found strong correlations between the attractiveness of a road or estate as a place to live, and the surrounding environment, particularly the presence of an attractive river. A number of studies have been undertaken to estimate the resulting increase in value (e.g. Feitelson 1991). The danger here is of double-counting since proximity to the water should be expected to increase the number of visits made to that water which may be included separately.

Similarly, pubs and leisure facilities situated near water may also attract more customers; again, this increase in custom and revenue should in turn be reflected in an increase in the value of those properties. In a different way, proximity to water may also generate a higher rent or sales price, and improvements to waterways have been undertaken as a way of stimulating economic regeneration (Button and Pearce 1989).

21.4 Abstraction

In principle, improving the quality or quantity of flow in a river may result either in allowing that water to be abstracted for some purpose, or reduce the cost of treating that water so that it can be used for that purpose. In the first case, the benefit is given by the least cost alternative for providing an equivalent quantity of water and in the latter, the cost of the treatment that is avoided. In some cases, the critical parameter for industry can be the reliability of characteristics of supply; Husain (1978) reports that a dyeing company experienced problems during a drought not because of the quality of the water but because the water's characteristics had changed and so in turn did the colours of the dyed cloth.

21.5 Environmental Value

Part of the value of biodiversity is given by the functional value of that asset. A second component is given by what is loosely labelled as 'nonuse' value. Deep ecologists (e.g. Naess 1993) argue that in addition, species have an inherent right by reason of existence. It is necessary to consider the two cases: valuing a loss caused by our actions or avoiding a loss, and achieving an improvement.

There are both pragmatic and theoretical reasons for avoiding putting a money value on a loss caused by our actions. The pragmatic reason is that doing so is unlikely to enhance a common understanding between the different stakeholders (Section 13.2). Putting a monetary value on, for example, the avoidance of the loss of a breeding pair of a Red List species may in one instance mean that this loss is avoided. But in another project, this additional cost will be insufficient to justify not doing the action that results in the loss. In this case, a significant proportion of the stakeholders are likely to conclude that the analyst is mad, bad or simply does not understand what the choice involves. The theoretical reason is that 'is' cannot imply 'ought' so that even if we could put a value on the loss of a breeding pair of a Red List species, it is open to anyone to argue that this is not the value that we ought to put on their preservation. Moreover, there may be no option that does not involve some environmental loss, a critical part of the choice being to decide which is the least worst option (Green and Penning-Rowsell 1999).

Hence, when action would result in an environmental loss, the adoption of the critical natural capital/constant natural asset approach (Section 7.1.1) is recommended. The same approach is recommended when the decision involves avoiding a loss that would otherwise occur. For example, in an assessment of the benefits of renewing the weirs and other structures on the River Nene in East Anglia, it was found that a large number of important nature reserves had developed as a result of the extensive modification of the river over hundreds of years. These were deemed by the local authorities as being critical natural capital; hence the benefits of reconstructing the weirs could be estimated as the costs of maintaining the existing water regimes of those reserves by other means (Balfour Maunsell 1995).

This approach is not possible when an investment to improve environmental quality is considered. Here, we are forced to consider explicitly how much we are prepared to sacrifice now to gain an improvement. Unfortunately, we are confronted with all of the difficult and unresolved problems surrounding that which is loosely labelled as 'nonuse' value (Section 5.1.2). What is important here is whether the action is one of the first actions we should take; if we deem pollution to be morally wrong, is this action one of the first we should do?

Case Study 21.1 General Environmental Value of River Water Quality Improvements

The form of this study was designed to address four problems:

- We knew from previous studies (Green *et al.* 1990; Green and Tunstall 1991b), and the focus groups confirmed, the finding that people value clean rivers and are prepared to pay towards the achievement of such improvements in river water quality. However, whilst such 'nonuse' motivations appear to be important, economic theory regarding preparedness to pay for such goods was highly speculative (Section 4.3).
- Those earlier studies and the focus group studies indicated that for some people at least, there is a moral component to such a desire for clean rivers. For example, in one focus group when one respondent said (correctly) that untreated raw sewage was being discharged into estuaries, the general reaction from other respondents was that this sort of thing should not happen in this day and age.
- We were asking respondents to state a preparedness to pay for a change about which they were unlikely to have thought about until they were asked the question.
- Given some 35 000 km of river in England and Wales, it is not possible to ask people to value improvements in each and every kilometre. On the other hand, such specific values are necessary for use in the benefit–cost analyses of proposed new treatment works.

Conventionally, experiments are intended to test hypotheses (Blaug 1992) but the purpose of this study was to obtain real values rather than to test whether conventional economic theory is an adequate or appropriate description of the way in which people approach choices for collective goods. For the purpose of the study, what was important was that the amounts offered represented real money, a preparedness to make a real sacrifice, and not the reasons why they were prepared to make that sacrifice.

If something is a moral wrong there can be no optimum level of 'wrongness', however, there are resource constraints which will influence the rate at which we can correct those moral wrongs. In addition, it will take time to make even initial improvements. Hence, the study was framed to determine where we should start: at what point we should stop seeking to improve water quality can be left to the future.

Thirdly, rather than assuming respondents simply had to recall whether or not they were prepared to pay, and how much they were prepared to pay, the preparedness

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to pay question was designed so as to help respondents decide how much they were prepared to pay.

Both the possibility that some respondents would see the choice in terms of a moral wrong and the implausibility of assuming that they could differentiate between improvements to each of some 35 000 kilometres of river, led to the study being developed as a choice between different programmes of improvements, a choice of where we should start work on improving river water quality. The initial intention had been to undertake a conjoint analysis in which different packages of improvements at different cost levels were offered. However, the focus groups did not identify any attributes, other than the existing water quality, by which people wished to prioritise improvements.

To define such a programme, it was necessary to develop a simple means of defining different standards of water quality. It was not possible to use the water quality ladder that Mitchell and Carson (1981) developed for their study in the USA because of the difference in the scale of rivers in the two countries. The USA scale differentiates between boatable, fishable and swimmable water quality. In the UK, the 95% exceedance flow for more than 75% of UK gauging stations is less than 1 m^3/sec (CNS 1991); hence, most rivers will never be boatable, or fishable for any practical purpose. Moreover, with such low flows, and thus the small capacity to dilute runoff discharges or naturally occurring loads of bacteria (for some UK rivers, 70% of the flow is treated wastewater), few of those rivers can be expected to achieve swimmable water quality. In addition, the US water quality ladder is strictly use orientated whereas the studies of preferences for river corridors in the UK (Tunstall *et al*. 1997) have found that what people want is a river that looks like a natural river that supports a wide range of flora and fauna. Hence, an appropriate water quality ladder had to be developed that related to people's preferences for river corridors to recognisable species that are in turn truly indicative of water quality. Thus, although the kingfisher is an iconic species for rivers, its presence or absence depends more upon the physical form of the river than on water quality, and hence it could not be included as an indicator. On the other hand, the indicator species used in biological water quality indicators (WRc/OXERA/FHRC 1996) could not be used because these are obtained through grab-netting. After consultation with specialists from the Natural History Museum, English Nature, the Royal Society for the Protection of Birds and the National Rivers Authority, three descriptions of water quality were agreed which could also be matched against the formal criteria used to define water quality in the UK (WRc/OXERA/FHRC 1996) and to the output of water quality models.

