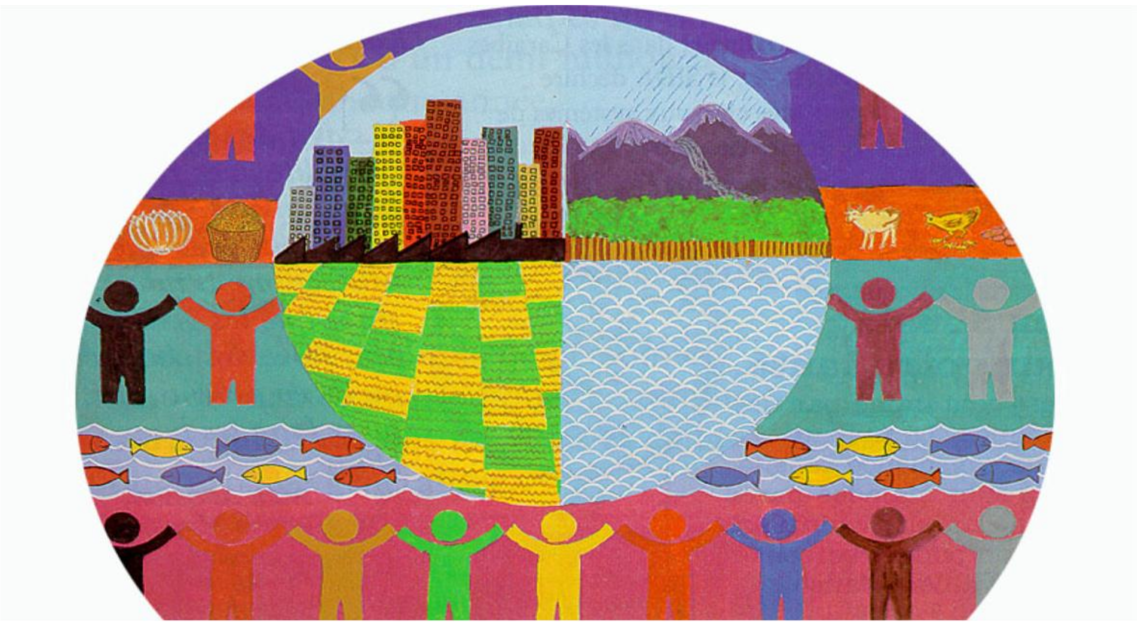
World Health Organization

A Manual for Economic Assessment of Drinking-Water Interventions



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A Manual for Economic Assessment of Drinking-Water Interventions

WHO acknowledges the efforts of Dr John Cameron and Professor Paul Jagals to produce this Manual; the views expressed in this publication do not necessarily reflect WHO policies or positions, and Dr Cameron and Professor Jagals are responsible for the views expressed in this publication.

Contents

Objective of the manual

This manual describes a practical technique for appraising or evaluating small-scale interventions that seek to provide safer and more accessible drinking-water to rural people.

The strength of such economic assessments is that they permit drinking-water interventions to be compared with a wide range of health and non-health interventions aimed at improving human well-being though creating opportunities for more productive livelihoods.

Target audience of the manual

The manual is primarily aimed at experts who are involved in advising on the most appropriate drinking-water interventions to install in small-scale, mainly rural, settings. These experts may be working in any of the disciplines relevant to drinking-water. They include health professionals, engineers and economists.

The manual presents practical techniques in a way that will satisfy the expert yet also be accessible to the non-expert.

Why this manual was written

The making of this manual was inspired by the Millennium Development Goals for 2015, in particular Target 10 under Goal *7* which aims to "halve by 2015 the proportion of people without sustainable access to safe drinking-water and sanitation".

If connections to safer sources for drinking-water between 2004 and 2015 match the rate achieved between 1990 and 2004, then the target of halving the proportion of people not reaching the standards set by the Millennium Development Goals will be reached for the global population. But achieving the target is not a given.

Many of the 800 million people still without access to safe drinking-water live in small and remote rural settlements. This makes them increasingly hard to reach in engineering terms and costly to reach in economic terms.

In this challenging context, the World Health Organization (WHO) provides this manual as an economic assessment tool to evaluate safe drinking-water interventions. The aim is to put such interventions on a level playing field with all other developmental activities.

Outline of the manual

This manual sets out a practical method for doing an economic assessment of a drinking-water intervention in the following five logical steps:

- assessing the situation in terms of placing drinking-water interventions in people's livelihoods;
- costing feasible interventions and assessing cost efficiency;

- identifying and measuring the benefits in physical terms and assessing cost-effectiveness;
- putting values on benefits and undertaking a social cost-benefit analysis;
- conducting sensitivity tests on four social cost-benefit scenarios to take account of:
  - possible inaccuracies in variables;
  - risks and uncertainties around engineering and institutional management of the intervention;
  - demographic changes and associated incremental challenges;
  - aspirational changes and sequencing interventions.

This manual follows these five steps section by section seeking to provide a practical set of tools that can be applied to any small-scale drinking-water intervention in any economy.

This manual is designed to complement a book edited for WHO by John Cameron, Paul Hunter, Paul Jagals and Katherine Pond.[1] The book gives an overview of the steps required to undertake economic assessments of small-scale drinking-water interventions, incorporating the knowledge and expertise of public health and engineering specialists. It was commissioned in an effort to ensure that drinking-water interventions designed to improve access to safe drinking-water (in the words of the Millennium Development Goals) would be accorded priority in line with their potential to contribute to improving human well-being.

A case study to illustrate the economic assessment

In this manual, to give a sense of how the assessment method is applied in practice, a particular case-study is discussed at each step.

The case-study concerns an intervention to provide a drinking-water system for a cluster of villages in the north-east of the Limpopo province of South Africa close to the Zimbabwe and Mozambique borders.

This case study is not offered as typical or representative. Rather, it offers a range of characteristics that are more challenging than might be expected in the context of considering a small scale drinking-water intervention. The case study results should therefore not be taken as indicative of parameters or results for small scale drinking-water interventions in general.

Data for the case study were collected by researchers from the University of Johannesburg in South Africa. The field data were collected by environmental health and civil engineering experts and their graduate students, as well as by economists, over a period of two years for a variety of research purposes.

[1] Cameron J et al., eds. Valuing water, valuing livelihoods: Guidance on social cost-benefit analysis of drinking-water interventions, with special reference to small community water supplies. Geneva, London, World Health Organization/IWA Publishing, 2011.

Some of the data were collected in areas adjacent to the case study site, and related to similar water schemes that opened at different times. Secondary data for most small scale schemes in South Africa were available from government sources and proved very valuable. Also some estimates of variables were synthesized using global conventions widely accepted in the public health and engineering fields.

The case study was unusually well informed – arguably over-informed. This manual has, however, been robustly designed for a much lower threshold of available evidence. The special strength of the method set out in this manual is that it can be used to make an appraisal even when future uncertainties require "guesstimates" of many variables.

Though the design is robust and the economic assessment could be conducted sitting at a desk, we would urge any agency planning a drinking-water intervention to spend time in the field with the target population collecting primary data.

The primary data for the case study were collected using a variety of techniques:

- questionnaire-based surveys;
- direct expert field observation (a very important source);
- semi-structured focus groups (which proved a very cost-effective technique for collecting the kind of broad parameters we needed);
- group conversations at communal taps where people were collecting water or washing clothes.

To understand the local context, we suggest that primary data be collected in this way by any agency planning or evaluating a small scale water intervention.

For the purposes of this manual, we have cited only the final parameters we derived from the primary and secondary data. We have not described in detail how the derivation was actually made. That seemed appropriate for our purposes here, because our aim is to show how such parameters can be used for economic assessment.

In the following sections of the manual, we derive robust conclusions consistent with the likely inaccuracies in our primary data. In the final section of the manual we emphasize the vital importance of sensitivity tests to assess tipping points in terms of decision-making. Some of those tipping points are attributable to data inaccuracies.

It is worth mentioning that the case study intervention was actually in the early stages of operation at the time when much of the data were collected. This had the advantage of giving a sense of grounded reality to the case study, even though we did not wait for the final impact to be visible. For example, we would have had to wait years to see what happened when children advantaged in schooling by the intervention became adults.

Though we were neither appraising a proposed intervention nor conducting an impact evaluation, the techniques described in this manual are – we claim – applicable to any stage in the project cycle. So we have purposely written the manual in ambiguous terms in regard to whether it is intended for use in appraisal or evaluation. It is intended to be used for both.

Assessing the situation in terms of placing drinking-water interventions in people's livelihoods

The first step in any economic assessment of the impact of a drinking-water intervention is to describe the context in which the intervention is being introduced. There are quantitative as well as qualitative dimensions to such a description.

The quantitative dimension involves identifying the demographic scale of the target group of local people who will be primarily affected by the intervention.

In areas where local or municipal demographical data are not available, the starting point will often be to a construct a map or other form of layout of the proposed or current intervention area (for example, a water supply scheme within a village). The map will show all the dwellings, taps and water sources within the area. Making such a map is a common entry point for participative activities, and it starts with an open invitation to local people to come to a meeting. Constructing a map together is usually uncontroversial and fun, and can easily lead to wider but necessary discussions on subjects such as livelihood patterns, relative wealth and social interactions.

Alternatively, a household census (with a house to house survey) can establish a more precise description of the demographic characteristics of the target population, especially where complex patterns of intra-household migration are involved. In areas where formal addresses do not exist, a global positioning system (GPS) address can be allocated to a household.

But whether participative or household survey methods are used, it is important to be aware of people who may be considered marginal, vulnerable to strangers, or socially embarrassing, and who may therefore be missed. People who may be missed (unless there is some specific probing) include:

- the very young;
- seasonal migrants and refugees;
- young women (especially if betrothed);
- people with physical impairments considered likely to hamper marriages of siblings.

