Paper 4

The Economics of Arsenic Mitigation

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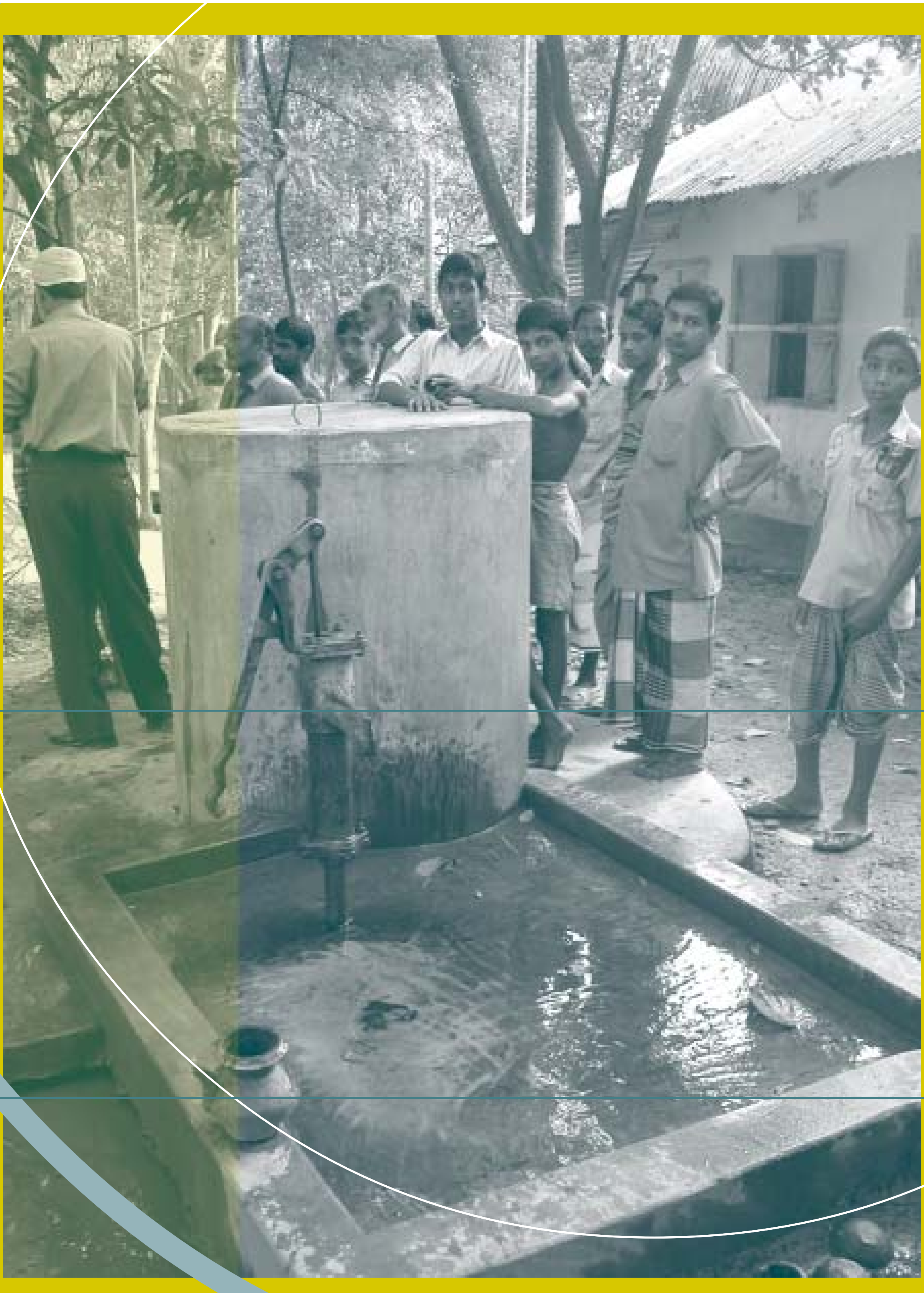
VOL II TECHNICAL REPORT



Summary

1. This paper introduces an approach that provides a quick and readily applicable method for performing a cost-benefit analysis of different arsenic mitigation policies. In particular, our suggested approach estimates benefits of mitigation activities as the sum of forgone medical costs and saved output productivity achieved by reducing arsenic exposure. The present value of these benefits is then compared with the present value of costs of various mitigation measures in order to investigate when and which mitigation policies pass a cost-benefit analysis (that is, produce a positive change in social welfare).

2. The paper applies this approach in order to provide some estimate of costs and benefits of arsenic mitigation in one case study country: Bangladesh. This case study serves as an applied example of such rapid socioeconomic evaluation and is also used as a basis for discussing trade-offs in decisionmaking with respect to the allocation of financial resources. Our approach is applicable to both cases: (a) the risk that arsenic might be found in an area where a project is planned; and (b) approaches in regard to risk mitigation options where a project aims at arsenic mitigation per se.

3. Our case study showed that for the case of Bangladesh the cost-benefit ratios for many relevant mitigation techniques and policies are positive under varying levels of success in terms of their effectiveness. These results indicate the imminent need for facing the arsenic crisis in Bangladesh, but also the clarity with which our approach can answer the difficult question on the balance of relevant costs and benefits of various mitigation options and policies.

VOL II TECHNICAL REPORT

1. The Issue

Aims of This Paper

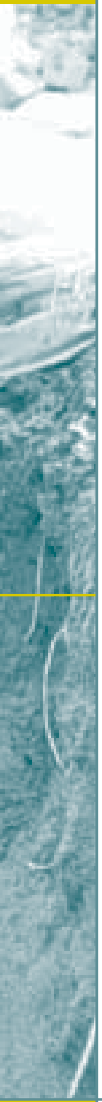
This paper reviews existing studies and data on arsenic mitigation in those countries where it has been undertaken, and the costs of achieving such mitigation. Then these costs are compared with relevant benefits, while taking into consideration the limited knowledge base regarding the epidemiology of arsenic in the region. Discussion of the different limits for arsenic in drinking water in different countries and simulation of cost implications from implementing each limit, as well as the trade-offs between different water sources (ground or surface water, for example) in a range of socioeconomic circumstances, is central to the paper.

All decisions imply a money value of benefits, while policies can only be accepted or rejected. If a policy costs $X, accepting and implementing it implies that benefits exceed $X. Rejecting the policy implies that benefits are less than $X. Hence, there is no escape from monetary valuation. This paper provides a general introduction to the way of thinking about costs and benefits of mitigating (natural) pollutants, including considerations of trade-offs in decisionmaking with respect to the allocation of financial resources in a budget-constrained environment.

In particular, a methodology is suggested for analyzing options in order to choose between different approaches in dealing with (a) the risk that arsenic might be found in an area where a project is planned; and (b) approaches to risk mitigation options where a project's goal is arsenic mitigation per se.

The paper also provides decisionmakers and project managers with an efficient and readily applicable methodology for rapid assessment of the socioeconomic desirability of different arsenic mitigation policies under various scenarios. The proper way of deciding whether to implement a particular mitigation policy involves conducting a cost-benefit analysis (CBA), which in turn involves (a) consideration of several different policy options to test costs and benefits of each; (b) a general equilibrium approach to the costs of a policy; (c) behavioral studies of water user responses to different levels of mitigation; and (d) behavioral studies of user responses to nonavailability of contaminated water, especially substitution with other sources of water. The true compliance cost of any arsenic mitigation policy is unknown but some estimated figures can be used. However, we do not know the full behavioral reactions to different possible mitigation policies.