Four possible programmes (A, B, C and D) of improvements in river water quality (Table 21.6) were also developed; these programmes were designed in such a way that given a preparedness to pay for each programme it was possible statistically to derive a value of improving one kilometre of river from one class to the next. Each programme was described as taking 10 years to implement.

An interview schedule was then developed from the theoretical model shown in Figure 21.5 and a framework developed covering four regions on two dimensions: high–low water quality, high–low charges. A random, preselected address sample was drawn in two stages in each of the four regions. First, eight census enumeration districts (EDs) were drawn for each region, where the probability of drawing each ED was proportional to its population size. Secondly, 27 addresses from each ED were drawn from the postcode address file, 27 being used to cover reserves, the target being to complete 500 interviews. The fieldwork was contracted to a

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Table 21.6 *Programmes for river water quality improvements*
'Improving the standard of the moderate and poor quality waters would be both expensive and take several years to achieve. So we have to decide what our priorities are: where to start and how much it is worth spending.'

Water quality	At present	Improvement programmes – proportion of rivers in each category after completion of 10-year programme			
		A	B	C	D
Good There are abundant fish, birds and plants: fish like trout or dace and grayling which are sensitive to pollution will form a breeding population; rarer species of birds, crayfish, dragonflies and other insects will be found, many plants growing in the water	53%	53%	87%	70%	87%
Moderate Some species such as roach can live in the water but not species sensitive to pollution; some species of birds and some insects will visit the river; some plants will grow in and near the water	34%	47%	0%	23%	13%
Poor This supports very few if any fish and plants; water visited by swans and common types of duck which do not depend on the water for food. There are often many midges and, in really bad cases, the water may be discoloured, covered in foam and smell badly. There may be obvious signs of pollution by sewage or oil	13%	0%	13%	7%	0%
Mean rank (1 = best programme)		2.7	2.9	2.4	1.9
% prepared to pay		39.3	29.7	44.1	46.5
mean amount prepared to pay (£)		8.24	6.32	9.29	13.18

professional fieldwork company who complied with the UK quality and ethical codes of practice.

The interview schedule itself was long, taking an average of 38 minutes to complete. Amongst the questions preceding the preparedness to pay questions were three in which respondents were asked to rank eight different national problems (e.g. healthcare, law and order, the environment) in terms of priorities, then to rank eight environmental problems (e.g. noise pollution, sea pollution), and finally the nine different water and wastewater services in terms of importance. This last set had been used in earlier studies (Green *et al.* 1993; Green 1997). The discharge of sewage to rivers was one of the service aspects included in the third level.

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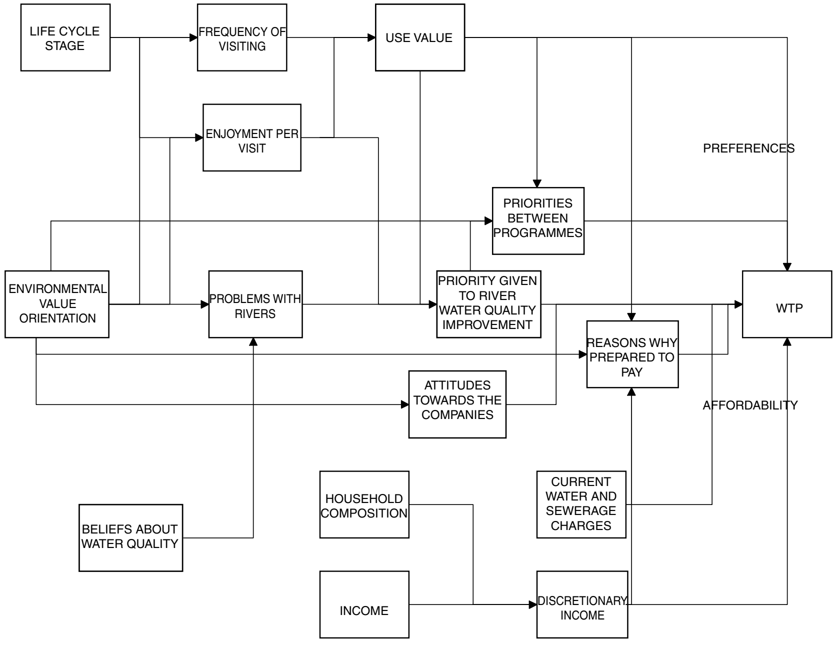

Figure 21.5 *Conceptual model of preparedness to pay for river water quality improvements*

Respondents were first asked to rank order the four programmes; as logically it should, D was generally rated the best programme, whilst B was rated the worst programme, with very mixed views being held about A. When they were asked an open-ended question why they ranked that particular programme as the best, by far the commonest reason given for their preference was that it improved the poor-quality rivers. Next, they were asked whether or not they would be prepared to pay towards the cost of each programme. All those except those who said that they were definitely not prepared to pay towards the cost of a programme were then asked about how much they were prepared to pay. The format was used as described in Section 14.7. Thus, each respondent was started at one bidding level, completed that ladder, and was then offered the opportunity of starting at the other starting point on the same ladder. At the end, the respondent was asked an open-ended question as to the amount that they would be prepared to pay (Table 21.7). When Guy Garrod and Ken Willis at the University of Newcastle-upon-Tyne analysed the data, the implied value of improving one kilometre of river from one class to another is as shown in Table 21.8.

The proportions of respondents who were prepared to pay fell away from 57% (visitors to rivers) and 44% (non-visitors) for the most preferred option to 29% (visitors) and 19% (non-visitors) for their least preferred option. The usual question was asked as to what were the reasons for their decision as to whether or not

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Table 21.7 *Reasons why prepared to pay: visitors v. non-visitors*

	Non-visitor	Visitor
What your household could afford to pay	4.9	4.4
Your household's fair share of the cost	4.6	4.1
The other things upon which you would like to spend more money	4.5	3.9
The value to wildlife of improvements in water quality	4.4	4.7
The value to you of the improvements to rivers as a place to visit	3.7	4.3

Note: All differences significant at 5%. Scale: 1 = not important; 5 = very important.

Table 21.8 *Value of river water quality: general environmental value*

From	To	Value (£)
Poor: Supports few fish and plants; water visited only by swans and common types of duck that do not depend on water for food; many midges; water may be discoloured, covered in foam, and may smell bad; may be obvious signs of pollution by sewage or oil	**Medium:** Some fish such as roach survive but not species sensitive to pollution; some species of birds and insects will visit the river; some plants will grow in and near the water	0.00541 /household /year
Medium: Some fish such as roach survive but not species sensitive to pollution; some species of birds and insects will visit the river; some plants will grow in and near the water	**Good:** Abundant fish, birds and plants; fish like trout, dace or grayling which are sensitive to pollution will form a breeding population; rarer species of birds, crayfish, dragonflies and other insects will be found; many plants growing in the water	0.00201 /household /year

they were prepared to pay for their preferred programme. There were significant differences in the importance the respondents attached to the different reasons between those who visit river corridors and those who do not, although, as usual, a principal components analysis found two factors which could be readily identified as 'value' and 'affordability', with fairness cross-loading on the two factors. In addition, over 80% of respondents, with no difference by gender, said that they would expect to discuss such a commitment with their partner before making it.