For this reason the would-be assessor should make sure that local permission (from the community leadership) as well as internationally accepted ethical clearances are obtained from the relevant government departments, nongovernmental organizations, as well as participating universities.

The demographic pattern provides a vital scaling factor for scaling up estimates of variables based on household or individual observations into aggregate estimates (for example, total days of illness prevented). Sex and age are essential characteristics for improving the accuracy of such estimates.

In the case study village, a number of issues arose in creating a demographic data base. First, there was a decision to be made on the precise area to be covered for the specific scheme being assessed. While the pattern of the standpipes supplying water from the nearby clean water reservoir did seem to create a clear picture of the extent of the scheme, there were contiguous and earlier drinking-water interventions. These created a fuzzy frontier between households that would benefit directly or indirectly from the case study scheme and those that would not.

Also, new households seem to have been attracted to the area by the drinking-water intervention, causing further uncertainty over the population being served by the scheme. The surveys conducted for the case study showed that there were initially about 850 directly-affected households, of which about 250 already had access to good quality water from an earlier phase of the current scheme. Therefore these 250 households would not be expected to receive significant health or water-access benefits from the complete scheme, introduced in 2004.

The fuzzy frontier of the scheme had three other elements. Water was being piped to schools (treated for our purpose as part of the supply to the target households), though not to health clinics that had their own independent boreholes. An indeterminate number of other households in neighbouring villages were being served by the scheme through tanker-trucks drawing water from an overhead outlet perched on the current system. To further complicate matters, a small local mine was taking an indeterminate volume of water from the scheme and paying for only part of it, on an ad hoc basis in both physical and financial terms.

All elements of uncertainty are included as additional benefits in one of the sensitivity tests in the final section of this manual.

The demographic characteristics of the case study area revealed that the sex ratio was heavily female (113 females per 100 males), indicating that considerable numbers of adult males migrate. This needed to be taken into account both in aggregating variables and in understanding livelihood patterns. The extent of adult male migration was also indicated by a survey report that, in 2007, about 4% of the resident population had not been resident for at least three months of the year.

The relative youth of the population is indicated by an estimate that 45% of the total population are under 18 years of age.

Livelihoods analysis explores the frontier between quantitative and qualitative information. Cameron et al. (2011) describe how the livelihoods approach emerged in the early 1990s as a technique for capturing the totality of activities of households. At its most ambitious, livelihoods analysis seeks to observe all forms of wealth assets to which a household has access and all the activities that contribute to the material well-being of a household. This includes observing how households seek to preserve their livelihoods when under pressure or enhance their livelihoods when new opportunities emerge, for example as a result of a drinking-water intervention.

Cameron et al. (2011) also describe some direct linkages between drinking-water interventions and livelihoods (see Table 1). But every context will have a particular pattern of linkages, and the task of the investigator is to scope the situation and create the pattern that seems most relevant to the specific context. In that respect, the importance of direct observation and informal conversations, especially close to water access points, should not be underestimated. Spending time watching and listening can reveal much about livelihoods.

The major goal of scoping the livelihoods pattern in the catchment area is to identify what people do with additional time, energy and any other resources released by drinking-water improvements.

In the case study area, we have already mentioned the sex ratio and its indication of substantial male emigration from the catchment area. Triangulation of various observations suggested a very low level of monetized economic activity and little produced wealth. The occasional general store or vehicle maintenance and repair workshop were the only signs of commercial activity and investment in technology within the village. This direct observation was confirmed in house to house interviews in which very little economic activity was reported. Only a quarter of the year-long resident population aged 18 years and over appeared to be earning any income.

Direct observation, as well as conversations about new housing construction as an indicator of the distribution of produced wealth, suggested a heavy influence of remittances from urban areas – older women were observed living alone in newly constructed sizeable houses, some with private water connections.

Table 1 Possible livelihood benefits of providing small-scale drinking-water improvements for rural populations

Effect	Socioeconomic implications	Possible indicators
Increased water availability enhances natural wealth	Natural wealth available for greater use in a sustainable manner	Higher agricultural production in terms of crops/livestock/forest products
Experience gained with using produced wealth in the form of new equipment	Incentive to acquire mechanical skills and new technology	Adoption of new technologies in other activities increasing productivity
Improved health status of economically active individuals	More time and energy available for economic activity	Increased economic activity © additional time in value adding occupations
Less time spent caring for sick family members and fetching water	More time and energy available for productive, reproductive and social activities	Additional time in useful activities with direct and indirect gains to the household and society
Fewer infant/child deaths	Gain of net lifetime earnings	Average net lifetime earnings
Young people’s school attendance improved	Gains from improved educational standards	Improved access to higher earning occupations
Nutritional gains: improved absorption of nutrients and/or additional food production	More time and energy available for a range of activities	Dietary observation – anthropometric measures
Collective activity in planning and implementing improvements	Spin-offs to other local, collective projects	Evidence of consequent successful, local collective activities

Source: WHO, 2008.

There are therefore both productive and vulnerable parts of the population, but they are spatially separated for much of the year. Thus it is difficult to talk accurately about the distribution of economic activities and overall labour productivity for many households. Protection against poverty appeared to rest significantly on intra-family remittances and regular payments of State monetary allowances, both for child support and old age pensions.

In terms of human wealth development, there were both primary and secondary schools active in the case study area. Direct observation suggested a high take-up of formal education at both levels. Therefore impact on school performance (not necessarily enrolment) is a factor to be considered in the economic assessment.

There was significant local agricultural activity. For instance, tomatoes are marketed nationally from this area, using natural wealth close to the main river. But household surveys suggested very little involvement of the intervention target households in this activity. Similarly, the presence of natural wealth with tourism potential – in the form of a nearby game park – appeared to be having very little influence on local livelihood activities.

It was difficult to find evidence of strong social wealth in the area. The support of kin or neighbours, and the presence of benign local chiefly authority and well-attended churches probably operated to smooth day-to-day life, protect against vulnerabilities and settle disagreements. But there was a lack of clear collective, deliberative institutions, such as collective meeting places (other than the water taps), and there were no posters advertising events or public meetings.

This limited local social wealth was reflected to some extent in the institutional management arrangements for the water scheme. The drinking-water intervention had not been designed or implemented through self-generated local institutions and there was a widespread sense of powerlessness with respect to undertaking even minor repairs to taps. This vulnerability of the system to breakdown is dealt with in one of the sensitivity tests.

Taken together, these livelihood observations in the case study area suggested it would be very unlikely that a full economic assessment, in the form of a social cost-benefit analysis, would show significant net economic benefits (in terms of rate of return) from a drinking-water intervention that links improved access to safe drinking-water to significant additional high-value local economic activities.

If the case study intervention provides significant economic benefits in terms of high value added, these would be captured only by taking account of links to the wider South African economy over the long term. In order to encompass that wider view, the economic assessment would need to be extended to a full social cost-benefit analysis.

Costing feasible interventions and assessing cost efficiency

Cameron et al. (2011, chapter 8) set out a framework for costing a drinking-water intervention.

The first step is to decide on a realistic physical life for the intervention, say 20 years (from 1998 to 2017 in the case study). All costs to all affected organizations (public and private) and households will need to be entered onto a spreadsheet (an Excel spreadsheet is fine for this purpose) on an annual basis.

The costs should be entered for the year when the money was actually spent, without any consideration of depreciation. Also the costs should be real, in terms of not including any price inflation element. That is, costs should all be calculated on the basis of the level of overall prices for a specific base year.

The pattern of total costs for the case study might then look as shown in Table 2. This is a time profile of expenditures for the case study system. The costs have been synthesized from the technical specification of the system, based on standard parameters used by engineers.

The pattern shown in Table 2 suggests six years dominated by construction and then two years of normal running, followed by some fine tuning maintenance or repairs, and then normal running costs with a major maintenance or repair cost in year 2012, say replacement of the pump. The intervention ends in 2017 with an endpoint estimate of the costs of restoring the natural environment minus the residual value of the remaining assets.

The significance of a hypothetical moment of closure is that it forces decision-makers involved in any intervention, not just a drinking-water intervention, to reflect upon the environmental impact of the intervention, rather than letting the discounting factor erode concerns for the future into insignificance.

One major consideration for the endpoint scenario in any water interventions is whether or not it has depleted the stock of water available to future generations by “mining” non-recharging or slow recharging sources, such as fossil aquifers. In such cases, the cost of replenishing the source from the least costly alternative should be included in the endpoint costs. Whether or not this is actually done is irrelevant to the economic assessment – what inclusion of such cost will do is make such “mining” interventions

Table 2 Synthesized time profile of costs for the drinking-water intervention scheme

Year	Total costs (thousand rands)	Comments
1998	1500	Start of construction
1999	1500	
2000	1500	
2001	1500	
2002	1500	
2003	1500	
2004	175	Taps turned on (normal operation)
2005	175	
2006	500	Repairs of teething problems
2007	175	
2008	175	
2009	175	
2010	175	
2011	175	
2012	500	Replacement of pump
2013	175	

2014	175	
2015	175	
2016	175	
2017	500	End of project environmental refurbishment minus residual value of remaining assets

All costs expressed in terms of prices prevailing in 2007.

less economically attractive than more sustainable interventions and therefore less likely to be prioritized for implementation.

Putting aside the endpoint costs, an economic assessment needs to make estimates (often these will be in a margin of plus or minus 10%), for each year when the intervention is operating, for the cost variables listed in Table 3. These costs are directly associated with ensuring local water supplies.

There may also be less direct managerial and other costs that could be attributed to the scheme from agencies providing services, such as water quality testing and regulatory or support services. Deciding on an appropriate amount to be attributed would require consulting these agencies. For such costs, it may be appropriate to attribute a percentage of the scheme's costs or a cost per unit of capacity.