An alternative, equally ideal model on which decisionmaking could be based involves (a) estimation of changes in levels of exposure; (b) exposure-response functions linking levels to human mortality, human morbidity, and ecosystems and species; (c) willingness to pay for measures that avoid impacts identified in exposure-response relationships; and (d) allocation of benefits and costs to time periods (years). Such a procedure for estimating health benefits is more tractable than a CBA, but remains very difficult due to the absence of (a) a behavioral model of the economic sectors that use arsenic-contaminated water; (b) knowledge of change in exposure; (c) knowledge of exposure-response functions; and (d) internalization assumptions for occupational effects.



In the absence of a full study (because of missing information and prevailing uncertainties) and given the millions of people around the world who are currently menaced by arsenic poisoning, health policymakers need to devise policies capable of counteracting this threat based on an "nth best" approach. One method of analysis would be a cohort study, selecting control (no intervention) and intervention villages (with implementation of mitigation methods) and tracking the effects of the disease on people’s health and livelihood, including coping mechanisms, over some period of time. Any study method using real populations would, however, only provide results after long periods, which limits this method’s applicability to the immediate public health concern. In addition, it is questionable whether long-term cohort follow-up would be achieved in a country where tracking of individuals is limited. Finally, ethical considerations would preclude such studies as soon as it becomes apparent that mitigation methods do work and provide relief.

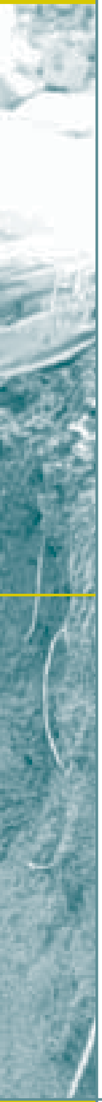
Our suggested approach attempts to estimate the medical costs and forgone productivity from specific diseases or health end states. The paper applies this approach in order to provide some estimate of costs and benefits of arsenic mitigation in one case study country, namely Bangladesh. Of the regions of the world with groundwater arsenic problems Bangladesh is the worst case that has been identified, with some 35 million people thought to be drinking groundwater containing arsenic at concentrations greater than 50 µg L^{-1} and around 57 million drinking water with more than 10 µg L^{-1} (see, Paper 1 of this report). The large scale of the problem reflects the large area of affected aquifers, the high dependence of Bangladeshis on groundwater for potable supply, and the large population accumulated in the fertile lowlands of the Bengal Basin. Today, there are an estimated 11 million tubewells in Bangladesh serving a population of around 130 million people. The scale of arsenic contamination in Bangladesh means that it has received by far the greatest attention in terms of groundwater testing and more is known about the arsenic distribution in the aquifers than in any other country in Asia (as well as most of the developed world). However, much more testing is still required. Our Bangladeshi case study serves as an applied example of such a rapid socioeconomic evaluation and will also be used as a basis for discussing trade-offs in decisionmaking with respect to the allocation of financial resources.

Situational Analysis

Groundwater is a significant source of drinking water in many parts of the world. Well-protected groundwater is safer in terms of microbiological quality than water from open dug wells and ponds. However, groundwater is notoriously prone to chemical and other types of contamination from natural sources or anthropogenic activities. One of these is contamination caused by high concentration levels of arsenic in water. Arsenic is a chemical that is widely distributed in nature and principally occurs in the form of inorganic or organic compounds.

The available treatment technologies for arsenic removal provide varying results depending on the concentration of arsenic in the water, the chemical composition of the water (including interfering particles), and the amount of water to be treated. Another important consideration is the feasibility and cost of the treatment process. The most commonly used biophysical methods are coagulation, softening, iron and manganese oxidation, anion exchange, activated alumina membrane processes, and electrodialysis. The frequently prohibitive cost of these technologies in rural contexts has prompted the search for alternative sources of arsenic-free water, such as rainwater harvesting.

Reliable data on exposure and health effects are rarely available, but it is clear that there are many countries in the world where arsenic in drinking water has been detected at concentrations greater than the WHO guideline value of 10 $\mu g\ L^{-1}$, or the prevailing national standard. These include Argentina, Chile, Japan, Mexico, New Zealand, the Philippines, the United States of America, and some countries in South and East Asia, as described in detail in Paper 1.



2. An Ideal Approach to Evaluation of Arsenic Mitigation Measures

In order to show what is necessary for a proper evaluation of arsenic mitigation measures this chapter lays out an "ideal" approach – one based on a conceptually sound model, but which as a function of its assumptions has certain limitations. This permits us to judge the gap between what should be done and what can be done in practice.

Uncertainty and the Ideal Approach

One misconception needs to be dispelled at the outset. One of the criticisms of economic (cost-benefit) approaches to policy evaluation is that they add to the uncertainty associated with evaluation. As such, it is argued, the approaches are best not adopted in the first place. There are indeed uncertainties, and often significant uncertainties, in cost-benefit appraisal. The problem is that the uncertainty is not reduced through nonadoption of cost-benefit analysis (CBA). Invariably, uncertainty is actually increased when CBA is not used. There are many reasons for this conclusion, but two will suffice.

First, what CBA does is to compare benefits and costs in the same units (money).[1] This permits a decision of whether or not to adopt the policy at all. Adoption follows if benefits exceed costs and not otherwise. Failure to monetize benefits means that the choice context is one of cost-effectiveness in which costs are in money units but effectiveness is in a different unit, for example some notion of risk reduction (such as lives saved). However, cost-effectiveness can only rank alternative policies; it cannot say whether anything should be done. We may, for example, choose policy A over B because A secures more risk reduction per dollar than B. Nevertheless, both A and B could still fail cost-benefit tests, indicating that neither should be undertaken. Thus, a failure to adopt CBA increases risk because a new risk emerges, namely that incorrect policies are adopted.

Second, the risk reduction in question will show up in various ways. On the simplest level it may manifest itself in reduced mortality and reduced morbidity. Cost-effectiveness analysis cannot now be conducted unless we have some idea of the relative importance of reducing one form of risk over another form of risk. Relative importance is measured by a set of weights, such that the ratio of the weights on any two forms of risk reduction reflects the relative importance of reducing one risk compared to another. If weights are not adopted, it is not possible to make any comparison between options, and rational decisionmaking is not possible. All decision analysis involves one means or another of selecting weights: by implied political preference, overt expert judgments, or, in the case of CBA, individuals' willingness to pay for one change compared to

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[1] This simple observation also explains why one cannot logically avoid monetization. First, all policies have costs. If they did not have costs, there would be no need to consider whether or not they are "good" policies. Hence the acceptance of a policy implies that benefits must exceed costs, which sets a lower bound on the scale of monetary benefits. If the policy is rejected, the reverse applies. Second, costs are measured in monetary terms and few people have difficulty in agreeing that this is the correct way to measure costs. But costs are simply negative benefits, since all costs are properly measured by the forgone benefits of spending money on the chosen project rather than on something else. So, positive money costs are the same thing as negative money benefits. It follows that benefits must also be expressible in monetary units.

another. In short, CBA's weights are prices. Compared to a situation in which there is no knowledge of weights at all, CBA reduces uncertainty and does not increase it. It then becomes an issue of which set of weights is preferable. One advantage of CBA weights (prices) is that they reflect the preferences of those exposed to risk, and are hence more democratic than expert weights.[2]

An Ideal Model

The ideal approach to measuring the social benefits and costs of arsenic mitigation would be as follows.

First, some assessment would need to be made of the extent to which the selected mitigation strategy will reduce human and environmental exposure to arsenic contamination. Refer to this change as ΔX where X refers to exposure. This stage of the analysis would therefore produce the policy effect on exposure.