Case Study 21.2 Grootvlei, South Africa

The Problem

The remaining gold mines of East Rand Basin, east of Johannesburg, are marginally profitable. Gold mines are also deep and require extensive pumping in order to remain workable. Since the mines are interconnected for safety reasons, it is possible to use one pumping station to drain the entire basin. This pumping station is, logically, located below the deepest level of the deepest working mine. Minewater is commonly loaded with heavy metals, is acidic and may be saline.

With the closure of the then deepest mine, pumping was shifted to No. 3 shaft of the Grootvlei mine after the appropriate environmental assessment and granting of the necessary permit; pumping commenced in November 1995. Unfortunately, both the volume and quality of the water pumped were worse than predicted and breached the permitted limits. The discharge point for the untreated water is immediately adjacent to the Blesbokspruit, a Ramsar designated wetland. The immediate result was a red plume of water spreading downstream through the wetland as iron and manganese oxidised and were then deposited on the bed of the wetlands. This particularly affected bottom-feeding fish and the death of these fish reduced the food supply for some bird species and hence the number of those species using the wetlands. The discharge permit was therefore withdrawn and pumping stopped.

As an immediate but interim response, a lagoon system for aeration, liming and clarification was constructed whilst permanent works were designed and constructed. An interim permit was issued and pumping recommenced. However, whilst both the temporary and permanent works would remove the iron and manganese, the effluent would still be very saline which could cause a number of negative effects. But the only way to reduce this salinity is through partial or complete desalination, with the Grootvlei discharge contributing 30% of the total salt load entering the Vaal Barrage (Water Research Commission 2000). However, desalination is a process which is both expensive in capital and operating costs, and leaves the problem of disposing of the saline wastes captured through the process.

All of the possible options that the government of South Africa could adopt were markedly unattractive. Since the Blesbokspruit is a Ramsar site, it was argued that should the South African government allow such damage to occur, it would reduce the credibility of South Africa's commitment to the environment, a right guaranteed by the Constitution, and reduce the confidence of foreign investors where foreign investment is in turn essential if the economy is to be expanded. Again, if the government were seen to violate one constitutional right then its credibility with respect to protecting all constitutional rights would be reduced.

Equally the objective of the government had to be to improve the living standards of the majority of the population by expanding employment and also in providing basic water and sanitation. The government's emergency water and sanitation programme had an initial objective of providing a water point within 200 m of every household in the 12 000 to 15 000 communities currently lacking such facilities (Department of Water Affairs and Forestry 1994). Any government-financed treatment of the minewater could be at the expense of the progress of the emergency water and sanitation programme. At the same time, the East Rand Basin directly employs 6000 people in an area where unemployment was already 30%.

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The government therefore set up an interdepartmental committee, the Grootvlei Joint Venture Committee, to commission research on the issues and to undertake a cost–benefit analysis relating to mining in the East Rand Basin (Grootvlei Joint Venture Committee 1996). As part of this process, the Water Research Commission asked the Foundation for Water Research to apply the UK methodology to the assessment of the options (Foundation for Water Research 1996) and a longer discussion of the FWR study is given in Green (1999).

The options

The baseline was taken to be the permanent aeration, liming and clarification works. The two main alternative immediate 'do something' options were then to stop pumping and close the mines, or to install a form of desalination plant, either putting the treated water into the potable supply or discharging it to the Blesbokspruit. However, sooner or later the mine will close and a decision will then have to be taken as to what to do then; either to continue pumping but from a higher level in another mine or to allow the water level to rebound to its natural level and to decant downstream. Identifying what would happen under the baseline option and its consequences proved to be important in assessing the do-something option.

The benefits

In turn, a wide range of impacts from one or another option were identified; obtaining sufficient information to be able to evaluate each was more difficult. For example, wetlands are well known to yield benefits in terms of removing polluting loads (e.g. Maltby 1986). However, there was insufficient water quality sampling data to determine what pollution load is removed by the wetlands at present. So, this benefit could not be evaluated. Other categories of benefit which were evaluated, such as the recreation value of the wetlands, proved to have trivial benefits. Therefore, analysis focused upon the five most important categories of benefit to the decision: mining, potable water, irrigation, critical and constant natural capital, and the dolomitic layer.

Mining

The very high unemployment rate indicated that the opportunity costs of the labour employed in the mine were well below the financial costs of wages. Methods of estimating the opportunity cost, or shadow wage, of labour are well established (Squire and van der Tak 1975) if difficult to apply in practice. Using available data, two different estimates of this opportunity cost were made. The estimates of the yield from mining were further adjusted to take account of the remittance of wages and profits overseas. The net effect was to show that the economic value of the mines was significant, a present value of around R580 million.

As export earners, the contributions of the mines to the South African economy depend critically upon both the level of gold prices and the dollar–rand exchange rate in the future. Analyses of projects involving exports or import substitution typically depend critically upon projected future exchange rates. The higher the

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dollar gold price, the greater the proportions of gold reserves which it will be financially viable to extract in the future, the greater the contribution of the mines to the economy, the longer the viable life of the mines and the lower the grade of ore which it will be viable to mine. The assumption was made that neither the exchange rate nor the world price for gold would change in real terms in the future. Therefore, whilst the mine has significant reserves of low-grade ore, it was assumed that it would be uneconomic to mine these and that the economic life of the mine would be a minimum of 12 years and a maximum of 30 years at current output levels. In this particular instance, the final conclusion did not depend upon future movements in the world price of gold and the dollar–rand exchange rate, both of which have moved since the analysis.

Critical natural capital or constant natural asset

The Blesbokspruit wetlands are designated under the Ramsar Convention. Thus, two critical questions were: the extent to which discharges would damage the wetlands; and how to incorporate that damage potential into the cost–benefit analysis in a way which would both work and help the decision process. The approach adopted was the use of the concepts of constant natural assets and critical natural capital (Countryside Commission *et al*. 1993). Consequently, if the Blesbokspruit reserve, a designated Ramsar site, is part of critical natural capital then there can be no question of allowing any discharge which would result in damage to that site. Conversely, if it is better classed as part of constant natural assets then any damage would be acceptable providing that equivalent sites were created or provided. Strictly, such sites should have been created prior to the loss occurring but this could, in this instance, be counterbalanced by requiring a greater area to be provided in compensation for the area lost.

The evidence indicated that the existing wetlands were themselves created by relatively recent human activity; the road, rail and pipeline embankments partly damning the river corridor and resulting in permanent wetlands. The peat samples taken in the wetlands (Breen *et al*. 1996) were all, except one at the very top of the wetlands, dated after the start of nuclear testing, giving the date of earliest peat deposition to be slightly over 50 years ago.