In the final section of this manual, we will look at costing from the perspective of sensitivity tests. But it is useful here to bring out the kind of considerations that complicate costing and make it not just an accounting exercise.

An economics assessment is concerned that costs are necessary and sufficient to produce a socially optimal outcome – a drinking-water intervention that delivers the planned supply of safe water over the whole lifetime of the intervention.

Table 3 Basis for calculating costs for the drinking-water intervention scheme

Capital cost of intervention (may be spread over several years)	
Wage/salaried labour	Person-days at cost
Equipment (including pump, piping, joints and taps, additional water storage and/or treatment)	Types and amounts at cost
Construction materials	Types and amounts at cost
Village labour	Voluntary local labour in person-days costed at local agricultural wage rate
Running costs to sustain system at design level (not necessarily actual costs) [a]	
Wage/salaried labour	Person-days at cost
Fuel and equipment	Types and amounts at cost
Village labour	Voluntary local labour in person-days costed at local agricultural wage rate

Regular maintenance costs to sustain intervention at design level (not necessarily actual costs) [b]	
Wage/salaried labour	Person-days each year at cost
Equipment	Spare parts, tools at cost
Village labour	Voluntary local labour in person-days costed at local agricultural wage rate
Estimated repair costs to sustain intervention if unforeseen events occur (clearly this has to be an engineering judgement taking account of risk analysis) [c]	
Wage/salaried labour	Person-days as and when needed at cost
Equipment	Spare parts, tools at cost
Village labour	Voluntary local labour in person-days as and when needed costed at the local agricultural wage rate

[a] Running costs may be similar in all years and based on actual costs if considered sufficient to sustain the system at design level.

[b] Maintenance costs may follow a regular pattern but vary from year to year as more or less durable parts of the system have to be replaced. Any necessary system down-time will have to be included (with any associated tanker costs). May be based on actual costs if considered sufficient to sustain the system.

[c] Repair costs can be based on actual costs for similar interventions in similar environments, or can be derived wholly synthetically from an engineering and social risk assessment. By their nature, these costs are bound to have an element of uncertainty and it will be a matter of judgement on when they are likely to occur. In extreme circumstances of complete breakdown, the system may close down prematurely and all forecast benefits after that time be lost.

The actual costs in a public sector budget plus household contributions may or may not be necessary or sufficient for this purpose. For instance, there may be:

- delays in construction and loss of valuable benefits to households in the early years of the intervention;
- sub-optimal running costs (in other words, expenditure below the amount needed to sustain the system at design level of delivery), leading to loss of supply to some households;
- sub-optimal maintenance costs, leading to more system down-time and/or more repairs;
- insufficient repairs, leading to more down-time and/or an early end to the programme;
- incremental growth of the system and/or sequential improvements to the system that need to be incorporated at appropriate years in the spreadsheet;
- prices for labour and/or materials that do not reflect their scarcity values to society as a whole.

Sensitivity tests can vary all these variables to assess the effects of modifying costs on the feasibility and desirability of any intervention.

Turning to the case-study, about 900 households in the water service area receive water from a supply system configured to pump untreated but good quality groundwater to elevated clean water storage tanks from where water is gravity-fed to communal taps in the village cluster. Capital costs therefore include installing the pump, building the reservoirs, burying piping and constructing communal taps.

Running the system on a day to day basis is the duty of a villager who is paid 300 rands a month. This cost seems necessary to sustain the system at its physical design operational capacity, but is arguably insufficient to build the social capital necessary to ensure speedy repairs, local ownership and fair distribution of the water. Arguably, running costs to genuinely sustain the system should be considerably higher than this. We have put these higher costs in Table 2.

It was difficult to get maintenance costs for the case study intervention – the system seems to be repaired (rather slowly in terms of the taps) rather than receiving preventive maintenance. Though the pump equipment appears to have functioned well for the first five years (from 2004 to 2007), in terms of likely future breakdowns requiring major repairs, the pump is a clear candidate for concern. Therefore in our costing spreadsheet we made provision for the pump being replaced in year 2012. Other than this we have included estimated maintenance costs to sustain the system – probably much higher than actual expenditure.

Finally, the intervention appeared to involve no additional expenditure on water transport or processing by households. Observation suggested that households were using the same numbers and types of containers (and occasionally wheelbarrows) they would have used with the unimproved drinking-water sources. We also assumed, for the purposes of this manual, that the scheme did not impose significant additional costs on public sector agencies in terms of water quality and regulatory or support services.

It is worth noting here that if households paid a tariff or fees for water provision this would not affect the costing spreadsheet. In terms of an economic assessment aimed at understanding the social value of an intervention, the concern is with the monetary value of the real resources being used, not who pays the bills.

Discounted cost efficiency

Cost efficiency is the simplest form of economic assessment – it is where economics and accountancy overlap to a considerable degree. If the goal is to give a particular target group of people a specific improvement in access to safe drinking-water, then the intervention with the minimum total cost of sustainably achieving that goal should be prioritized.

But different interventions will almost certainly have differing cost profiles across time. An intervention with a lot of initial expenditure on construction will have a very different pattern from one that has a low construction cost but high running costs.

To create a level playing field for comparison requires that all costs be expressed in terms of one point in time (usually the first year of the intervention, t0). This will require discounting at a specific rate of interest. That is, costs in the future will be reduced by inverting the normal accountancy compound interest calculation, to discover what amount would be needed in year 0 to pay that cost when it is actually incurred. For example, in the case study, the heavy expenditure to replace the pump in year 2012 will have the values in 1998 as shown in Table 4 for different interest rates.

All the interest rates are real, in the sense that they ignore price inflation over the life of the intervention. The rate of 3% is included because it is a rate often used by WHO and other public agencies – it roughly corresponds to the historic very long term rate of return to low risk investments ("blue chip" securities) – plus taking significant responsibility for the future environment. We will therefore use an interest rate of 3% for the remainder of this manual.

The dramatic power of discounting as a way of putting a value on time is clearly revealed in Table 4. So what prevents discounting from becoming a de facto technical rule of always postponing to tomorrow rather than doing today? The answer is the politically set goal of delivering a given level of service to a given group of people.

In general, postponing expenditure on an intervention will mean not achieving that goal. So if the political decision is to provide a cost efficient service as fast as feasible, then heavy expenditure up front may be economically justified in terms of the lowest present value of costs to achieve that specified goal. This reasoning is valid independently of all other considerations, for example fulfilling a constitutional right to safe drinking-water as in South Africa.

For the synthesized costs presented for the case study, the total present value discounted at 3% per annum amounts to 10.7 million rands (see Table 5). This is the estimated simple cost efficiency of the system taking account of the time profile of the expenditures as shown in Table 2. Any other proposed scheme to provide the target population with safe drinking-water on a sustainable basis would have to match this total cost in 1998 (adjusting for price inflation between 1998 and 2007).

As we have seen, this measure of cost efficiency has involved a large amount of synthetic calculation (as would happen in an economic appraisal). But there are elements such as the lengthy construction period and the periodic exceptional repairs that introduce an element of speculation on the performance of a real system under conditions of institutional and physical risks and uncertainty. We will return to this in the first scenario of the sensitivity tests in the final section of this manual.

There are circumstances in which taking the most cost efficient option (in terms of minimum cost to achieve a given goal) may not be the most socially cost-effective decision in terms of achieving socioeconomic impact. We will discuss this in the next section of this manual.

Identifying and measuring the benefits in physical terms and assessing cost-effectiveness

Cameron et al. (2011) explore the ways in which improved access to safe drinking-water can produce benefits in addition to saving direct costs of diagnosis and treatment. In identifying these additional benefits, a basic distinction is made between health benefits and wider livelihood benefits. But most aspects of both forms of benefit share the

Table 4 Discounted values in 1998 of actually spending 500 000 in 2012, at different interest rates

Interest rate (%)	0	3	5	10	15
Present value in 1998	500 000	331 125	252 500	143 600	70 188

Table 5 Discounted costs

Year	Total costs (thousand rands)	Discounted value at 3% per annum $y(0) = y(t)/(1.03)^t$
1998	1 500	1 500
1999	1 500	1 456
2000	1 500	1 414
2001	1 500	1 373
2002	1 500	1 333
2003	1 500	1 294
2004	175	147
2005	175	142
2006	500	395
2007	175	134
2008	175	130
2009	175	126
2010	175	123
2011	175	119
2012	500	331
2013	175	112
2014	175	109
2015	175	106
2016	175	103
2017	500	285
Total		10 732

All costs expressed in terms of prices prevailing in 2007.

common characteristic that they can be measured in terms of health gains as well as in terms of people's time and energy made available for other activities.

This ability to aggregate various forms of benefit into time as a common element can be seen as an advance on simply looking at a more specific physical indicator, for example episodes of diarrhoea prevented. Such specific indicators can be used as cost-effectiveness indicators (for example, cost per episode of diarrhoea prevented) if that is the policy focus. This may be seen as an advance on the simple cost-efficiency measure of minimum cost to achieve a highly specific output target (see the previous section of this manual) because it includes an element of an actual outcome in terms of human well-being and can be used to compare any interventions, anywhere and on any scale, that have reducing episodes of diarrhoea as a major goal.

Freeing time is a more general effectiveness indicator, allowing an even wider range of interventions aimed at improving livelihoods and well-being to be compared. In an economic assessment focused on time saving, health benefits come from time freed by fewer episodes of ill-health that can now be used for additional livelihood activities. The economic assessment may also include time made available by preventing premature deaths. We will discuss this separately below. In the simplest case, the number of days ill in a year are treated as days totally unavailable for any meaningful livelihood activities. But a simple dichotomy of being either totally in or totally out of economic activity ignores the possibility that some activities can continue to be undertaken during an episode of less acute illness.