Second, we need an exposure-response relationship. Two effects can be identified. The first is the effect on human health, call this ΔH. Again, there will be many different health effects, ranging from reduced premature mortality to changes in, for example, hospital admissions and days away from work. Therefore, ΔH is a vector. It is helpful to divide human health effects into reduced occupational risks (ΔH_O) and reduced public health risks (ΔH_P). This is because there may be differences in the way the two effects are to be valued in monetary terms. The second effect is the environmental impact on ecosystems and biodiversity. Call this ΔE. Then, the sum of the effects is $\Delta H_O + \Delta H_P + \Delta E = \Delta I$ where I is overall impact.

Third, we need economic values for each impact since it is implicit in the equation for ΔI that the effects are expressed in the same units. We refer to these as the shadow prices because they are the prices that would be attached to the reduced risk if there were an overt market for risk reduction. These shadow prices reflect individuals' willingness to pay for avoiding the ill health or negative environmental impact associated with arsenic. Again there will be a whole set of shadow prices covering all of the impacts. We refer to these shadow prices as P and they are formally equivalent to the weights discussed in next section.

Fourth, we need to know when in time the changes in exposure will occur. This is because future changes in exposure will be valued less than near-term changes in exposure. The economic

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[2] *It could be argued that political weights are best of all since politicians are elected to make such decisions. Unfortunately, the political model underlying this view is naïve, and assumes politicians always act in the best interests of voters. Moreover, techniques such as CBA are designed as checks on political decisionmaking; this is the purpose of policy analysis.*

concept that reflects the different weights attached to time is known as a discount factor. The process of attaching weights to time is known as discounting. The discount factor (DF) is linked to the discount rate(s) (expressed as an interest rate; that is, in percentage terms) as shown in equation 1:

Equation 1. Discount Factor

$$DF = \frac{1}{(1 + s)^t}$$

Where t = time (years from the present).[3]

Timing is important, however; not all mitigation measures can predict the exact timing of exposure reduction. For example the regulator or policymaker, in a situation where a village's groundwater resources are contaminated, can decide to introduce piped arsenic-free water supply. Exposure to arsenic will be reduced at the moment piped water supply is introduced, if the regulator can effectively monitor that the inhabitants of the village do not continue to use other contaminated groundwater sources. Monitoring of abstraction activities is difficult, time consuming, and hence expensive, especially when areas are heavily populated. As a result monitoring will have to be coupled with an attempt to increase social awareness of the adverse effects of using contaminated water (for example through an educational campaign). An educational campaign, however, will be costly and a medium-term measure. Overall, even for mitigation measures as drastic as introducing another source of water, the timing of reduction exposure is not as evident as might be imagined.

Moreover, if a regulator is interested in restricting groundwater abstraction in order to reduce the possible anthropogenic impacts of pumping on groundwater contamination, then the exact timing of the contribution of this measure to exposure reduction (and possibly the timing of reintroducing groundwater as a water source) becomes even more difficult to identify. The significant impacts of pumping on groundwater flow may result in medium-term or long-term changes in the aquifer systems (see Paper 1 of this report). Not only is it difficult to quantify these impacts, both with regards to their time and space dimension, but it is also necessary to be aware of the various dimensions of the potential human influences. These include the impacts of pumping-induced flow on transport of arsenic both within and between aquifers, impact of pollutants such as organic carbon and phosphate on aquifer redox and sorption or desorption, and impact of seasonal waterlogging of soils for rice production on subsurface redox conditions.

Fifth, we need to know where the exposure changes occur. For example, if they occur in heavily populated areas the benefits of risk reductions will be higher. Environmental effects are even more location specific.

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[3] *Space precludes further discussion of discounting. It should be noted that it is not possible to avoid discounting. Not discounting is formally equivalent to discounting at 0%. Unfortunately, zero discounting has logical implications that make it undesirable, however reasonable it may at first appear (Koundouri and others 2002).*

The ideal model can now be summarized as follows. The benefits that ensue from arsenic mitigation are given by equation 2.[4]

Equation 2. Ideal Model of Benefits Ensuing from Arsenic Mitigation

$$PV\,(B) = \frac{\sum_{i,t} \Delta\, I_{i,t}(\Delta X_t)}{(1+s)^t}$$

Where:

i = the individual impacts
PV(B) = the present value of benefits from arsenic mitigation and is the value that would be compared to the present value of costs.

A particular mitigation option would pass a cost-benefit test if PV(B) > PV(C) (present value of costs), as shown in equation 3.

Equation 3. Mitigation Option Passing a Cost-Benefit Test

$$PV\,(B - C) = \frac{\sum_{i,t} \Delta\, I_{i,t}(\Delta X_t)}{(1+s)^t}\; PV\,(Costs) \geq 0$$

Notice that the situation in equation 3 could be met overall in a country but a particular mitigation option could fail in any one region of the country. Similarly, a mitigation policy could fail a cost-benefit test at the country level, but pass it in a given region.

Problems with the Ideal Model

Models of the kind shown in equation 3 have been used fairly extensively for such air pollutants as sulfur and nitrogen oxides, particulate matter, and volatile organic compounds (Olsthoorn and others 1999; Krewitt and others 1999). These models make use of long-established emission-diffusion-deposition models (such as RAINS Europe), which also contain measurable ecosystem impacts based on notions of critical loads.[5] They also have established exposure-response relationships for human health. The policies that are simulated also have known, or reasonably known, time schedules over which the pollutants are reduced. Finally, they utilize economic values per effect based on longstanding work under the ExternE program of DGXII in the European Commission.

The contrast with what is known about arsenic pollution is a stark one. In order to be able to provide an overall policy-level model that will be able to measure the social benefits and costs of

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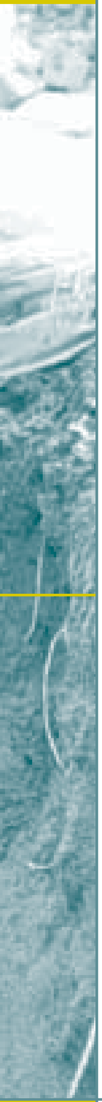
[4] *Equation 2 ignores location for convenience of exposition, but it will be appreciated that benefits and costs vary by location.*

[5] *A critical load is the maximum level of deposition of airborne pollutants that produces no discernible change in the receiving ecosystem. Above this level, some form of ecological damage occurs. Note that critical loads relate solely to ecosystems and not to health effects. A critical level would be that ambient concentration that produced no discernible change in, for example, human health, materials corrosion, or crop loss.*



arsenic mitigation one would need to know the following (and unfortunately we do not):

- The effects of mitigation activities on exposure (ΔX), since this is dependent on the behavioral reaction of producers, users, and regulators to (a) the changes in information generated by arsenic mitigation efforts and relevant educational campaigns; and (b) the costs of regulation. Put another way, we have no economic model of the relevant economy – including all users – with which to simulate the effects of any policy change.
- The health and environmental exposure-response functions ($\Delta I(\Delta X)$) for arsenic pollution, of which, in any event, there are many thousands.
- The locations at which risks will change.
- The split between occupational and public health effects.
- The time schedule of ΔX, although some assumption could be made about this.

We do have some economic values for health end states, but valuation of environmental effects would not be possible since we have no idea of the end states of the changes in, for example, groundwater flows (both in terms of quantity and quality).