Moreover, it was also found that some 50% of the water flow in the river originates from the discharges of the wastewater plants upstream; given that the potable water supplies are pumped up from the Vaal Barrage rather than originating in the catchment, the seasonal stability of the flow in the wetlands and a large part of the total flow may also be argued to result from human intervention. On these grounds, it was concluded that it would be appropriate to treat the wetlands as a constant natural asset rather than as part of critical natural capital.

The deposition of metal salts undoubtedly caused major damage to the wetlands but this deposition stopped with the completion of the aeration, liming and clarification works. The wetlands will, however, continue to be subject to both a high salt load and also to increased water flows. We did not find an ecologist who was prepared to argue that the saline load would damage the value of the wetlands; indeed, some argued that the increased salinity would make the wetlands more attractive to some Red List species. In the end, it was concluded that the main problem would be the increased flow of water, which would double current flows, and it was claimed that the wetland is already suffering from overwatering.

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However, the policy of extending basic potable water and sewerage provision to the population necessarily means that wastewater flows to rivers will increase and the major proportion of the current flow comes from the upstream treatment works. Therefore, the local sewerage utility was asked to provide estimates of the growth to be expected in those discharges; their estimate was that growth in those discharges over the next 12 years would equal the current flow in the river. Thus, if there were to be no minewater discharges then flows through the wetlands will double and if minewater is discharged then they will treble. Hence water flows would seem to potentially pose a major threat to the wetlands, irrespective of whether pumping continues. Therefore, it was recommended that a management plan be developed for the wetlands, including a water management plan, and that the ecological health of the wetlands should be monitored. As a result of that monitoring, it may become necessary either to provide a bypass channel for the main flow through the wetlands or to construct an equivalent site.

Irrigation

Without desalination, the high salinity of the discharges will make the river waters unsuitable for irrigation use and hence those farms downstream which currently use irrigation will have to abandon its use. As discussed in Section 17.3.4, irrigation yields benefits in a number of ways. On the other hand, water which is used for irrigation is largely lost through evaporespiration. Therefore, water which is freed from irrigation use is available for other uses which may have higher values than its use for irrigation and which, like most potable water uses, return a far higher fraction of the water used than do irrigation uses.

In order to evaluate the value of the water currently used for irrigation, and to compare it to its value in other uses, estimates were required of:

- how much land is being irrigated;
- how much water is used;
- for what crops;
- what cropping pattern would be followed if irrigation water were not to be available; and
- the relative profitability of the farming under the cropping pattern with irrigation water compared to without water.

The estimates of the area under irrigation varied between 640 ha and 1000 ha. The amounts of water that the farmers abstract is not metered and three widely differing estimates of the amounts of water abstracted were also found:

- 16 557 ml/annum based upon an assumed rate of application of irrigation water;
- 3020 ml/annum based upon the amount of water which disappears from the system; and
- 4808 ml/annum (Breen *et al*. 1996).

Breen *et al*. (1996) estimated the loss if all land were converted to dryland maize growing as R2 486 000/year, very small relative to the cost of desalination.

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Potable water supplies

Thus, the economic justification for any desalination had largely to lie in the benefits from increasing the local water resource. Discharge of minewater will increase the salinisation problem which is already affecting the Vaal Barrage, the principal water resource for the province. Conversely, desalination could yield an additional resource close to the centre of demand. However, the new resource would equal a maximum of 2% of current output whilst demand is growing at approximately 3.5% annually in Gauteng Province.

The local water utility, Rand Water, estimates the marginal value of potable water available in the Springs area as being around 55 c/m^3, this being the saving in pumping treated water up to the area from their existing works. Thus, the benefit of desalination would be in the order of R11.7 million/year. That water which was not lost through leakage and evapotranspiration and so was returned to the river after wastewater treatment would be available for reuse but no value was put on this water. These benefits were considerably below the estimated capital and operating costs of a desalination plant, which had a present value of R3000 million, the other benefits resulting from desalination being insufficient to justify desalination.

The dolomitic resource

An outstanding question at the beginning of the Joint Venture Committee study was the consequences of ceasing pumping and allowing water in the basin to rise until it naturally discharged downstream. The basin is overlain by a layer of dolomite. Scott (1995) estimated that the total inflow to the dolomite layer from rainfall might be of the order of 51 Ml/day. This is a potential water resource, with the 51 Ml/day being the upper bound of the potential yield from the aquifer and it could be evaluated in the same way as above. Since this water is currently a significant part of the flows which require to be pumped from the mines, such use would reduce the pumping costs, where again this reduction can be evaluated both in terms of the savings of pumping and treatment costs and also in terms of the downstream consequences of discharging the water from Grootvlei.

In addition, the Scott (1995) report concluded that, if the water level were to be allowed to rebound to its natural level, then there would be a risk of polluted water breaking through the surface as springs so spreading pollution. Thus, there would be a risk of dispersed and diffuse pollution. Furthermore, it is likely that additional sinkholes might be formed. Neither loss can be evaluated without more data but the potential consequences are such to make the acceptability of this option appear very problematic. One consequence is that pumping from some depth will have to continue after the mines have closed.

Lessons

The final conclusion of the analysis was that neither closing the mines nor the use of desalination was economically justified, and that the existing approach of aeration, liming and clarification was the best option. A further study by the Water Research Commission (2000) concluded that when compared to a number of desalination options, the best option was the construction of a 130 Ml/d channel around the

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Bleksbrokspruit, on the assumption that 50% of the water entering the Grootvlei workings originates from the Bleksbrokspruit.

Two almost equally important findings were, firstly, that the wetlands were probably under threat irrespective of the decision about the minewater discharges because of the anticipated doubling of flows through the wetlands from the waste-water plants upstream. Secondly, the conclusion was that the uncertainties as to the consequences of allowing the water in the basin to rebound to its natural level were too great for this to be an acceptable option. In turn, this implies that pumping and treatment will have to be continued after the mines have closed.

22 Information

In water management, data is sparse, unreliable and it is expensive to collect and process. River water quality changes over both time and distance yet water quality sampling is usually collected at a limited number of points, typically where access is convenient, and with a limited frequency. Similarly, flows in rivers are generally measured at only a few points. In turn, even estimates of probable maximum flows, critical for the safe design of dams, can be very inaccurate. The Macchu II dam in Gujarat was built with a spillway capacity of 5415 m^3/sec; overtopping and dam failure caused a 8–10 metre flood wave to sweep down the valley, killing at least 2000 people. The dam was redesigned on the basis of a PMF (probable maximum flood) of 20 925 m^3/sec but before it was rebuilt on this basis, a cyclonic rainstorm produced 700 mm of rainfall in the catchment in a single day. The PMF was reassessed upward to 26 420 m^3/sec (Herschy 1998). Again, a major problem in the Colorado River Compact is that the original allocation of 7.5 million acre-feet (maf) per year to the lower basin states was based on estimates of an annual flow of 16.4 maf whereas subsequently the best estimate of mean annual flow was revised to 13.5 maf but ranging from 4.4 to 22 maf (Gelt 1997).