A more subtle approach to assessing the overall gain in human well-being from fewer episodes of illness uses the WHO DALY (disability-adjusted life year) indicator. The DALY summarizes the total effect of all episodes of illness in a year. As a statistic, the DALY indicates the proportion of a chronological year lost as a result of ill-health. A year in good health has a DALY value of zero, while dying at the beginning of a year gives the year a DALY value of one. Thus DALYs allow very different forms of ill-health to be compared against a standard measure expressed in terms of time and therefore are useful in looking at overall changes in health status, as shown in global comparisons by WHO (see the WHO web site for such comparisons).

When making economic assessments of small scale drinking-water interventions, however, DALYs are more analytically sophisticated than really needed. Simply treating a day ill as a day lost to livelihood activities is necessary and sufficient. The acuteness of an illness is then indicated by the duration of the illness. For example, the long term impact of excessive arsenic intake from drinking-water can be distinguished from an episode of bacteria-induced dysentery in terms of days of ill-health.

In the case study, the reduction in the number of days affected by drinking-water related illness (taking days with diarrhoea as a proxy) was estimated to be just over six days per person per year for those who previously used surface water from the river. The number of episodes decreased from ten episodes per thousand people to three per thousand. The total number of episodes of diarrhoea prevented was therefore 2450 for the 3500 people previously using the river as a source of drinking-water.

The total time savings from diarrhoea reduction can be calculated assuming an estimated average time unavailable for livelihood activities of three days per episode. The total time made available for livelihood activities as a result of the drinking-water intervention for the 3500 people in the catchment area who previously used river water can then be calculated as 7350 (calculated as 3 x 2450) days per year (or 20 person–years per year). Those in the study area who previously had access to an earlier smaller scheme are assumed to have no health (or water collection) benefits.

Additional livelihood benefits for those who previously used the river also appear as time made available through time freed from caring for sick people, and through spending less time collecting and treating water. There might also be time savings in obtaining water for washing clothes and personal hygiene that could be taken into account as benefits.

Of course, providing better quality water does not necessarily mean decreasing the time and effort involved in collecting water – the better quality water may be further away. But, in general, interventions seek both to improve quality and decrease collection time.

In the case study, the time dedicated to caring for sick people was directly linked to the time that the people were ill. Time devoted to care was estimated at half a day for every day of illness. For the part of the case study population who previously used the river, the total time devoted to care was estimated to be 3750 days a year (about 10 person–years).

Given the large area covered by the case study system and the wide differences in distances from previous surface water sources, the time saved by households in collecting water for all activities was very variable. But for households previously using the river, an average saving per household of 1.5 hours a day in collecting water seems reasonable. There was no indication that home-treating of water was a common practice before the intervention, so no savings (time or produced inputs) were identified. Therefore the total time saved in a year by the households that previously used the river was estimated at around 330 000 person–hours (1.5 x 600 x 365, rounded to two significant figures). If on average a person spends ten hours a day on very broadly defined socially valuable livelihood activities (including care for children and the elderly, pre-school learning, formal schooling and community decision-making) that would otherwise have been disrupted by illness, then this is equivalent to 33 000 days or 90 person–years.

As indicated above, the discussion so far has been put in terms of morbidity as prevented episodes of illness and not prevented deaths. Diarrhoea is a significant mortality threat for very young children. In the case study area, about 50 at-risk babies (in households that used river water) were born in the year before the intervention came into operation, and there were a further 230 young children in the highly vulnerable age range of 1–5 years. Given the wide access to local mother and child health advice and care facilities in South Africa, it might be expected that young children would be shielded from drinking unsafe water. Therefore it is assumed that five early deaths are prevented on average per annum by the drinking-water intervention. Thus we will add five years per annum on a cumulative basis to our annual person–years made available in each year over the whole life of the intervention. For our purposes here, no account will be taken of the expectation that these gains will continue beyond 20 years and no account will be taken of the savings in funeral expenses.

In addition to time savings for periods of ill-health avoided, fewer episodes of illness reduce the amount of resources needed for health sector treatment. These benefits may appear as savings for households and/or the public sector (if health care is provided on a subsidized or free basis).

In the case study area, health treatment costs were borne both by households (for example, in the form of transport and any private health sector costs) and by the public sector in providing subsidized health services. Households would respond to an episode of diarrhoea in rather different ways depending on who was ill, how severe the symptoms were, and how much time and money were available to seek and fund treatment. Non-treatment, treatment with purchased drugs, using the local public sector clinic or visiting the more distant public sector hospital were all possible responses.

Our estimate of the cost of health sector treatment per episode of diarrhoea is based on the cost of private sector consultation and treatment. In an economics assessment, this can be justified as representing the "social" cost of treatment by assuming that private sector charges represent market tested pricing. Consulting a private sector doctor involves a fee of at least 900 rands, and with medicine a total cost of about 1000 rands seems appropriate. For the population previously using the river, this suggests maximum savings of 2.8 million rands per year arising from reducing the number of episodes of diarrhoea by 0.8 episodes per person per year for 3500 people, assuming that episodes were treated. But in many cases, symptoms would be recognized and medical advice would not be sought or would be sought only from a nurse in the local public health service clinic (free to the household but a social cost in public sector resources). Therefore a much lower figure for health sector treatment would be reasonable. Assuming this to be the equivalent of about one in seven episodes being treated privately, then the total monetary equivalent cost to households and the public sector would be 400 000 rands a year.

We are now in a position to undertake a cost-effectiveness analysis of the impact of the drinking-water intervention.

First, we suggest that discounting should be used for all indicators of effectiveness. Preventing an illness now, for example, is more socially valuable than preventing the same illness in the future. There is an element of inter-generational bias in favour of the current generation in this recommendation, but at a discount rate of 3% we suggest that this bias is acceptable. The hope is that future generations will have an advantage in terms of access to better medical technology.

Another complexity is that we have three different dimensions of effectiveness measured in three different units:

- reduction in total number of episodes of diarrhoea discounted over the whole life of the intervention;
- greater time available for broadly defined livelihood activities for the sick, those caring for the sick, and time released from collecting and treating water, discounted over the whole life of the intervention;
- monetary and budgetary savings in treatment costs by households and the public sector, discounted over the whole life of the intervention.

A conventional cost-effectiveness approach to the last indicator is to subtract the monetary present value saved in health care from the present value of building, operating and maintaining the system, in other words to treat the savings as a negative cost. This will reduce the total cost of the intervention, making it more of a "social" cost in the sense of widening the costs taken into account beyond the costs of interest to a cost accountant, who would only be concerned with direct costs to the agency that was building and operating the drinking-water intervention.

A problem of interpretation arises if the savings are so great that the result is a negative number for this discounted total social cost. Interpreting such a result is complicated, because the exercise has de facto become a matter of estimating net monetary benefit effectiveness, rather than being a cost effectiveness exercise. For example, the greater the absolute value of the benefits per episode of diarrhoea, the better the intervention. That is to say, a present value cost of minus 100 is inferior to a present value cost of minus 150, while a present value cost of plus 100 is superior to a present value cost of plus 150.

But putting this complication to one side, having disposed of this dimension in the costs numerator, the remaining two dimensions are both candidates for the effectiveness denominator. The first (reduced number of episodes of diarrhoea) is simpler from a health perspective, and can be used to compare different interventions. It can be estimated just using engineering costs and health service statistics (as an indicator of prevalence of episodes of ill-health). The need for data from the target population is minimized. The second (greater time available) is evidentially richer in including both health and wider livelihood impact, but is more demanding in terms of making local observations.

In the case study, our calculations suggested the following values for cost-effectiveness indicators (see Annex A):

- deducting the present value of financial savings on medical treatment from the present value of capital investment and operation and maintenance costs: at a discount rate of 3% per annum, the net present value after this deduction falls significantly to 6.7 million rands (instead of the simple cost efficiency calculation of 10.7 million rands derived in the previous section of this manual);
- total discounted reduction in numbers of episodes of diarrhoea was estimated at 22 500: dividing this figure into the total discounted social costs of 6.7 million rands gives a cost effectiveness measure of about 300 rands per episode prevented in addition to the costs of health treatment avoided;
- total discounted gains in terms of time for livelihood activities released by less illness, less caring for the sick, less time collecting water, and reduced infant mortality was estimated at 1400 person–years: dividing this into 6.7 million rands gives a cost effectiveness figure of 4800 rands per person–year of livelihood activity gained.

In themselves, the absolute values of these cost effectiveness indicators have no meaning. Putting them in a South African context, however, gives them weight. In particular, the sum of money involved in preventing one episode of diarrhoea does not appear cost-effective, because 300 rands is equivalent to more than a week’s wages for a low paid, full time employee. The livelihood time cost effectiveness indicator looks more cost effective. A low-paid full-time worker might expect to receive an income of over 12 000 rands a year. So 4800 rands may be an acceptable price for gaining a whole year of activity.

These results are consistent with global economic assessments of small scale drinking-water schemes. Such assessments conclude that a large proportion of the benefits come from time saved in collecting water.

As a final point on using cost effectiveness analysis to prioritize interventions, it should be borne in mind that cost effectiveness statistics need to be used cautiously in making comparisons. Before comparing and making decisions informed by such comparisons, it is crucial to ensure that like is being compared with like, in terms of the specification of the cost-effectiveness indicator. For instance, it is helpful to ask:

- Have monetary savings been deducted as negative costs in all cases?
- Is the specified effectiveness indicator identical for all cases?
- Have the same discounting procedures been followed for all variables at an identical discount rate?