We conclude that it is not possible to approximate the ideal model in the case of arsenic mitigation. The information is simply not available. After recognizing that we have to move away from the first-best world of full information and certainty, in the next section we develop a so-called nth best model, which allows approximation of the costs and benefits of arsenic mitigation, but does not claim to be an exact representation (model) of the actual situation. The reasons for the need to have an approximate rather than an accurate model have been explained in this section and need to be taken very seriously by any policymaker who would choose to make use of this paper. This paper should be thought of as providing guidance on the methodological approach that one should use when contemplating the economic costs and benefits of different arsenic mitigation policies. However, the empirical application of the suggested methodological approach should be treated with great caution and results should be read as case study specific, derived under conditions of severe information scarcity and pervasive uncertainty, with regards both to the human and physical reactions to implementable mitigation policies.

The merit of our methodological approach compared to an approach attempting to implement the first-best (ideal) model, is that it explicitly accepts, identifies, and characterizes the heroic assumptions made in the evaluation process. We hope that this feature of the proposed nth best model will act as a constant reminder of the pervasive uncertainties and incomplete information that prevail in arsenic mitigation policies.

The Nth Best Model

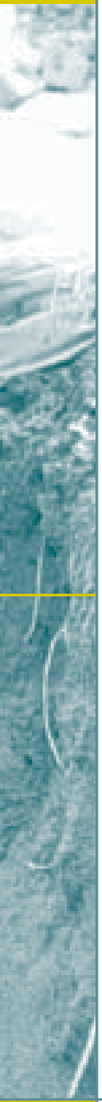
Given the circumstances, we have to proceed in a far more ad hoc way.

The first thing to do is to invert equation 3 and find out just how large the benefits need to be for a particular arsenic mitigation policy to pass a cost-benefit test. We do this for health effects only since we cannot estimate environmental effects. This procedure gives us a benchmark. If health benefits exceed this level then we know that the particular policy comfortably passes a cost-benefit test. We also have a minimum estimate of benefits since environmental effects are not calculated and these unknown benefits would need to be added.

Second, we need some crude ways in which benefits can be estimated given certain assumptions. Water intended for human consumption should be both safe and wholesome. This has been defined as water that is free from pathogenic agents, free from harmful chemical substances, pleasant to taste, free from color and odor, and usable for domestic purposes (Park 1997). Without ample safe drinking water, communities cannot be healthy.

Cvjetanovic (1986) reviews the various mechanisms by which the provision of safe water supply is transformed into health benefits. His conceptual framework shows that an investment in water supply and sanitation results in an improvement in the quantity and/or quality of water available to the household. This yields direct health benefits resulting from improved nutrition, personal hygiene, and the interruption of water-related disease. Moreover, the health benefits from reducing water-related disease can in some circumstances translate into greater work capacity, which may contribute to increased production and hence to overall economic development. According to Becker (1971, 1981), the household uses time, labor, and purchased goods to create commodities for the household. The household attempts to produce safe water for consumption, which is dependent on time and resource constraints. Safe water for household use is dependent on the time and labor used in the collection of water, the time and resources used to boil or sterilize the water, and managing water within the household. Households may not have access to safe water supplies because the financial, labor, or time and energy costs of collection and management are too high, either at a given point in time or perpetually.

The provision of a local safe water supply source is likely to considerably reduce the burden of producing safe water for the household. The labor cost of collecting water is borne largely by women and girls, who are responsible for domestic chores in most developing countries. It has been found in Kenya that carrying water may account for up to 85% of total daily energy intake of females (Dufaut 1990). While this is not currently the case everywhere in South and East Asia, if arsenic mitigation activities imply switching wells to a safe well, which might be located at a significant distance from the house, then it may mean that even in these countries women have to walk long distances for water. A number of physical ailments may result from carrying heavy loads, including head, neck, and spinal problems (Dufaut 1990). Clearly there is considerable



health benefit to be gained from decreasing women's weight-bearing responsibilities. In addition, Krishna (1990) points to the indirect health benefits that may be gained from mothers having greater time to spend on childcare. The extent of benefit is related to service level (proximity to point of use) and to reliability.

All of these health benefits should be seriously considered in a CBA of various potential mitigation measures, especially when mitigation measures are likely to deprive women of these health benefits. That is, due consideration should be paid to the incentives that various mitigation measures create for the people, which will to a large extent define the acceptability and effectiveness of the measures. If a mitigation measure is too costly in terms of time and adverse health effects then implementation will be difficult and monitoring very expensive, if it is possible at all.

Access to safe water will also depend on nonmaterial factors, such as basic hygiene knowledge, social position, and water quality. Basic hygiene knowledge and high water quality facilitate access to safe water. It is said that these factors alter the efficiency of the household as a safe water producer. Social factors affecting access to water supply sources will also determine the ability of the household to produce safe water. Lower-caste households may not have access to high-quality water supply sources due to cultural norms, which embrace principles of social exclusion. Conversely, higher-caste households may be unwilling to share high-quality water supply sources with lower-caste households, which instead may choose alternative sources of lower-quality water. In other social contexts, the effects on higher castes may be adverse, for example if they are socially excluded from water sources used by lower castes.

A model for calculating these benefits is developed in chapter 4. Our model, however, takes into account only some of the identified health benefits and occupational benefits. Other social benefits, such as those outlined in the last three paragraphs of this section, are not included in the application of our model due to the lack of relevant information. In the case that such relevant estimates exist, our model is flexible enough to accommodate such benefits.

Is Passing a Cost-Benefit Test Sufficient?

The requirement that benefits be greater than costs is not sufficient for a policymaker to sanction investment in a particular project. We can say that a cost-benefit ratio >1 is a necessary condition for approval of a project, but is not a sufficient condition for its approval. This is because every government invariably faces a limited budget and cannot undertake all projects where social benefits exceed social costs. We therefore require a procedure to rank different projects. It is tempting simply to rank them using the net present value of benefits, but this is actually a mistake. This is easily demonstrated by table 1.

Table 1. Ranking of Projects

Project	PV (costs)[a]	PV (benefits)	NPV (benefits)[b]	PV (benefits)/ PV (costs)
X	100	200	100	2.0
Y	50	110	60	2.2
Z	50	120	70	2.4

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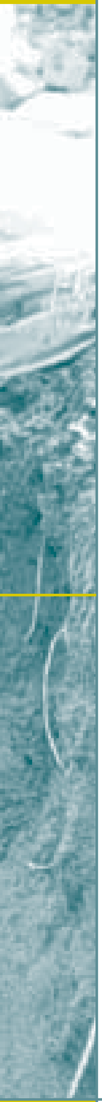
[a] *PV = present value.* [b] *NPV = net present value.*

This shows three projects, X, Y, and Z, with the present value (PV) of their benefits, costs, and net benefits. Suppose the budget constraint is 100 units. Then a ranking by NPV (benefits) would suggest X, Z, Y and we would undertake X only with a cost of 100. The gain to society would be NPV(X) = 100. But casual inspection shows that we could afford Y and Z, and the NPV would be NPV(Y) + NPV(Z) = 60 + 70 = 130. Clearly, ranking by NPV does not give us the right answer. This is given by a ranking of PV (benefits) divided by PV (costs), or the so-called benefit-cost ratio.

The above discussion points to an additional consideration: that one should try to develop a clear picture of how arsenic mitigation interventions figure in the overall water and sanitation sector and in the broader economy of a country. For example, interventions in sanitation that would drastically reduce diarrhea and infant mortality rates might be another way of achieving significant social benefits in a developing country such as Bangladesh. Alternatively, perhaps investing in education and transport infrastructure or investing in other sectors of the economy would produce higher social net present value. Given the different potential social welfare-increasing projects, the policymaker should rank them according to the cost-benefit ratios associated with each one, as discussed above.