Again, the accuracy of bulk water supply meters is normally only within plus or minus 10%, and often estimates of the flows of wastewater are no more than guesses. Thus, the legal prospectuses for the water and sewerage companies in England and Wales gave details about the quantity of water each supplied but were entirely silent, since no accurate data existed, on the quantities of wastewater that were treated. Generally, data on the state of distribution and collection networks is similarly sparse; one problem in a major water mains burst in Leeds (Jeffrey 1986) was that the location of the stop valve for that mains was not known with any precision. One of the tasks that the privatised water companies in England and Wales have therefore undertaken is simply one of finding out what networks they have acquired and where those pipes and sewers are actually located. The physical state of those networks is also generally largely unknown and, as discussed in Section 2.1.3, judgements as to the probability that an embankment will fail have to be made qualitatively. Similarly, we have seen (Section 14.4) how little is generally known about how much water households

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and industries use for what purposes. Thus, it is as well for the economist to work on the basis that although engineers may produce estimates to the nearest millimetre, they will be wrong to the nearest metre.

In addition, it is necessary to distinguish between data and information: information is a structure imposed on a set of data so that the data can be interpreted to reduce uncertainty as to the answer to one question. Therefore, economists will usually find themselves either in a situation where both data and information are sparse, or, sometimes, where there is an abundance of data and a scarcity of information. In turn, an important question in water management is whether it is worth collecting any more data, or whether it is worth improving the accuracy or reliability of data collection. For example, whether it is worth undertaking CCTV surveys of sewers in order to assess their condition, or installing district meters in a water supply network in order to monitor patterns of demand and improve leak detection.

The appropriate theoretical approach to undertaking such analyses is the use of Bayesian analysis (e.g. Hadley 1967),

$$p(f_I \mid e_k) = \frac{p(e_k \mid f_I)p(f_I)}{_{(u=1 \text{ to } s)}\Sigma^s p(e_k \mid f_u)p(f_u)}$$

where $p(f_j \mid e_k)$ is the *a posteriori* probability that f_j is true given that event e_k occurs, and $p(f_j)$ is the *a priori* probability that f_j is true.

Enis and Broome (1971) give a simple example of how this equation can be used. Their example refers to a decision as to whether or not to expand a franchise but the approach can equally apply to one concerning enhancements to water resources and other decisions in water management. As shown in Table 22.1, there are three possible courses of action and the outcome of each depends upon the state of nature which the decision maker assesses as having the probabilities of occurrence of 0.5, 0.3 and 0.2 respectively. Thus, the expected value of A1 is 1070, that of A2 is 790 and for A3 the expected value is −250. Hence, we should choose action A1. Alternatively, the regret matrix (Table 22.2) can be calculated; the loss that is incurred by adopting each course of action if we were certain as to the state of nature. Using the original probabilities, the expected opportunity loss can then be calculated as the probability of each outcome times the opportunity

Table 22.1 *Payoff matrix*

Course of action	State of nature		
	S1 0.5	S2 0.3	S3 0.2
A1	1000	1100	1200
A2	−500	2000	2200
A3	−2000	500	3000

Table 22.2 *Regret matrix*

Course of action	State of nature		
	S1	S2	S3
A1	0	900	1800
A2	1500	0	800
A3	3000	1500	0

loss. So, for example, the expected opportunity loss for A3 is 1950. The maximum value of perfect information is therefore given by the minimum of the three expected opportunity losses for A1, A2 and A3; here, this is 630 for A1. The question is then what is it worth paying for imperfect information?

Ennis and Broome give the example of a survey which would have a reliability, a conditional probability, of 0.70: that is, the likelihood that it will assert that S_j is true when S_j is actually true is 0.70. The conditional probabilities that it will assert that S1 is true when the true state of nature is S2 or S3 is 0.15 in each case.

In this case, the Bayes formula can be simplified to:

$$P(S_j \mid R_k) = \frac{P(R_k \mid S_j)P(S_j)}{P(R_k)}$$

Table 22.3 shows the process of calculating the *a posteriori* probabilities. When the values in the payoff matrix are multiplied by the appropriate values of $P(S_1 \mid R_k)$, a revised set of expected values is given. The value of the information given by the survey is then given by the sum of maximum value for each survey result times the probability of that outcome, $P(R_k)$; in this case, a value of 1244.23. The value of the information gained from the survey is 1244.23 minus 1070, and so it would be worth spending 174.3 to acquire this information. The same approach can be applied when the states of nature are not discrete and where there is a probability distribution associated with different states of nature (Hadley 1967).

This Bayesian approach is equally applicable on the supply side of the equation, to the estimation of water availability, as to the demand side of the equation. For

Table 22.3 *Calculation of* a posteriori *probabilities*

Survey result	$P(R_k \mid S_j)$ State of nature			$P(R_k)$	$P(S_1 \mid R_k)$	$P(S_2 \mid R_k)$	$P(S_1 \mid R_k)$
	P(S1) 0.5	P(S2) 0.3	P(S3) 0.3				
R1	0.70	0.15	0.15	0.425	0.823	0.106	0.071
R2	0.15	0.70	0.15	0.315	0.238	0.667	0.095
R3	0.15	0.15	0.70	0.260	0.289	0.173	0.538

example, in principle, it could be applied to predictions of future water demand as well as the estimation of sustainable river flows. However, it is more difficult to see what information we could acquire that would reduce our uncertainty about the future.

The practical problems of applying this theoretical approach are that we need a great deal of information: it is necessary to be able to specify both the prior probabilities and also the reliability of the information that will be obtained. Where the states of nature are not discrete, it is necessary to be able to define the probability distribution. In practice, whilst Bayesian approaches have been tried to assess the value of the data to be gained from hydrometric gauging (e.g. Attanesi and Karlinger 1977), few hydrologists or others have been prepared to venture guesses as to the prior probability distributions or the reliability of the proposed method of obtaining further data. For example, the engineers who were asked to assess the probability that dikes would fail (Section 18.2) before they were overtopped were extremely reluctant to venture even point estimates. So, similarly, were those engineers who were asked to estimate the probabilities that sewers would collapse (Section 16.1.3).

A further limitation of the Bayesian model as a method of valuing data is that it assumes that we collect data simply to refine our estimates of that which we already know. But an important reason to collect data is to find out things that we did not know in advance: to uncover 'surprises' (Brooks 1986). For example, the ozone hole was discovered by accident. It would not have been possible in advance to estimate a prior probability of discovering the ozone hole, or equally of the payoffs from discovering an ozone hole, given that the existence of such a hole was not predicted or anticipated. So, one reason for monitoring is to detect surprises, particularly unanticipated changes. Moreover, generally we cannot go back in time to collect data that now turns out to be useful. It would, for example, be extremely interesting to compare Adam Smith's time series data on wheat prices (Section 17.2) for climatic data for that period but the time series of rainfall data was not started until after the end of the wheat price series. There are sometimes surrogate data sets, such as tree ring series or core samples, that can be used to reconstruct past time series but this is limited; for example, tree ring data cannot tell us the variations in daily stream flows.

22.1 Streamflow Gauging

The two types of decisions that use streamflow data are operational decisions and those concerning capital investments. The former require real-time information whereas the latter typically require estimates of extreme or average values of hydrometric parameters, whose estimation can be improved by increasing the length of record. An additional purpose of gauging is to comply with international law; whilst it can be possible to assess the benefits of introducing a law, it is not legitimate to attempt to assess the benefits of complying with an existing law.