Social cost-benefit analysis is an extension of cost effectiveness analysis that can remove problems of ensuring comparability, not just between drinking-water interventions or across the whole health sector. At its most ambitious, it seeks to compare all interventions coming from every sector that claims to offer improvements in human well-being anywhere in the world. Therefore, as the logical next step in economic assessment, the following section of this manual is devoted to social cost-benefit analysis.

Putting values on benefits and undertaking a social cost-benefit analysis

In the cost effectiveness analysis in the previous section of this manual, we arrived at two estimates of cost effectiveness. These allow unit cost comparisons between any interventions aimed at reducing episodes of diarrhoea and/or any interventions aimed at increasing time available for livelihood choices.

The first field of comparison is confined to interventions aimed at reducing incidence of diarrhoea as a specific medical condition. If expressed in DALYs, the comparison could be extended to include all health damaging conditions, but only for those people who were sick.

The second field of comparison is potentially much wider and could include an aspect of all health interventions (in returning people to a more “normal” life), plus other interventions where releasing human time is a significant element, for example transport projects.

To open up the field of comparisons to include all interventions aimed at improving human well-being requires a common standard of comparison – a “numeraire” in economics jargon. A possibility with such potential is to put all imaginable costs and benefits into monetary terms.

Social cost-benefit analysis is a technique of economic assessment that has been developed for this purpose. Its origins lie in the 1960s, but the version we will describe here is designed for practical use in the 21st century. We have put some of the more theoretical debates to one side (for example universal shadow pricing, differences between foreign exchange, consumption and saving gains as the macro-economic goal, and whether notional or actual compensation for losses should be made) – although some of the applied issues they raise will appear in the sensitivity tests in the final section of the manual.

Social cost-benefit analysis demands that all costs and benefits be given a monetary equivalent value. The analyst must choose these values, even where there is no buying and selling in observable markets. The basis for choosing a price is that it reflects the scarcity of the good or service, for example water in a depleting aquifer. If there is no market but there exists a public sector charge for a good or service, the analyst should reflect on how that charge was decided.

An example of the challenges that social cost-benefit analysis might face in the drinking-water field would be a factory employing local people while polluting their drinking-water supply. If there are no effective anti-pollution regulations, then the factory would pay nothing for its actions, and the price of its products would not reflect the cost of the pollution. The social costs of the pollution would be an externality to the factory owners, but have significant effects on the lives of those dependent on the polluted water as a source of drinking-water, perhaps forcing them to buy bottled water on the open market with their earnings from the factory. Even if there is regulation and the factory is fined by the public sector, this charge may not reflect the costs to the affected population. Rather, the fine might be set during a closed door negotiation between public sector officials and the factory owners. Untangling this complex mix, and deciding what monetary values would reflect the existing situation and guide interventions towards an improvement in human well-being for the whole society is what the social cost-benefit analysis economist attempts to do.

Fortunately, most small scale drinking-water interventions are not as complex as the example above, and robust conclusions can be drawn from a relatively simple framework.

In the case study, we worked with cost estimates provided by an experienced water engineer plus some direct observations from the field. If we add to that expert judgement and those direct local observations the broad economics assumption that the South African economy is both internally competitive and externally open to trade, then the pattern of costs in Annex A can be treated as acceptable for the purposes of social cost-benefit analysis, that is reflecting close to the values that correspond to an open market allocation of resources unaffected by institutional factors.

In terms of the benefits side, we can now treat the savings in health-care costs as a monetary benefit. In the previous section, we used the price that people pay for private health treatment as a market tested monetary value, therefore the “shadow” price, even though people overwhelmingly actually use public sector clinics or hospitals when they seek treatment. This has an economic theoretical rationale in social cost-benefit analysis of approximating a market price where demand and supply are operating and equated. It also has a practical advantage, given that we found it impossible to work out a full social costing for the use of local public sector health facilities, because the local facilities are embedded in a wider and complex public sector accounting system. This device of using a chain of equivalents (for example, different channels for receiving medical treatment) until an open market transaction with a price is identified, is a common practice in social cost-benefit analysis.

In the cost-effectiveness analysis in the previous section of the manual, we calculated the present value of the savings on health treatments as 3.7 million rands. This sum is assumed to have become available to support changes in time-use for example using the extra time (freed-up by the drinking water supply intervention) to undertake additional livelihood activities. What remains is to make decisions on how to use that time more effectively in terms of being able to afford purchased inputs.

But we have no monetary value for the benefits expressed in terms of gains in person–years of livelihood choices as an indicator of effectiveness. The starting point for an economist is to ask what activities will now be chosen for the released time and whether there is a market price for those activities.

Given the very low proportion of adult people's time that is directly sold locally, and that so much of the time accrues to people under 18 years of age (who comprise more than 40% of the population), it might be assumed that there is little monetary value that can be attached to additional time available. So perhaps a monetary equivalent close to zero would be appropriate.

But context is important in developing this aspect of social cost-benefit analysis. First, it is useful to distinguish analytically between the sexes and the generations. Assuming that episodes of diarrhoea are evenly distributed by sex and age, then around 25% of time sick will involve adult men, 35% adult women and 40% young people under 18 years of age. Regarding time savings in caring for sick people and collecting water for all its uses, about 75% will be adult women's time, 5% adult men's time and 20% young people's time.

So in a typical year, adult women will gain a large proportion of the time saved (about 60% or 72 person–years), followed by young people under 18 years of age (25%). Therefore evaluating the value of time for these two groups is crucial.

Given the high level of local male open unemployment and their limited contribution to work in the home in the case study context, men over 18 years old resident in the case study area will be given a zero value for their time. The men working as migrants outside the catchment area are vital to the local economy because of the remittances they send, but are less likely to suffer from illness induced by local drinking-water, to care for the sick, or to be involved significantly in water collection. Therefore male migrants do not receive significant time saving benefits from the drinking-water intervention and their livelihood activities are therefore assumed to be unaffected by the intervention.

In the case study area, adult women might use time saved to improve the quality of life in the home environment by spending more time in improving hygiene and providing better child care. This time has indirect economic value in terms of facilitating other people working (including both a physiological and psychological impact on rural-urban migrant workers when visiting the locality) and young people studying at school. We will calculate the induced gains in studying when looking at economic gains by young people.

The indirect monetary equivalent gains for supporting other adults generating incomes outside the household (in the local economy or as temporary migrants) can be looked at from a wages for housework perspective. That is, the additional time freed by the water intervention will assist other household members to be more productive in the wider economy, and this merits recognition in monetary terms. On this basis, it is reasonable to attribute a minimum value of 50 rands (the local wage of a woman working as a cleaner) per person–day to the additional time made available by the drinking-water intervention. Thus, in a typical year, the 72 years of adult women's time freed up by the drinking-water intervention will be worth a monetary equivalent of 1.3 million rands (72 x 50 x 365).

It is impossible to estimate with any precision the qualitative educational gains from the increased total time for studying (30 person–years per year) by people under 18 years of age, freed up because of less illness and less time spent caring and collecting water (plus the extra support available from adults) as a result of the drinking-water intervention. But an order of magnitude for the case study can be made from the following assumptions:

- in each one-year cohort, 200 young people benefit from the intervention;
- as a result of the increased study time, energy and adult support attributable to the drinking-water intervention, 10% of each cohort (20 young people) leave formal education having successfully completed one more year than they would have done before the intervention;
- an additional year in formal education is worth on average an additional 1000 rands a year over a 30-year working life after the intervention for each person achieving the extra grade.

Using these assumptions, we estimate that each young person who achieves an extra year of formal education can expect an increased income valued at a present value of 20 000 rands on a 3% discount rate. Thus 20 young people a year will add a present value equivalent of 400 000 rands to the benefits in every operational year of the intervention.

Putting an economic value on infant deaths saved requires taking into consideration that the children will be a net cost to their families in terms of consumption costs for many, if not all, of the 20 years of the intervention. But to acknowledge economically that an additional 65 people (5 deaths prevented in each of the 13 years in which the intervention is in operation) will be alive at the end of the intervention who would not have been alive without it, a lifetime net present value of 400 000 rands has been credited to each of those 65 people in the final year of the intervention (equivalent to an average net undiscounted gain to society from their activities of 20 000 rands a year for 30 years for each person whose death is prevented). The total discounted benefits will then be 260 million rands credited in 2017 (year 20 of the intervention).

Putting all these benefits into a spreadsheet gives the pattern shown in Table 6. Thus the total present value for 20 years of intervention for all four types of benefits in monetary equivalent form is 34 million rands.

Table 6 Summary of total discounted benefits

Year(s)	Total monetary equivalent benefits (thousand rands)	Discounted benefits (million rands) at 3% per annum	Comments
1997-2003	0	0	Scheme in process of development
2004-2016	2100 each year (400 from medical cost savings, 1300 from added adult women's time for livelihood choices, 400 from income effect of improved school performances)	19	Each year is credited with the same sum of 2.1 million rands in benefits, so the discounting calculation can be simplified as: benefits multiplied by the sum of all the discounting factors from year 7 to year 19 inclusive. Thus the present value (PV) is calculated as: PV = 2 300 000 $((1/1.03)^7 + (1/1.03)^8 + (1/1.03)^9 + (1/1.03)^{10} + (1/1.03)^{11} + (1/1.03)^{12} + (1/1.03)^{13} + \ldots.. + (1/1.03)^{19})$= 2 300 000 x 9.2 = 21 160 000
2017	26 000 (from future earnings of saved infant lives)	15	Benefits attributed to saved children's lives
Total	Not economically meaningful	34	

We are now in a position to bring costs and benefits together in a social cost-benefit analysis calculation (see Annex A). Annex B is a skeleton Excel spreadsheet for use by anyone following the steps in this manual. To complete the spreadsheet, rows for all the identified types of costs and benefits can be inserted at the appropriate points.