It should be noted, however, that the ability to perform such a ranking exercise depends on the availability of CBAs for all potential investments, which is an expensive endeavor. Developing countries will not have the means to accommodate such an expensive and holistic exercise; however, they should implement this exercise for policies when possible to prioritize projects. Prioritization will reflect ethical judgments within the country, or binding constraints imposed by the national or international political and policy arena.

Another point to note, and one which was touched upon in this section of this paper, is that when embarking on such CBA one should be aware of the long-run effects of proposed projects and mitigation measures. In the calculation of present values of costs and benefits of public sector projects and policies, future values are multiplied by a discount factor that is calculated from the



social discount rate (social time preference rate). However, at even a modest rate, the practice of discounting reduces the value of costs or benefits for long periods of time (many years) and hence almost to zero. This disenfranchizes future generations from consideration in today's decisions. Recent work on discounting over the long term has now made it clear that constant rate discounting has only a limited justification, and that it is possible to make recommendations for better practice (Koundouri and others 2002; Pearce and others 2003). The recent literature argues that discount rates vary with time and that, in general, they decline as the time horizon increases.[6] The effects of declining discount rates on the appraisal of relatively long-term government policies, programs, and projects can be summarized as follows:

- Is small over a short (for example 30-year) period, but large over a very long period
- Can influence the choice of a policy or project
- Does not always support the option perceived as best for the environment
- Can affect financial planning, in both public and private sectors
- May result in reevaluation of hurdle cost-benefit ratios or budgets in the public sector

Finally, one should keep in mind that economic policy is about making comparisons of the economic situation, which requires knowledge about the desirability of the change that an action seeks to bring about. In the real world, choices lead to gains by some and losses by others. To avoid making value judgments in this context, a number of compensation tests have been devised in an effort to find a basis to compare states that is founded on efficiency.[7] However, attempts to devise a criterion based solely on efficiency, and without resort to ethical judgments, are simply not available and economists' policy recommendations are controversial.

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[6] *There are several strands to the arguments in favor of declining long-run interest rates. The first set of arguments derives from empirical observations of how people actually discount the future. There is some evidence that individuals' time preference rates are not constant over time, but decrease with time. Individuals are observed to discount values in the near future at a higher rate than values in the distant future. While some evidence still supports time-constant discount rates, the balance of the empirical literature suggests that discount rates decline in a hyperbolic fashion with time. The second set of arguments in favor of time-varying discount rates derives from uncertainty about economic magnitudes. Two parameters have been selected for the main focus of this approach. The first is the discount rate itself. The argument is that uncertainty about the social weight to be attached to future costs and benefits – the discount factor – produces a certainty-equivalent discount rate, which will generally decline over time. The second uncertain parameter is the future state of the economy as embodied in uncertainty about future consumption levels. Under certain assumptions, this form of uncertainty also produces a time-declining discount rate. The third set of arguments for time-declining discount rates does not derive from empirical observation or from uncertainty. Instead, this approach – the "social choice" approach – directly addresses the concerns of many that constant-rate discounting shifts unfair burdens of social cost onto future generations. It adopts specific assumptions (axioms) about what a reasonable and fair balance of interests would be between current and future generations, and then shows that this balance can be brought about by a time-declining discount rate. Any one, or all, of these three lines of arguments supports the hypothesis that the social time preference rate decline with time. Moreover, there have been a number of attempts to construct models to quantify the shape of this decline and, in some cases, to test them empirically.*

[7] *An excellent discussion of compensation tests can be found in Chipman and Moore 1978.*

3. The Cost of Arsenic Mitigation Measures: Review of Possible Actions

As indicated in chapter 2, the CBA undertaken in this paper will only take into account some of the health-related costs of arsenic contamination and resulting occupational hazards. These costs will translate into benefits if avoided through the implementation of effective mitigation measures. Hence, in order to derive the cost-benefit ratio of the different mitigation measures these benefits should be compared with the costs of the relevant mitigation measures. These costs and benefits are described in this chapter.

Health Effects of Arsenic in Drinking Water

The World Health Organization (WHO) recommendations on the acceptability and safety of levels of arsenic in drinking water have dropped twentyfold from a concentration of 200 μg L^{-1} in 1958 to 10 μg L^{-1} in its 1993 Drinking Water Guidelines. However, some countries are still using the former WHO standard of 50 μg L^{-1}. For example, the Bangladesh Standards for Testing Institution sets the maximum permissible limit for arsenic at this former level.

Differences in standards derive partly from the fact that there is no widely accepted complete definition of what constitutes arsenicosis. Inorganic arsenic is a classified carcinogen (IARC 1980) that also has a multitude of noncancer effects. The widespread effects of arsenic are perhaps responsible in part for the lack of a widely accepted care definition for arsenicosis. Furthermore, some symptoms of arsenicosis (such as shortness of breath) may be observationally indistinguishable from the health effects of other illnesses. A comprehensive review of the health effects of arsenic contamination of drinking water is undertaken in Paper 2 of this report. The purpose of this section is to highlight some of the main findings of the literature on health effects, especially with respect to predictive use of the available information. In addition, arsenic poisoning may be acute or chronic. In the context of community drinking water supply, only chronic exposure is relevant. Acute poisoning is therefore not discussed further.

According to the United States National Research Council report (NRC 1999, p. 89), the most widely noted noncancer effect of chronic arsenic consumption is skin lesions. Over time, arsenic exposure is associated with keratoses on the hands and feet. The time from exposure to manifestation is debated in the literature, while the youngest age reported for patients with hyperpigmentation and keratosis is two years of age (Rosenberg 1974). In Bangladesh, Guha Mazumder and others (1998) suggest a minimum time gap of five years between first exposure and initial manifestations.

Cancer Health Effects[8]

Hutchinson (1887) identified arsenic as a carcinogen because of the high number of skin cancers

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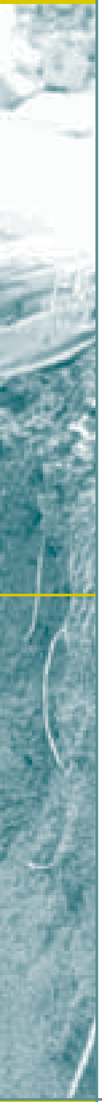
[8] *Arsenic is also associated with peripheral vascular disease, which is a condition that results in gangrene in the extremities and usually occurs in conjunction with skin lesions. Other cardiovascular problems such as hypertension (Chen and others 1995) and ischemic heart disease have also been found to be associated with arsenic (Tsuda and others 1995). Moreover, Guha Mazumder and others (1998) found evidence of liver enlargement and restrictive lung disease. In terms of hematological effects, anemia is commonly cited (NRC 1999). Another widely suggested health effect is diabetes mellitus.*



occurring in patients treated with arsenicals. The International Agency for Research on Cancer (IARC 1980) classified inorganic arsenic compounds as skin and lung (via inhalation) carcinogens. In the period following this classification, concerns have grown over the possibility of arsenic in drinking water causing a number of other cancers.

An early study by Tseng and others (1968) found evidence of a dose-response relationship between concentration of arsenic in drinking water and prevalence of skin cancer. The International Program on Chemical Safety (IPCS 1981) estimated skin cancer risk from lifetime exposure to arsenic in drinking water at 5% for 200 µg L^{-1}, based on the findings of Tseng (1977). Based on the increased incidence of skin cancer observed in the population in Taiwan, China, the United States Environmental Protection Agency (EPA 1988) has used a multistage model that is both linear and quadratic in dose to estimate the lifetime skin cancer risk associated with the ingestion of arsenic in drinking water. With this model and data on males, the concentrations of arsenic in drinking water associated with estimated excess lifetime skin cancer risks of 10^{-4}, 10^{-5}, and 10^{-6} are 1.7, 0.17, and 0.017 µg L^{-1} respectively. Considering other data and the fact that the concentration of arsenic in drinking water at an estimated skin cancer risk of 10^{-5} is below the practical quantification limit of 10 µg L^{-1}, the provisional guideline value of 10 µg L^{-1} is recommended (WHO 1996). The guideline value is associated with an excess lifetime risk for skin cancer of 6 x 10^{-4} (that is, six persons in 10,000).