For capital investment, the requirement is to be able to estimate flows, usually extreme flows, in the future. Hence, the length of record is an important factor: Herschy (1980) calculated that in order to achieve a precision of 10% around estimates of the mean monthly discharge of UK rivers, 50 years of record were required (the average length of record in the UK is now 30 years). There are therefore two decisions: whether it is worth installing a local gauging station rather than rely upon the use of regional growth curves; and what is the value of each additional year's data? For operational use, it is accuracy and immediacy of the flows now that are important in so far as these can then be used to predict flows some distance downstream.

The data yielded by a particular gauge must usually also be applied to another, or other, locations and other points in time. Therefore, marginal changes in the information yielded by a hydrometric network can be made in seven ways:

- a change in the accuracy of the gauge reading;
- a change in the reliability of the operation of the gauges, a reduction in the proportion of the time when the gauge is not working;
- changes in the accuracy of transferring data from gauged sites to ungauged sites by proximity, modelling or other methods;
- changes in the density of gauging;
- changes in the speed and reliability with which data is transmitted to the decision maker;
- changes in the speed, accuracy and reliability of methods of analysing and integrating that data; and
- increases in the length of record.

In each case, a different baseline option is defined. In addition, the comparison may involve different technologies, e.g. the assessment of the benefits of installing weather radar against a current reliance on telemetered rainfall and streamflow gauging.

The most detailed formal approach of the value of data in capital decisions is that of Mawdsley *et al.* (1988); they concluded that the value of local streamflow data for the design of three hypothetical impounding direct supply reservoirs varied between 0.4% of the construction cost and 3.8% for four years and 50 years of records respectively. The optimum length of record was then highly dependent on the coefficient of variation of the flow but in their example, the optimum length of record was 50 years.

CNS (1991) undertook a benefit–cost analysis for the UK's streamflow gauging network and the associated data archive. Now the existence or otherwise of the network as a whole is a non-marginal decision and in turn different baselines had to be used in order to get some estimate of the marginal value of the data provided for different purposes. In turn, in order to put a value on the information to a decision, the decision itself must be capable of economic analysis. In short, if those decisions are not themselves based on an economic analysis, or the means are not available to calculate the opportunity losses associated with making incorrect decisions, then the value of information to those decisions cannot be calculated. At the time of the CNS study, economic analysis was only being applied to some decisions in water management and approximations had to be made in other cases. Thus, for example, potentially it is possible to set effluent adjustable discharge consents (e.g. Eheart 1988) so that treatment standards vary according to the assimilative capacity of the river, which in turn is dependent upon the flow and the temperature of the water (Boner and Furland 1982). However, whilst seasonal discharge consents were widely used in the USA (Lamb and Hull 1985), they were little used in the UK (Mathews 1986); indeed, as the study was undertaken, consents were set essentially at a level at which each individual plant could achieve (Green 2001b). But in principle, setting seasonal discharge consents on the basis of flows can significantly reduce costs (Eheart *et al.* 1987), as can adjusting the discharge point according to flow conditions (Kuchenrither *et al.* 1983).

The payoff from over- or underestimating river flows is then as shown in Figure 22.1. It is likely to be asymmetrical as the ecosystem may take a significant time to recover from the effect of a pollution pulse. Moreover, the costs of underestimating the flow are considerably easier to evaluate than those of overestimating the flow which requires calculating the probability of different pollution pulses affecting different stretches of river for different periods of time, taking into account the time taken for the ecosystem to fully recover from the pulse.

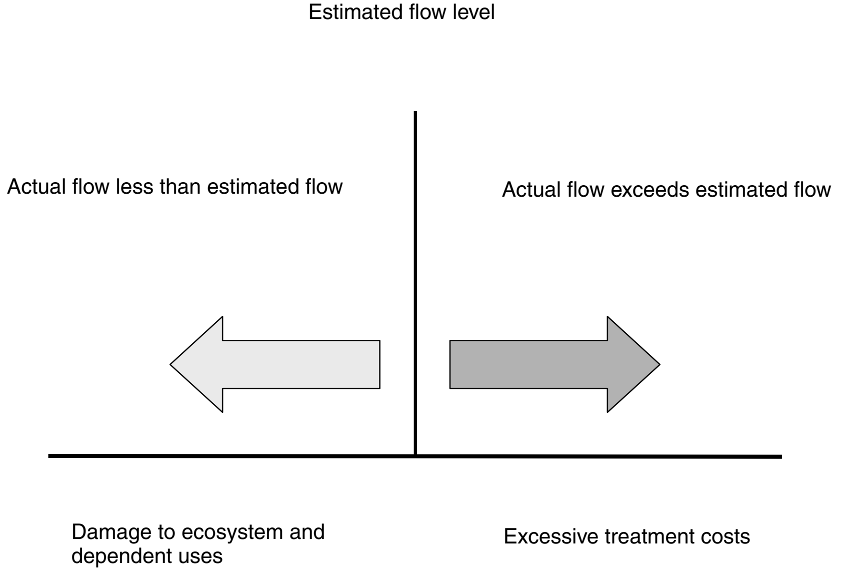

Figure 22.1 *Asymmetries of the costs of incorrect estimates of river water quantity*

A similar pattern as shown in Figure 22.1 should also be expected for water abstractions, with the penalty for incorrectly estimating flows depending upon the nature of the consent given for abstraction. If unrestricted private entitlements to abstraction are created then the penalty is borne by the environment, and the uses dependent upon the environment. Conversely, if as in the UK, major abstractions are limited so that a minimum flow must be maintained at some designated control point, then the costs fall either on the abstractor or the consumer. In this UK context, if flows are greatly overestimated then the decision to abstract the water and the investment made may have been wrong, and another alternative may offer a better return; indeed, it may be necessary to undertake further capital works to create the capacity that it was believed the original source offered.

The CNS study looked at three major abstractions. For example, the flow on the Severn at Bewdley, which is supported by discharges from the Clywedog Reservoir, must equal some $9\,m^3s^{-1}$ before any abstractions are permitted. In turn, errors in gauging at Bewdley would result in unnecessary releases from the reservoir. Replacing the existing gauge by an ultrasonic gauge was estimated to reduce unnecessary releases by up to 5 million m^3 a year. Scaling this figure up by the ratio of total surface water abstractions to the total volume from the three abstractions, and using a value of $1.5\,p/m^3$, the result is an annual benefit of approximately £10 million.

Irrigation in the UK is unsupported and limited to supplementary irrigation. In the absence of streamflow gauging, the assumption was made that licences would be restricted to winter abstraction with the farmers having to construct on-farm reservoirs to store that water for the summer months. Morris (n.d.) estimated the relative costs of constructing such storage being in the range of £1.1 to £5.1/mm/ha/year, giving an estimate of the benefit of streamflow gauging in the range of £7.7 to £35.7 million/year.

Mawdsley *et al.* (1988) calculated the benefits of streamflow gauging to the design of flood alleviation schemes as equalling 4–5% of the cost of these schemes. Given an annual capital spend of some £58 million a year, and the proportion of schemes undertaken on rivers for which gauging data is likely to be available (50%), this gives a value of around £1 million per year.