Going back to the original cost estimates in Table 5 of this manual, the rounded total present value of the costs was close to 11 million rands. This indicates a net present value (present value of benefits minus present value of costs) of 23 million rands.

But net present value (NPV) in absolute terms is sensitive to the scale of the operation. Generally, a much larger initial investment might be expected to produce a much larger NPV. One way to remove the question of scale is to convert the NPV into a ratio of the present value of benefits (PVB) to the present value of costs (PVC), that is:

PVB/PVC = 34/11 = 3.1

This looks a very impressive ratio by any standards and certainly suggests that the investment was justified. Generally, a ratio greater than 1.5 is judged to be very satisfactory in assessing public sector investments.

Another way of taking account of scale is to calculate the discount rate that would reduce the NPV to zero; in economics language this is the internal rate of return (IRR). Calculating the IRR starts with discarding our assumption of a 3% discount rate. Instead, we calculate the maximum rate of interest we could afford to pay if a lump sum was borrowed to pay all the costs at the beginning and the whole loan was paid back at the end of 20 years.

The IRR can be found by trial and error using an Excel spreadsheet, by adjusting the discounting factor in the first two years, and using the ***Paste special*** followed by ***All***

using source theme option to rapidly recalculate the discount rates, which automatically multiplies both the costs and benefits. Inspecting the totals will reveal how quickly they are approaching each other, that is how close the NPV is getting to zero (see Table 7 for the case study result).

Table 7 Comparing costs and benefits at varying discount rates

Discount rate	Discounted total costs (million rands)	Discounted total benefits (million rands)	Comments
15 %	7.2	7.7	Need to raise interest rate (IRR) to reduce value of later benefits relative to earlier costs
16 %	7.0	6.9	The interest rate (IRR) that almost equates costs and benefits – the rate the intervention could afford to pay – and therefore the higher the better
17 %	6.9	6.2	Costs are now higher than benefits and the rate of interest (IRR) needs to fall to increase the value of later benefits relative to earlier costs – the intervention can afford to pay a higher rate of interest on a loan

IRR, internal rate of return.

Anyone familiar with Excel can find the IRR in a few minutes. This can be done even more rapidly with specialist statistical or accounting software packages, though an element of hands-on feel for the patterns of the data will be lost.

In the case study, the IRR is about 16% per annum – a very creditable rate of return by commercial standards. But it must be emphasized that this return comes over a period of 20 years. When informing decision-makers, analysts must always stress the fact that social cost-benefit analysis estimates are based on estimates of future values of variables, often far into the future, that involve considerable uncertainty. This may even apply to impact evaluations if, for instance, they involve estimates of future incomes for people still in school.

This concern with uncertainty about the future (added to doubts about the accuracy of current observations) explains why all the data cited in this manual are expressed in rounded numbers, with just two or three significant figures. Economics is not a precise science. Therefore this section, like previous sections, must end with a warning. Beware the temptation of offering or demanding spurious accuracy from a social cost-benefit analysis. Citing numbers that give the illusion of much greater accuracy than is justified by the procedure for deriving those numbers is very unprofessional. And it verges on being unethical if it is intended to inhibit discussion of the assumptions being made by the analyst or the likely sampling and measurement errors in the data. Such concerns lead us to the final section of the manual, and to the necessity of sensitivity tests.

Conducting sensitivity tests on four scenarios to determine the robustness of the results of the social cost-benefit analysis

As stated at the end of the previous section of this manual, a social cost-benefit analysis is only as good as the assumptions and data that go into the matrix.

A social cost-benefit analysis can look convincing in terms of technical presentation and yet be a total fantasy in its relationship to the underlying realities of a drinking-water intervention. Just as the artist Escher can make water in a canal appear to flow uphill, so a social cost-benefit analyst can calculate the benefits of a phenomenon without any concern about its physical impossibility. Economics is notorious for its use of assumptions in developing theories. And the assumption that water in an open channel can flow uphill – or more generally that the force of gravity does not exist – is not a problem in principle for economics theorizing.

Similarly, assuming that there is no institutional corruption and that markets operate smoothly to allocate resources in a non-discriminatory and socially just fashion is what many economists do every workday as they sit down at their desks.

Therefore a constant challenge for the harder headed, practical economist is to offer advice to decision-makers in a technically rigorous form, while not seeming to remove the need for debate on that advice. The challenge is to tread the narrow line between being convincing in principle and avoiding closure on application.

Humility is a desirable virtue for economists, but unfortunately it is a rarity in practice. Too often economists behave like the rascally tailors in the story of the emperor's new clothes, and gullible decision-makers breathe a sigh of relief thinking that the decision has been made for them, especially if the economists are cunning enough to tell them what they want to hear.

Fortunately there are ways to avoid this unhealthy situation and ensure that decision-makers do not appear naked in the streets of public opinion when recommendations made by economists are exposed as at best overconfident or at worst plain wrong.

The first tactic to meet this challenge is the one highlighted at the end of the previous section. Only express numbers with a degree of accuracy that is justified by the likely accuracy of the data being used. One of the few truths in economics is that estimates of any mean are only accurate to plus or minus 5% (generally taken to be the range of sampling error). In a drinking-water intervention, as outlined by Cameron et al. (2011, chapter 6), once other forms of inaccuracy are factored in then the margin of error is likely to be plus or minus 10% or more.

Any decision-makers faced with figures rounded to three significant figures, and words and phrases such as "about", "estimated", "assumed", "close to", "probably" and "approximately", will be alerted to the fact that they are not being offered a precise engineering blueprint of the current situation on the ground. Decision-makers may well complain about this sense of uncertainty, but an economist with integrity will accept this criticism rather than resort to statements of spurious accuracy.

The second tactic is to present sensitivity tests that make explicit both concerns about inaccuracies in the data and judgements about assumptions that underpin the “most likely” scenario derived from the social cost-benefit analysis.

A sensitivity test constructs a scenario that adjusts some of the parameters, on the grounds that they are:

- comparatively very vulnerable to sampling or wider measurement error (in which case both high and low values may be tested to assess impact on cost-benefit ratio or IRR);
- comparatively very influential on the results of the social cost-benefit analysis because of the sheer scale of their effects (large numbers occurring relatively early in the life of the intervention);
- comparatively very open to future uncertainty, in the judgement of local key informants or judging by experiences of similar interventions elsewhere (and here it is worth distinguishing risk from uncertainty: risks tend to have known probabilities attached to a known range of outcomes and can be incorporated in the “most likely” social cost-benefit analysis scenario, for example as engineers do automatically for structural risks; uncertainties are unquantified and more dramatic, with a tendency to have human causes);
- comparatively of particular concern to decision-makers (in economic assessment terms, this means parameters that have a higher weighting in the decision than the monetary equivalent value they have been given in the “most likely” scenario);
- comparatively of particular concern to people in greater poverty and suffering greater discrimination (in economic assessment terms, this means parameters that have a higher weighting for such people than the monetary equivalent value they have been given in the “most likely” scenario).

In the case study, the umbrella variables that set the parameters for the social cost-benefit analysis are:

- total costs in each year from 1998 to 2017 (which include construction, equipment, operation and maintenance, repairs and replacements, and end-of-intervention adjustments);
- livelihood time benefits from fewer diarrhoea episodes;
- livelihood time benefits from caring for fewer sick people;
- livelihood time benefits from improved access to water;
- numbers of infant deaths prevented;
- savings from reduced societal resources needed for health treatment;
- lifetime income gains from better school performance (not differentiating between boys and girls);
- valuation of livelihood time gains (differentiating between adult women and adult men);
- valuation of lifetime livelihood gains made possible by the prevention of infant deaths.

Table 8 shows these parametric variables lined up against the criteria for prioritization in sensitivity testing. Reflecting on Table 8 suggests that a case can be made to run sensitivity tests on all of the parametric variables. But rather than treat each variable separately, it is more convenient and more stimulating to group the modifications into scenarios with a sense of a plausible story bringing out interrelationships between the variables.

Given the positive result of the "most likely" scenario derived from the social cost-benefit analysis, it seems appropriate first to test changes in those benefits most vulnerable to measurement inaccuracy. This will be Scenario A.

Table 8 Indicative framework for identifying criteria for selecting parameters for sensitivity testing[a]

Parameter variable	Inaccuracy in measurement	Scale of influence	Vulnerability to future uncertainty	Interest to decision-makers	Interest to poor
Total costs in each year from 1998 to 2017	X	XXX	XXX (histories of poor maintenance locally and globally)	XXX	X
Livelihood time benefits from fewer diarrhoea episodes	XX	XX	X (if system maintained and population using system remains manageable)	X	XXX
Livelihood time benefits from caring for fewer sick people	X (once episodes reduction known)	XX	X (if system maintained and population using system remains manageable)	X	XX
Proportion of people seeking formal health treatment for diarrhoea episodes	X	XX	XX (availability and quality of health services)	XX	XX
Health treatment cost per episode of diarrhoea	XXX	XX	X	XX	XXX
Livelihood time benefits from improved access to water	X	XX	X XX (rising aspirations to have in-house connections)	X	XX
Number of infant deaths prevented	XX	X X (through monetary equivalent value attributed)	X (if system maintained and population using system remains manageable)	XX	XXX
Value of infant deaths prevented	XXX	XXX (distant in time but very high value)	XXX (development of economy)	XX	XXX (source of social security for current generation)
Savings from reduced societal resources needed for health treatment	XX	XX	X (if system maintained and population using system remains manageable)	XXX	XX
Proportion of young people improving school performance	XXX (attribution to drinking-water improvement?)	XX	X	XXX (especially girls)	XX
Lifetime income gains from better school performance	XXX	XX	XXX	XX	X (poorest unlikely to get the highest gains)
Valuation of livelihood time gains (differentiating between adult women and adult men)	XX	XX	X	X	XXX (social justice and inequality dimension)

[a] Sensitivity of the column criteria to changes in the value of the row variable (in economics terms, the relative degree of elasticity of percentage response of the column variable to a percentage change in the row variable): X, low sensitivity; XX, medium sensitivity; XXX, high sensitivity.