High levels of arsenic in drinking water are also associated with a number of internal cancers. However, it is difficult to quantitatively establish risk in many of the studies, due to problems in measuring exposure to arsenic. Chen and others (1985) calculated standardized mortality ratios for a number of cancers in 84 villages in Taiwan. Mortality for the period 1968-1986 was compared with age and sex-adjusted expected mortality. Significantly, increased mortality was observed among both males and females for bladder, kidney, lung, liver, and colon cancers. However, the authors were not able to directly estimate arsenic concentrations in well water. Chen and Wang (1990) were able to use data on arsenic concentrations in 83,656 wells in 314 precincts and townships collected from 1974 to 1976 in Taiwan. The authors used a multiple regression approach to control for socioeconomic confounding factors, and compared age-adjusted mortality rates with average arsenic concentrations in each township. They found a significant relationship between arsenic concentration and mortality from cancers of the liver, nasal cavity, lung, bladder, and kidney for both sexes.

The above-mentioned studies all used an ecological design and are thus susceptible to bias from confounding factors. However, the bladder and lung cancer results of these studies are also confirmed by cohort studies, which may be less susceptible to this form of bias. These studies are also useful in providing data on the latency period of internal cancers. Cuzick, Sasieni, and Evans (1992) studied a cohort of patients treated with Fowler's solution (potassium arsenite) in England from 1945 to 1969. The authors found evidence that the period between first exposure and death from bladder cancer varied from 10 years to over 20 years.

To conclude, the results from studies of cancer indicate strong evidence that exposure to arsenic is related to skin, lung, and bladder cancer. It is likely that arsenic causes a number of other cancers, but thus far epidemiological evidence has not been consistent for other sites in the body.

Treatment of Arsenicosis Sufferers

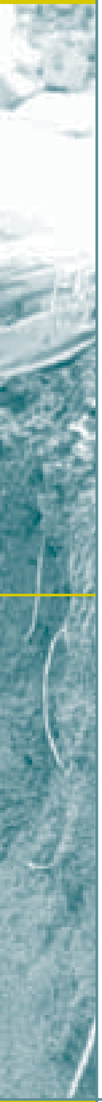
Guha Mazumder (1996) suggested that the first stage in treating those with arsenicosis should be the immediate cessation of consumption of arsenic-contaminated water. Once this has been achieved, the emphasis should be on the provision of a diet high in protein and vitamins. The chelating agents DMPS (dimercaptopropane sulphonate) and DMSA (dimercaptosuccinic acid) are recommended as treatment drugs (Angle 1995). However, Guha Mazumder (1996) notes that these drugs are very expensive. Palliative care may be the only affordable treatment in rural areas of developing counties, where expensive drugs and protein-rich diets are unlikely to be available to the vast majority of people. In the case of keratosis, application of ointment containing salicylic acid can help to soften the skin and ease the patient’s pain.

Mitigation of Arsenic in Drinking Water

This section will analyze the technologies that can be used to provide safe drinking water in rural Bangladesh, which serves as an example for most relevant mitigation options. The available options for safe water can be classified by source: groundwater, surface water, and rainwater. Recent years have seen increasing acceptance of strategies for incremental improvement in environment and health in general and of demand-driven approaches to water supply and sanitation in particular. It is inappropriate therefore to pursue a single overall technological solution but rather to inform communities and individuals of alternatives and their characteristics in order to facilitate choice of the most appropriate options.

Groundwater

The simplest and most immediately achievable option is the sharing of tubewells that are currently either free from arsenic or contain very low levels. Wells containing arsenic may still be used safely for such activities as washing laundry, and a simple color coding (using, for example, "traffic light" colors) may have a significant impact on community arsenic exposure if carefully and continuously backed up by awareness raising and education. However, in the most highly contaminated areas not enough tubewells will contain safe levels of arsenic. Furthermore, color coding would have to be monitored carefully over time, as tubewells with previously safe test results may be later found to contain increased levels of arsenic. The principal costs of such an approach relate to the ongoing testing and labeling of wells and of continuous awareness raising and education. These costs may be borne by the community or by an outside agency. In practice, the household burden of water collection is likely to increase (because a greater average distance will be traveled in order to collect the same volume of water).



For some countries, such as Bangladesh and Nepal, the other alternative for groundwater supply is the development of deep tubewells. The principal costs of such an approach relate to the costs of developing the deep tubewells. These include the costs of training and equipping drilling teams as well as the direct costs of drilling itself, including a proportion of unsuccessful bores. These costs may be borne by the community or an outside agency. If contaminated wells remain in use for other purposes such as laundering ongoing awareness raising and education will be essential. If new wells are appropriately sited then the household burden of water collection may be constant or even decrease. Deep tubewells have been in use for years in coastal areas because of high salinity in shallow aquifers. However, it is not possible to exploit this technology in all areas because rock formations may make drilling infeasible.

The Danish Agency for International Development (Danida) has conducted research in Noakhali in Bangladesh since November 1998 on the removal of arsenic using a mix of 200 μg L^{-1} alum and 1.5 μg L^{-1} $KMnO_4$ introduced into a large bucket (18 liters), of which the supernatant is drained off after 1–1.5 hours into a bucket standing beneath it. Cost of chemicals for an average family is Tk 10/US$0.2 a month. Lab tests show a reduction in arsenic levels of 1,100 μg L^{-1} to 16 μg L^{-1}. In the field tests arsenic ranging from 120–450 μg L^{-1} was reduced to 20–40 μg L^{-1} consistently. Though well within the Bangladesh standard, the removal efficiency was considerably less than in the laboratory. Stirring (time, mixing efficiency – paddle stick instead of cane stick) is believed to make a difference and Danida is currently verifying this in a field test. Danida has also designed a two-bucket column (total investment cost for the set is Tk 300/US$6), which circumvents the resuspension of the settled solids. Danida reports that 50–80% of the two-bucket systems deliver water within Bangladesh standards (Danida 2000).

Coprecipitation is a well-known phenomenon and has been the subject of a small study by WaterAid in East Madaripur near Chittagong. Iron ranges from 0 to 10 μg L^{-1}. In the first phase of the study it seemed that removal rates were very good. However, upon further study it was found that some wells showed very low removal rates. It seems that salinity has a detrimental effect on removal. Hardness may possibly have an effect as well.

The Danida and WaterAid studies also examined the sustainability of methods at the household level. Apart from initial acceptance of a suitable method, households will also have to apply the technique consistently and properly to continue to avail themselves of the benefits of arsenic avoidance.

The Pan American Center for Sanitary Engineering and Environmental Sciences (CEPIS)[9] in Peru has developed a technology called ALUFLOC for arsenic removal at the household level and it has been tested in Argentina. ALUFLOC is a sachet containing chemicals that are added to a bucket of arsenic-contaminated tubewell water. After about an hour the treatment process is complete and the water is safe for consumption. Preliminary field test results suggest that ALUFLOC is effective in reducing arsenic content to safe levels. However, it is necessary to

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[9] *CEPIS is part of the Pan American Health Organization (PAHO), the WHO Regional Office for the Americas.*

optimize the product for treating tubewell water with a concentration of arsenic greater than 1,000 μg L^{-1}. The cost of the technology is estimated at US$0.15 per bucket treated, given the assumption of production at an industrial level. The cost of such an approach relates to the ongoing need for awareness raising and education; the cost of treatment materials (including manufacture and distribution); and the costs of additional household expenditure on equipment (such as additional buckets) and in terms of time. It may however be deployed rapidly and costs may be borne by the community or an outside agency, or may be subsidized.