In the UK, we have got into the habit of believing that floods are relatively benign and hence flood warnings are intended to enable people to protect their property from flooding rather than to reduce the risk to life by moving above the anticipated flood level. Bussell *et al.* (1978) estimated that the annual benefits of flood warnings to domestic properties would amount to £3.2 million (1989 prices); however, this assumed that all of the coefficients in the equation given in Section 18.1.1 are one. Using more realistic coefficients reduced this figure to £0.53 million/year with a practical upper bound of £1.97 million/year. In practice, both these figures are likely to be too high because for small, flashy catchments, reliance on streamflow gauging gives too short a lead time for an effective flood warning system to be practical. Equally, three of the coefficients in that equation should be expected to vary with the warning lead time. The Working Group on National Weather Radar Coverage (1983) assessed the benefits of flooding to industrial and commercial organisations as being small. Hence, given the low reliability of flood warnings, no value was allowed for this stream of benefits. However, Neal and Parker (1988) had found in a post-flood audit of the performance of flood warnings in the Severn–Trent region that warnings had reduced flood losses by £90 000 to farms, largely by allowing farmers to move stock. Scaling the benefits up from these figures to the UK gave a best estimate of £1.5 million a year with an upper bound of £4.5 million a year.

But a major reason for all forms of environmental monitoring is to detect change if it occurs and to discover the unexpected. Thus, there is a quasi-option value associated with streamflow gauging and option value with the network itself. In turn, if significant change were to be discovered then methods of analysis based upon previously collected data would cease to be reliable. Hence, there is a risk that if the streamflow gauging network were to be closed down, then it would have to be reinstated in part at a later date. But since we cannot know in advance the probability that an unanticipated change will occur, it is only possible to make a crude estimate of this option value. Since much of the network is made up of

Table 22.4 *Benefits of the UK streamflow gauging network (1991 £ million)*

Purpose		Best estimate	Lower bound	Upper bound
Abstraction	Potable – capital investment	0.3	0.2	1.5
	Potable – operating	10.0	2.5	17.0
	Irrigation	8.0	8.0	35.0
Effluent discharges	Consents – seasonal	Not currently estimated; potentially significant		
	Consents – other			
	Consents – capital			
Floods	Flood alleviation – capital works	0.8	0.2	1.0
	Flood warnings	1.7	0.5	5.2
Structures (bridges, culverts, weirs etc.)	Capital			Not estimated
Risk of climatic or other change	Current	Cannot be evaluated but a main reason for gauging		
	Reinstating network if closed	7.6	2.4	46.0
Total annual benefits		20.8	11.4	59.7
Total annual costs		9.0		

physical structures in the form of velocity–area structures, crump and other forms of weirs, and flumes, abandonment of the existing network would not mean that these structures would require complete reconstruction if they were needed again after having been abandoned. Equally, the change that had been discovered by other means would not necessarily require reinstatement of the entire network. Hence, in determining the best estimate, it was assumed that only 40% of the network would require reinstatement and that the existing structures decayed at 3.3% per annum. In turn, the risk of requiring such partial reinstatement was assumed to be 0.01 in the first year, rising to 0.1 in year 50. A further series of analyses were then undertaken to calculate upper and lower bounds on the present value (Table 22.4).

The value of a formal data archive is then the increase in the probability that the data will actually be found when needed, coupled to the reduction in cost in accessing that data. Adams (1992) has reported on the problems in actually finding any data in the absence of a formal archiving system.

23

Implementing Integrated Catchment Management

Integrated catchment management is easier to define as an ideal rather than perform as a task, and the integration of the management of land as well as water is perhaps the most difficult part of the task. Land–water interactions present formidable problems of management. Runoff, as we have seen, is both the water resource and the problem where runoff is a function of the use of the land. Land use also generates pollution and influences sediment loads whilst runoff affects soil erosion. At the same time, water management is necessary to support those land uses. In terms of institutional structures to support the management of these interactions, France is probably the country with the most advanced approach in theory with the use of SAGE and related plans (Barraque *et al*. 1994). At the smaller scale, good practice is also developing in the USA (Center for Watershed Protection 1996; Schueler 1995). But, economic analysis should also help in managing the different land–water interactions.

23.1 Erosion Control

Newson (1997) pointed out that rivers are conveyors of sediment as much as of water, sometimes in very large quantities. The Yellow River in China carries some 1.6 billion tonnes of sediment each year, of which 1.2 billion tonnes is carried to sea, down from the loess plateau at its head (Leung 1996). On a smaller scale, 900 000 tonnes of sand arrive in the Netherlands as erosional material from the river bed of the Rhine where the greatest loads are carried and deposited by floods; over 300 000 tonnes in the January 1995 flood. A further 2.5 million tonnes of silt are carried by the Rhine into the Netherlands, the silt originating from soil erosion and urban sewer systems (Silva *et al*. 2001).

The original source of that material is from erosion of the land, much of it being from the natural processes of erosion but some also the result of human uses of that land. It is dangerous to focus exclusively on the problems of deforestation as to do so may result in the real causes being overlooked (Calder 1999).

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Moreover, forests are not permanent but a process, the natural processes of fire and regeneration having significant effects both on the yield of water and of sediment. Thus, in the forested catchments that supply Melbourne with water, it is estimated that after a bush fire, during the regeneration of mountain ash, runoff is reduced by up to 50% of that from the current mature forest, with full regeneration taking up to 150 years (Melbourne Water 2001). On small catchments in particular, the consequences of road construction and building activity (Calder 1999) or animal grazing can be a primary source of the problem. Moreover, only some of the material from soil erosion reaches the river and is deposited downstream, the proportion of upland soil erosion that is deposited in dams or deltas varying from 0.03 to 0.90 (de Graff 2000).

Works to control soil erosion as well as to control runoff were traditional in arid climates (Yapa 2001) and economic analysis can then be applied to assess the benefits of soil erosion control (e.g. Brooks *et al.* 1982). An assessment of the benefits of reducing the erosion from the loess plateau feeding the Yellow River was undertaken for a World Bank project (World Bank 1999b); parts of the plateau, covering some 430 000 km^2 of arid land, have been eroding at a rate of 1000 tonnes/km^2/year (Leung 1996). As a result of deposition, the Yellow River is now perched several metres above the surrounding flood plain. Reducing the rate of erosion through check dams and other means will reduce the rate at which the bed of the river is rising, and hence the rate at which the flood embankments have to be raised to match the rise in the level of the river bed. In addition, the rate of siltation of irrigation canals will also be reduced (World Bank 1999b).

23.2 Alien Species

Introduced species, both land- and water-based, are a significant problem in many parts of the world (Revenga *et al.* 2000); some of these introductions are deliberate but others are accidental such as the flat worms from Australia and New Zealand introduced in the UK with imported plants. Ballast water has also been a major route through which accidental introduction has taken place (Carlton 2001).