Scenario B will focus on the system's vulnerability to breakdown resulting from poor maintenance, and the vulnerability of the result of the social cost-benefit analysis to such a breakdown.

Scenario C looks to the future population pressure on the system and modifies the parametric variables to include increments in the population using the drinking-water system.

Finally, Scenario D takes a more optimistic view and models increasing incomes and higher aspirations to include a sequence of incremental improvements.

Scenario A – Possible inaccuracies in variables

Given the very positive results from the "most likely" social cost-benefit analysis scenario, we will test whether changes in the variables where accuracy is most in doubt can reverse this positive conclusion. If the "most likely" result of the social cost-benefit analysis had been negative, then it would be logical to reverse the argument and see whether modifying these variables in a positive direction might produce a positive result.

We could take each variable in turn and see if any feasible value exists that can reverse the result of the social cost-benefit analysis and reduce the IRR below 3% or the benefit/cost ratio below one.

But visual inspection shows that no individual benefits variable can reverse the result of the social cost-benefit analysis, so instead we create a scenario in which all the benefits variables considered to have high sensitivity (indicated as XXX in the appropriate column of Table 8) are radically modified in value, as shown in Table 9.

Table 9 Variables modified for Scenario A

Parameter variable	Adjustment made
Health treatment cost per episode of diarrhoea	Reduced to 500 rands from 1000 rands
Value of infant deaths prevented	Reduced to zero
Proportion of young people improving school performance as a result of the drinking-water intervention	Reduced to 5% of each cohort
Lifetime income gains from better school performance	Reduced to zero

Putting these modified values into the spreadsheet does not affect the present value of the costs, but it reduces the present value of the benefits to 13.8 million rands (see the lines for this scenario in Annex A). Therefore the benefit/cost ratio falls to 1.3 which, while still greater than one, takes the scheme into potentially vulnerable territory in terms of comparative prioritization.

At a conceptual level, this scenario does raise important issues of inter-generational relationships. Any estimates of the future state of the world in 15–45 years time must be subject to doubts about the accuracy of the variables involved – perhaps to the point of discounting them completely as in this scenario.

The "most likely" scenario puts a considerable value in economic terms on young people's long term futures and saving infants' lives. There will always be controversy over putting a value on a human life, and Scenario A brings that issue into stark focus. It encourages decision-makers to take responsibility for long term change and to think about the world of work that will be accessible to the next generation of people.

Scenario B – Risks and uncertainties around engineering and institutional management of the intervention

This scenario focuses initially on the costs side, and the widespread opinion that most drinking-water interventions suffer from poor maintenance and therefore have much shorter technical lives than envisaged in the original design.

To capture these concerns, we reduce the operating and maintenance costs by half (the operating and maintenance costs in the most likely scenario were estimated on the basis of ensuring the scheme could be sustained for at least 20 years). To estimate the sensitivity of this modification we then calculate the number of years the scheme we would need to run to give a benefit/cost ratio of one, which is to break even at a discount rate of 3% per annum.

Comparing the cumulative distributions of total discounted costs and total discounted benefits for Scenario B in Annex A shows that the scheme breaks even in year 12 (2009), and moves to a benefit/cost ratio higher than 1.3 in year 14 (2011). Of course, it requires an engineer to judge whether a scheme operating on only half the maintenance costs needed for sustainability can operate as designed for 12 years before completely breaking down. The conventional wisdom is that a chronically under-maintained scheme will break down in 5 years. This scheme is a chronic economic failure on that time horizon.

While on the subject of costs, it is worth examining the influence of speeding up construction. If the scheme were constructed in two years instead of six, the break-even point then occurs in the sixth year of operation and the benefit/cost ratio of over 1.3 occurs in the seventh year. The scheme is still economically a clear failure if it collapses in five years, although more cost efficient construction does provide significant protection to health and as well as resulting in time saving – more than just the time saved in construction. But completing the construction more quickly may reduce the involvement of local people in the construction, with implications for the sense of their ownership of the scheme. Less ownership by local people will tend to amplify the impact of below-sustainability maintenance and increase the risk of early close-down.

This concern with governance moves outside the remit of economic assessment, but this social cost-benefit analysis scenario does stimulate decision-makers to bear in mind both engineering and participation by local people as being significant for the economic viability of the intervention.

Scenario C – Demographic changes and associated incremental challenges

This scenario seeks to understand the implications for the social cost-benefit analysis variables of an increasing population using the scheme.

A growing population increases all the benefits. People are either being born into an improved drinking-water situation (as compared with conditions before the intervention) or migrating towards a superior drinking-water system (compared with the systems in their places of origin).

If this were the only consideration, then all the benefits would simply be scaled up. The scheme would be more unit cost efficient in terms of cost per m^3 of water, and the social cost-benefit analysis would produce an even more positive economic assessment result than in the “most likely” scenario.

But more people using the system will put a strain on the scheme, which depends on collective standpipes. The form of the strain and who bears it will depend on where new people accommodate themselves. If they are evenly distributed among the pre-existing population (as would be expected with natural population growth among the existing population), then everyone may spend more time queuing for water. If newcomers are concentrated in the area close to the reservoir, then pre-existing users may experience diminished water pressure and decreased access times, or even complete loss of access to the scheme’s water. If the newcomers are scattered on the periphery of the scheme then the newcomers will take the strain and it cannot be expected that they will have the same benefits per household as the original beneficiaries. Also as population pressure rises, the pressure on the infrastructure will increase and breakdowns will become more frequent.

In any of these cases, some people may start using less safe water for drinking, and so health benefits will be diminished. To capture such effects, the most plausible model is an inverted U-shaped curve – initially the benefits of a larger population outweigh the adverse effects, but after a tipping point occurring at a specific level of population, the adverse effects increasingly outweigh the benefits.

For this case study scenario, we will use a simple model in which the population grows by 4% per annum and the benefits grow proportionately until the population has increased by 25% compared with the original population. After this tipping point population is reached, the benefits fall by 6% per annum.

The scenario has a significant impact on discounted total benefits compared with the most likely scenario (see Annex A). The benefit/cost ratio falls from 3 to 2, a reduction of a third but still very attractive. An earlier tipping point in terms of increased size of population and/or a higher rate of loss of benefits after the tipping point could have a dramatic effect on the social cost-benefit analysis results, pushing them towards economic non-viability.

The scenario encourages decision-makers to think about the demographics of the local context, and consult engineers on the maximum carrying capacity of the system in terms of both total water availability and the effects of increasing demand on the physical delivery of water at critical points in the system. It also raises issues of possible socio-political tensions arising if there is conflict over access to water.

Scenario D – Aspirational changes and sequencing interventions

This scenario might be thought of as being more optimistic, because it looks towards rising real incomes for the poorest and rising aspirations for all, over time.

Rising incomes of the poorest means that the shadow price of adult women's time will increase and the time saved will become more valuable in terms of its monetary equivalent.

Rising aspirations means that everyone will aspire to have household connections rather than standpipes. The richer may be willing to pay for such connections and the associated increased access to water. For others, meeting these aspirations may be funded by the public sector out of general taxation – especially for the poorest households.

The sensitivity test modifies five variables (which are now applied to the whole local population, not just to those who previously used the river as the source of drinking-water):

- an increase in system costs to bring water closer to all households over a period of four years starting in 2009 and completed by 2012 – assuming that this will involve a total cost per year of making connections of 750 000 rands (also assuming no increased maintenance involved);
- a further reduction in cases of diarrhoea as a result of not using contaminated containers for transporting water from standpipe to household of two cases per 1000 people a year (3000 days for 6000 people) with a proportional reduction in days caring for sick people;
- a reduction in medical treatment costs (saving a further 170 000 rands in addition to the previous 400 000 rands a year);
- a further reduction in time collecting water of half an hour a day per household;
- an increase in benefits from increased real income per capita for the poor and hence increased value of adult women's time saved by 5% per year, starting from 50 rands a day – but the value of future incomes for young people with additional schooling and infants whose lives have been saved by the original drinking-water intervention will not be changed.

In this scenario, the present value of costs rises to 13 million rands and benefits rise to 46 million rands, giving a benefit/cost ratio of 3.5 (see the results for this scenario in Annex A). This is an improvement on the most likely scenario.

The result of Scenario D (the most likely scenario) is robust even if all the household connections were made in the last year of the construction period and without a real rise in income. If that were the case, then this modified version of Scenario D would show 45 million rands in benefits and 13 million rands in costs, with an internal rate of return still close to 16%. This result suggests that the drinking-water intervention could have been more ambitious at the outset in terms of in-household connections.

But in cases with a higher discount rate and relatively low additional benefits (in economics terms, marginal or incremental benefits) from later interventions, then a social cost-benefit analysis may indicate that sequencing interventions may yield a more positive economic assessment than including all interventions in the initial construction phase, especially if the extra work during the initial phase delays the scheme becoming operational.

Provoking thought and informing debate

The four scenarios offered here in addition to the "most likely" scenario are intended to show how social cost-benefit analysis can help decision-makers explore issues surrounding a particular small scale drinking-water intervention.

The scenarios are not applicable to all contexts and do not exhaust all the possibilities for the case study used in this manual. If they show how a social cost-benefit analysis can be used as an economic assessment tool to assist, rather than dictate, decision-making, then they have achieved this manual's purpose of demonstrating that any economic assessment should provoke thought and inform debate.