Surface Water

Surface water (including rainwater, rivers, lakes) is typically low in arsenic and therefore a potentially attractive source of drinking water in arsenic-rich areas. However, surface waters are frequently contaminated with human and animal fecal matter and other material and are unsafe for this reason. This risk initially led to the preference for groundwater sources in Bangladesh and other developing countries worldwide. The critical issues in arsenic-rich areas therefore concern whether treating surface water for fecal contamination can be reliably achieved at a lower overall cost than securing groundwater from low-arsenic sources or through treatment to remove arsenic from groundwater.

Surface Water Treatment

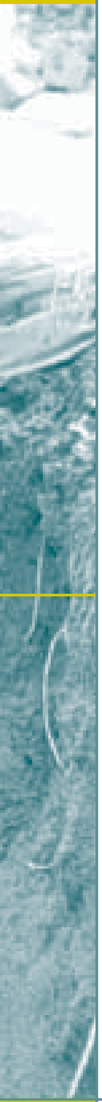
Treatment of surface water can be achieved by several means. Slow sand filtration, for example, is a typical method of treatment for rural areas and small towns. The water passes slowly through a large tank filled with sand and gravel. There is some reservation about the sustainability of this method in Bangladesh. The reasons for this include the need for careful maintenance and the risk of bacteriological infection if the system is not operated properly. However, pond sand filters are still useful as an option in Bangladesh, especially in the coastal belt where there are few alternatives.

The key elements in the decisionmaking process leading to the selection of technology using surface water rather than groundwater concern the costs of capital investment in infrastructure and the cost of maintenance, including supervisory support. If wells containing arsenic remain in use, ongoing awareness raising and education will be required. The household burden of water collection is likely to increase (as the number of available sources is likely to decrease) unless the opportunity is taken to make capital investments to develop piped distribution.

Rainwater

Rainwater harvesting is a recognized water technology in use in many developing countries around the world (WHO-IRC 1997). The United Nations Children's Fund (UNICEF) has promoted dissemination of the technology since 1994 in Bangladesh. The rainwater is collected using either a sheet material rooftop and guttering or a plastic sheet and is then diverted to a storage container.

Rainwater harvesting is capital intensive and the costs (and availability) of suitable roofing, materials for guttering, and storage tanks are important factors. Rainwater use has proven to be successful in Taiwan, Sri Lanka, and Thailand.



In some circumstances there is the possibility of chemical contamination of the collected water, particularly where air pollution is a major problem and where bacteriological contamination may be caused by bird droppings. There is also the possibility of contamination (for example intrusion of insects), particularly when the water is stored for long periods. Health inspections are needed regularly to ensure that the water is of good quality. However, these reservations might be less problematic as rainwater quality in many circumstances is at least as good as the piped water distributed in many towns in Bangladesh.

The above are only examples of technologies that might be considered as alternatives to groundwater abstraction. Other low-cost technologies that might be considered include use of springs and infiltration galleries.

In our empirical application we consider eight alternative technologies designed to provide arsenic-free water: dug wells, roof rainwater combined with dug wells for the dry season, deep tubewells, arsenic removal in existing shallow tubewells, pond sand filters, deep production wells (piped scheme), impoundment-engineered pond (piped scheme), and surface water infiltration (piped scheme).

Technology Choice

The following analysis is based on Bangladesh data and naturally it will vary in different countries, due mainly to the population density, the severity of the arsenic problem, and the geographic distribution of the population. Moreover, we take into account only the rural population of Bangladesh. The technology options considered can all be applied in Bangladesh, but some of them may not be applicable in other countries. For example, in some countries deep tubewells may not be useful because the aquifer structure is such that deep tubewells may also be contaminated (see Paper 1).

The choice between these technologies should take into account their cost-effectiveness in providing arsenic-free and microbiologically safe drinking water. Different options may have very different balances of cost between, for example, capital and recurrent costs and may impact differently on the household costs of water management. However, the criteria of sustainability and acceptance by rural users must be incorporated into the calculation of cost-effectiveness in order to aid the decisionmaking process concerning which mitigation method(s) to implement. Table 2 indicates the mitigation options for which cost evaluation is conducted.

The aforementioned technology options are evaluated for three kinds of villages: small (100 households), medium (500 households), and large (1,000 households). We further assume that each household consists of an average 5.5 members and that the distribution of income is as follows: 10% have high income, 20% have medium income, and 70% have low income. The level of service provided to each household depends on the income of the household. The high-income people will be provided water by multiple taps (one for each household), the medium-income people will have a single yard tap per two or three households, while a communal

Table 2. Arsenic Mitigation Technology Options

Option no.	Technology
A	Dug wells
B1	Roof rainwater harvesting/household (60 m^2) + dug well for dry season
B2	Roof rainwater harvesting/household (60 m^2) + deep tubewell for dry season
C	Deep tubewell
D	Existing shallow tubewell with household arsenic removal
E1	Pond sand filter
E2	Pond sand filter (30 households/pond sand filter)
F	Piped scheme deep production well
G	Piped scheme impoundment-engineered pond
H	Piped scheme surface water infiltration gallery

standpost will be provided per 10 households of low income. The distribution of income as well as the level of service is necessary for the most accurate cost estimation.

Table 3 shows the capital costs and operation and maintenance annual costs applied to a small village of 100 households.[10] The most expensive technology in terms of capital costs is option B (both B1 and B2), which combines rainwater harvesting with the construction of dug wells or

Table 3. Small Village: Capital and Operation and Maintenance Costs

Technology		Capital costs (US$)[a]	Operation & maintenance costs (US$)[a]
A	Dug wells	17,750	2,968
B1	Rainwater harvesting + dug well	33,913	3,523
B2	Rainwater harvesting + deep tubewell	35,335	2,819
C	Deep tubewell	21,561	1,083
D	Shallow tubewell with arsenic removal	7,966	4,237
E1	Pond sand filter	25,719	2,242
E2	Pond sand filter (30 households/unit)	3,810	332
F	Deep production well, piped	19,432	3,051
G	Impoundment, piped	19,432	3,390
H	River abstraction, piped	17,653	3,051

[a] *Costs are for a small village of 100 households.*

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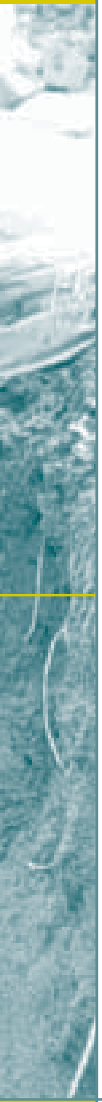
[10] *A detailed description of the costs involved in each technology for a village of 500 households is given in annex 1.*



deep tubewells. In terms of operation and maintenance expenses option D is the most expensive, due to the costs of the arsenic removal techniques. The level of service provided for a small village by each of the techniques is summarized in table 4.

Table 4. Small Village: Technology-Specific Level of Service

Technology		No. of households per unit by income			Total for 100 households
		High (10%)[a]	Medium (20%)[b]	Low (70%)[c]	
A	Dug wells	1	3	10	24
B1/2	Rainwater + dug well/tubewell	1	1	1	100
C	Deep tubewell	1	3	10	24
D	Shallow tubewell/arsenic removal	1	1	1	100
E1	Pond sand filter	1	2	10	27
E2	Pond sand filter (30 households/unit)	30	30	30	4
F	Deep production well, piped	1	2	10	27
G	Impoundment, piped	1	2	10	27
H	River abstraction, piped	1	2	10	27

Type of service: [a] multiple taps; [b] single yard tap; [c] communal standposts.