Alien plant species in South Africa are both forcing out native species and, in turn, the insect and bird species that depend upon those plants. But, in addition, they have increased the demand for water and hence reduced the flows in rivers. In turn, eliminating these species from the river corridors is a cost-effective alternative to water resource reinforcement (Water Research Commission 2001).

23.3 Agricultural Runoff and Infiltration

Over both the USA and Europe, the majority of river water quality problems are the result of agricultural runoff (US EPA 2000; Nixon 2000). But without the use of pesticides or other control measures such as integrated pest management (DFID 1999), the current global rate of loss of wheat would rise from 33% to

52%; that for rice, from 52% to 83% (Wood *et al.* 2000) with Schmitz (2001) calculating that a drop of 75% in pesticide usage in Germany would result in a drop in wheat production by 25% and a drop in farm incomes of 32–45%.

However, a significant part of the problem results from pesticide usage associated with urban usages, including on railway lines and the verges of roads (USGS n.d.). Some 800 different pesticides are now in use in Europe (Nixon 2000) and the cost of adopting activated carbon treatment of ground and surface water abstracted for potable supply has involved a capital spend of £1 billion with annual costs of a further £120 million in England and Wales alone (Water UK 2001). Not surprisingly, therefore, the option of adopting a Pigovian tax on pesticides has looked attractive (Rayment *et al.* 1998) but the problems of avoiding perverse incentives, given the number of pesticides available, have proved to be difficult to overcome (ECOTEC 1999).

Nitrates and phosphorus in runoff are equally a major problem in much of the world: Nixon (2000) reports that the surplus of nitrates applied in the Netherlands amounts to 200 kg/ha/year and that the agricultural surplus of phosphorus amounts to 13 kg/ha/year. Part of these loads are from fertiliser but animal wastes can also be a major problem: for example, the Delaware basin is badly affected by the wastes produced by factory chicken farming. Eutrophication then causes damage both in rivers and lakes. Nitrate concentrations in groundwater are also a problem; in Europe, 85% of groundwater below agricultural land now exceeds the EU guidelines for nitrate concentration (Stanners and Bourdeau 1995); again, the cost of treating water with high nitrate concentrations before it can be put into potable supply is non-trivial (Bhumbla n.d.).

The options to manage these externalities depend upon whether the water that is affected is groundwater or surface water; in the latter case, buffer strips (Applied Research Systems 1999; Eastern Canada Soil and Water Conservation Centre n.d.) can be an effective means of reducing pollution loads. The five general strategies are then:

- Education and training of farmers in good practice.
- Taxing inputs.
- Regulation; for example, groundwater protection zones (Cartwright *et al.* 1991).
- Subsidising changes in farming practices.
- Tradable permit systems.

It should not be a surprise that it has proved politically more feasible to subsidise farmers not to pollute than to tax or otherwise control these externalities associated with farming. In Germany, the water utilities pay farmers to avoid or reduce pesticide or fertiliser usage whereas in the UK, central government pays the costs of a number of different programmes which are either intended to reduce nitrate usage (ENTEC 1998) or have the indirect consequences of reducing nitrate and pesticide usage although the announced purpose is to protect traditional landscapes, for environmental conservation or other reasons (MAFF 2000).

On a more limited scale, buffer strips can significantly reduce the loads of nitrogen, phosphorus and suspended solids from agriculture to water courses. In the USA, a large-scale programme to pay farmers to introduce buffer strips has been introduced (Applied Research Systems 1999). The advantage of such programmes is that their economic cost is low, farmers being subsidised to produce environmental goods rather than crops that can only be dumped into overseas markets.

In the USA, a number of schemes for tradable pollution systems have been established in which urban areas can 'buy' the pollution from farms: instead of the urban area treating urban water runoff, the municipality can seek to reduce the pollution load from agricultural areas by an equivalent amount. However, at least as yet, there seems to be very little activity in these schemes (e.g. Environomics 1999). Equally, they raise the question of why agriculture should be further subsidised.

23.4 Integrating Integrated Catchment Management into National Policies

Integrated catchment management is not enough; indeed, it could become a snare. Water and land management need to be integrated with other local, regional, national and international policies (Figure 23.1). Thus, it is conventional wisdom

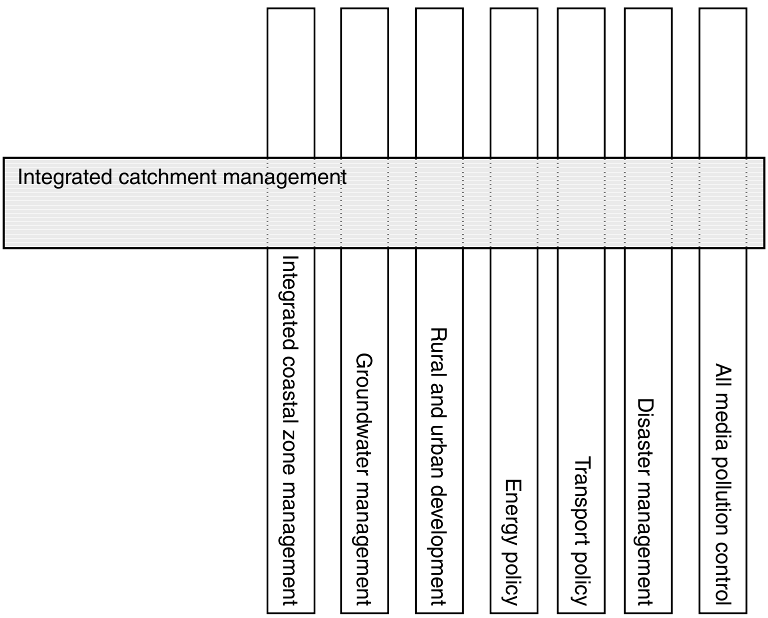

Figure 23.1 *Integrating catchment management into the wider context*

that there should be an 'all hazards' approach to emergency planning (UNDR 1984) and that the system will follow the existing institutional structure of local government. Again, most rivers also reach the sea and there is general agreement that integrated coastal zone management (OECD 1993) is as important as integrated catchment management, where the coastal zone certainly includes the estuary but also a substantial hinterland.

Groundwater is a critical element in water management, and land–groundwater interactions are similarly important. But aquifers and catchments do not necessarily coincide, a catchment therefore not being a logical geographic area over which to manage an aquifer. That there should be a national energy policy seems to be an almost self-evident truth; similarly, a coherent national policy for transport is also logically necessary not least because transport has in the past resulted in significant problems with introduced species (Carlton 2001).

Particularly in countries that are still largely rural societies, a national policy to cover urban and rural development is also a necessity and in developed economies, as the importance of agriculture to the national economy declines, a rural policy becomes more important. Decisions about the use of water for agriculture will impact on food prices, as well as on rural unemployment and migration to urban areas, and to ignore these linkages might outweigh the gains from an integrated catchment management approach. Similarly, the adoption of 'best environmental option' approaches to pollution management results in an 'all media' approach being adopted, as opposed to one that considers only water pollution. In turn, a catchment based approach is not appropriate when considering air or soil pollution.

All these different areas both impact on water management and are impacted by water management. We have therefore to integrate across a whole series of policy areas and not simply land and water management within catchments. It would be fair to describe this as a challenge.

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