Annex A: Summary tables																					
YEAR	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	TOTALS
COST EFFICIENCY																					
Total costs	1500	1500	1500	1500	1500	1500	175	175	500	175	175	175	175	175	500	175	175	175	175	500	
Discounting factor at 3 % pa	1	0.971	0.943	0.915	0.888	0.863	0.837	0.813	0.789	0.766	0.744	0.722	0.701	0.681	0.661	0.642	0.623	0.605	0.587	0.570	15
(Rs 000s)																					
Discounted total costs	1500	1456	1414	1373	1333	1294	147	142	395	134	130	126	123	119	331	112	109	106	103	285	10732
(Rs 000s)																					
COST EFFECTIVENESS																					
Monetary medical costs	0	0	0	0	0	0	400	400	400	400	400	400	400	400	400	400	400	400	400	0	
(Rs 000s)																					
Discounted medical treatment costs	0	0	0	0	0	0	335	325	316	307	298	289	281	272	264	257	249	242	235	0	3670
(Rs 000s at 3%)																					
Episodes of diarrhoea prevented	0	0	0	0	0	0	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	2450	0	
Discounted episodes prevented	0	0	0	0	0	0	2052	1992	1934	1878	1823	1770	1718	1668	1620	1573	1527	1482	1439	0	22476
(discounted at 3%)																					
Added livelihood years (all 3 causes)	0	0	0	0	0	0	125	130	135	145	150	155	160	165	170	175	180	185	190	0	

Discounted added livelihood years	0	0	0	0	0	0	105	106	107	111	112	112	112	112	112	112	112	112	112	0	1437
(discounted at 3%)																					
SOCIAL COST BENEFIT ANALYSIS																					
"MOST LIKELY" SCENARIO																					
Total costs	1500	1500	1500	1500	1500	1500	175	175	500	175	175	175	175	175	500	175	175	175	175	500	
(Rs 000s)																					
Discounted total costs	1500	1456	1414	1373	1333	1294	147	142	395	134	130	126	123	119	331	112	109	106	103	285	10732
(in Rs 000s at 3% pa)																					
Total monetary equivalent benefits	0	0	0	0	0	0	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2100	2600 0	
(Rs 000s)																					
Discounted total benefits	0	0	0	0	0	0	1759	1707	1658	1609	1563	1517	1473	1430	1388	1348	1309	1271	1234	1482 7	34092
(in Rs 000s at 3% pa)																					
Discounting factor at 3 % pa	1	0.971	0.943	0.915	0.888	0.863	0.837	0.813	0.789	0.766	0.744	0.722	0.701	0.681	0.661	0.642	0.623	0.605	0.587	0.570	15
Discounted total costs	1500	1293	1115	961	828	714	72	62	153	46	40	34	29	25	63	19	16	14	12	30	7026
(in Rs 000s at 16% pa)																					
Discounted total benefits	0	0	0	0	0	0	862	743	641	552	476	410	354	305	263	227	195	168	145	1550	6891
(in Rs 000s at 16% pa)																					
Discounting factor at 16 % pa	1	0.862	0.743	0.641	0.552	0.476	0.410	0.354	0.305	0.263	0.227	0.195	0.168	0.145	0.125	0.108	0.093	0.080	0.069	0.060	7

SCENARIO A																					
Total monetary equivalent benefits	0	0	0	0	0	0	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	0	
(Rs 000s)																					
Discounted total benefits	0	0	0	0	0	0	1256	1220	1184	1150	1116	1084	1052	1021	992	963	935	908	881	0	13761
(in Rs 000s at 3% pa)																					
Discounting factor at 3 % pa	1	0.971	0.943	0.915	0.888	0.863	0.837	0.813	0.789	0.766	0.744	0.722	0.701	0.681	0.661	0.642	0.623	0.605	0.587	0.570	15
SCENARIO B																					
Total costs	1500	1500	1500	1500	1500	1500	87.5	87.5	412.5	87.5	87.5	87.5	87.5	87.5	412.5	87.5	87.5	87.5	87.5	500	
(Rs 000s)																					
Discounted total costs	1500	1456	1414	1373	1333	1294	73	71	326	67	65	63	61	60	273	56	55	53	51	285	9929
(in Rs 000s at 3% pa)																					
Cumulative total discounted costs	1500	2956	4370	5743	7076	8370	8443	8514	8840	8907	8972	9035	9096	9156	9429	9485	9539	9592	9644	9929	
Cumulative total discounted benefits	0	0	0	0	0	0	1759	3466	5124	6733	8296.04086412072	9813	11286.0232933834	12716.021107369	14104.3684995881	15452.2785891212	16760.9291614835	18031.4636977575	19264.9923737517	34092.4290708617	
Total costs (Rs 000s)	3000	3000	175	175	500	175	175	175	175	175	500	175	175	175	175	500					
(assuming construction takes two years)																					
Cumulative total discounted costs	3000	5913	6078	6238	6682	6833	6979	7122	7260	7394	7766	7893	8015	8134	8250						
(assuming construction takes two years)																					

Cumulative total discounted benefits	0	0	2039	4018	5940	7806	9617	1137 6	1308 4	1474 1	1635 1	1791 3	1943 1	2090 3	2233 3						
(assuming construction takes two years)																					
SCENARIO C																					
Total costs	1500	1500	1500	1500	1500	1500	175	175	500	175	175	175	175	175	500	175	175	175	175	500	
(Rs 000s)																					
Discounted total costs	1500	1456	1414	1373	1333	1294	147	142	395	134	130	126	123	119	331	112	109	106	103	285	10732
(in Rs 000s at 3% pa)																					
Total monetary equivalent benefits	0	0	0	0	0	0	2100	2184	2271	2362	2457	2554. 9710 9504	2657	2507	2365	2231	2105	1986	1873	1767	
(increasing at 4% pa from 2004 to 2010 and falling by 6% subsequently)																					
Discounted total benefits	0	0	0	0	0	0	1759	1776	1793. 0325 5845 13	1810	1828. 0177 3515 028	1846	1864	1706. 9843 6834 319	1563	1432	1312	1201	1100	1008	21999
(in Rs 000s at 3% pa)																					
SCENARIO D																					
Total costs	1500	1500	1500	1500	1500	1500	175	175	500	175	175	925	925	925	925	175	175	175	175	500	
(Rs 000s)																					
Discounted total costs	1500	1456	1414	1373	1333	1294	146.6	142.3	395	134	130	668	649	630	612	112	109	106	103	285	12591
(in Rs 000s at 3% pa)																					

New total medical treatment savings	0	0	0	0	0	0	400	400	400	400	400	445	490	535	575	575	575	575	575		
Adult women's time saved (years)	0	0	0	0	0	0	72	72	72	72	72	86	100	114	128	128	128	128	128		
Value of women's time saved	0	0	0	0	0	0	1296	1361	1429	1500	1575	1976	2412	2887	3404	3574	3752.973220095 23	3941	4138		
(assuming 5% increase a year starting in 2004)																					
Total Benefits	0	0	0	0	0	0	2168	2233	2301	2372	2447	2907	3402	3936	4507	4677	4856	5044	5241	26000	
(including benefits to young people)																					
(in Rs 000s)																					
Discounted total benefits	0	0	0	0	0	0	1816	1815	1816	1818	1821.01813596 049	2100	2386	2680	2980	3002	3026	3051	3078.33129799 427	14827.4366971 1	46218
(in Rs 000s at 3% pa)																					
Total costs (Rs 000s)	1500	1500	1500	1500	1500	4500	175	175	500	175	175	175	175	175	500	175	175	175	175	500	
((all households connected in 2003)																					
Discounted total costs	1500	1456	1414	1373	1333	3882	147	142	395	134	130	126	123	119	331	112	109	106	103	285	13319
(in Rs 000s at 3% pa)																					
Total Benefits (in Rs 000s)	0	0	0	0	0	0	3311	3311	3311	3311	3311	3311	3311	3311	3311	3311	3311	3311	3311	26000	
(including benefits to young people)																					

Discounted total benefits	0	0	0	0	0	0	2773	2692	2614	2538	2464	2392	2322	2255	2188.96105506545	2125	2063	2003	1945	14827.43669711	45202
(in Rs 000s at 3% pa)																					
Discounted total costs	1500	1293	1115	961	828	2143	72	62	153	46	40	34	29	25	63	19	16	14	12	30	8455
(in Rs 000s at 16% pa)																					
Discounted total benefits	0	0	0	0	0	0	1358.97430520381	1171.52957345156	1009.93928745824	870.637316774349	750.54941101237	647.025354321009	557.780477862939	480.845239537016	414.521758221566	357.346343294453	308.057192495218	265.566545254499	228.936676943533	1549.78535512031	9971
(in Rs 000s at 16% pa)																					

Annex B: Model spreadsheet					
YEAR					
COST EFFICIENCY					
INSERT ROWS FOR ALL COST ITEMS IN MONETARY UNITS (CASH AND KIND)					
Total costs					
Discounting factor at 3 % pa					
Discounted total costs					
(Currency in 000s)					
COST EFFECTIVENESS					
Monetary medical costs					
(Currency in 000s)					
Discounted medical treatment costs					
(Currency in 000s)					
Episodes of illness prevented					
Added livelihood years (in terms of DALYs or from all sources)					
Discounted added livelihood years					
(discounted at 3%)					
SOCIAL COST BENEFIT ANALYSIS					
Total costs from row 8					
(Currency in 000s)					
Discounted total costs from row 10					
(Currency in 000s at 3 % pa)					

INSERT ROWS FOR ALL TYPES OF BENEFITS IN MONETARY UNITS					
(Currency in 000s)					
Total monetary equivalent benefits					
(Currency in 000s)					
Discounted total benefits at 3 % pa					
(Currency in 000s)					