In the same mode, for a medium village of 500 households, table 5 shows the capital costs and annual operation and maintenance costs, while table 6 shows the level of service.

Table 5. Medium Village: Capital and Operation and Maintenance Costs

Technology		Capital costs (US$)[a]	Operation & maintenance costs (US$)[a]
A	Dug wells	88,750	14,842
B1	Rainwater harvesting + dug well	169,566	17,616
B2	Rainwater harvesting + deep tubewell	176,677	14,097
C	Deep tubewell	107,803	5,415
D	Shallow tubewell with arsenic removal	39,831	21,186
E1	Pond sand filter	128,593	11,212
E2	Pond sand filter (30 households/unit)	16,193	1,412
F	Deep production well, piped	47,093	6,780
G	Impoundment, piped	48,246	7,627
H	River abstraction, piped	44,534	6,780

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[a] Costs are for a medium village of 500 households.

Table 6. Medium Village: Technology-Specific Level of Service

Technology		No. of households per unit by income			Total for 500 households
		High (10%)[a]	Medium (20%)[b]	Low (70%)[c]	
A	Dug wells	1	3	10	118
B1/2	Rainwater + dug well/tubewell	1	3	10	118
C	Deep tubewell	1	3	10	118
D	Shallow tubewell/arsenic removal	1	1	1	500
E1	Pond sand filter	1	2	10	135
E2	Pond sand filter (30 households/unit)	30	30	30	17
F	Deep production well, piped	1	2	10	135
G	Impoundment, piped	1	2	10	135
H	River abstraction, piped	1	2	10	135

Type of service: [a] multiple taps; [b] single yard tap; [c] communal standposts.

For a large village of 1,000 households, table 7 shows the capital costs and annual operation and maintenance costs, while table 8 (see page 234) shows the level of service.

Table 7. Large Village: Capital and Operation and Maintenance Costs

Technology		Capital costs (US$)[a]	Operation & maintenance costs (US$)[a]
A	Dug wells	177,500	29,684
B1	Rainwater harvesting + dug well	339,131	35,232
B2	Rainwater harvesting + deep tubewell	353,355	27,178
C	Deep tubewell	215,607	10,831
D	Shallow tubewell with arsenic removal	79,661	42,373
E1	Pond sand filter	257,186	22,424
E2	Pond sand filter (30 households/unit)	32,386	2,824
F	Deep production well, piped	87,075	9,322
G	Impoundment, piped	89,075	10,508
H	River abstraction, piped	85,024	9,322

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[a] Costs are for a large village of 1,000 households.

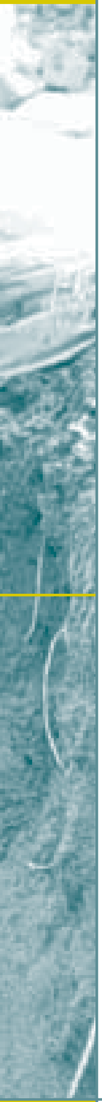

Table 8. Large Village: Technology-Specific Level of Service

Technology		**No. of households per unit by income**			**Total for 1,000 households**
		High (10%)[a]	**Medium (20%)[b]**	**Low (70%)[c]**	
A	Dug wells	1	3	10	237
B1/2	Rainwater + dug well/tubewell	1	3	10	1,000
C	Deep tubewell	1	3	10	237
D	Shallow tubewell/arsenic removal	1	1	1	1,000
E1	Pond sand filter	1	2	10	270
E2	Pond sand filter (30 households/unit)	30	30	30	34
F	Deep production well, piped	1	2	10	270
G	Impoundment, piped	1	2	10	270
H	River abstraction, piped	1	2	10	270

Type of service: [a] multiple taps; [b] single yard tap; [c] communal standposts.

We further conducted a present value analysis in order to identify the technology option with the lowest cost for each kind of village. Our analysis suggests that the most efficient option for small villages is option C, deep tubewells, while for medium and large villages option H, river abstraction (piped), should be employed. These options guarantee arsenic-free water. However, if we disregard the issue of the level of service, the most efficient technique is pond sand filters (30 households per pond sand filter). Special attention should be paid to avoidance of bacterial contamination of the water, as percolation of contaminated surface water is the most common route of pollution. Disinfection of the water by pot chlorination should be continued during operation. As regards option F, the deep aquifers in Bangladesh have been found to be relatively free from arsenic contamination. The study by the British Geological Survey and the Department of Public Health Engineering (BGS and DPHE 2001) has shown that only about 1% of tubewells having a depth greater than 150 m are contaminated with arsenic at concentrations higher than 50 $\mu g\ L^{-1}$ and 5% of tubewells have arsenic content above 10 $\mu g\ L^{-1}$ (See Paper 1 for a more detailed analysis). The combination of deep production wells with piped water supply can ensure the provision of good quality water to people. Details for the present value of the total costs of the various techniques for each of the three sizes of village are given in tables 9, 10, and 11. The numbers in bold indicate the least costly options.

The first column of tables 9, 10, and 11 refers to a discount rate of 10% for a 10-year period, the second column to a discount rate of 10% for a 15-year period, and the third column to a discount rate of 15% for a 20-year period. These figures can be used as the basis for a sensitivity analysis, whose reasoning derives from: (a) 10–15% is the lending rate in Bangladesh; and (b) 10-20 years is a reasonable payout period given the financial market in Bangladesh.

Table 9. Small Villages: Present Value Analysis of Technology Costs

Technology		**Costs (millions US$)[a]**		
		DR[b] 10% for 10 years	**DR[b] 10% for 15 years**	**DR[b] 15% for 20 years**
A	Dug wells	35,989	43,021	36,330
B1	Rainwater harvesting + dug well	55,561	63,908	55,966
B2	Rainwater harvesting + deep tubewell	52,660	59,339	52,984
C	Deep tubewell	**28,216**	**30,781**	**28,340**
D	Shallow tubewell with arsenic removal	34,002	44,041	34,489
E1	Pond sand filter	39,497	44,809	39,754
E2	Pond sand filter (30 households/unit)	**5,851**	**6,638**	**5,890**
F	Deep production well, piped	38,178	45,406	38,528
G	Impoundment, piped	40,261	48,292	40,650
H	River abstraction, piped	36,399	43,626	36,749

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[a] *Total costs of serving all small villages of 100 households. Figures in bold indicate least-cost options.*

[b] *DR = discount rate.*

Table 10. Medium Villages: Present Value Analysis of Technology Costs

Technology		**Costs (millions US$)[a]**		
		DR[b] 10% for 10 years	**DR[b] 10% for 15 years**	**DR[b] 15% for 20 years**
A	Dug wells	179,946	215,107	181,650
B1	Rainwater harvesting + dug well	277,807	319,539	279,829
B2	Rainwater harvesting + deep tubewell	263,300	296,697	264,918
C	Deep tubewell	141,078	153,907	141,700
D	Shallow tubewell with arsenic removal	170,012	220,203	172,443
E1	Pond sand filter	197,485	224,046	198,772
E2	Pond sand filter (30 households/unit)	**24,869**	**28,213**	**25,031**
F	Deep production well, piped	88,751	104,812	89,529
G	Impoundment, piped	95,111	113,180	95,986
H	River abstraction, piped	**86,192**	**102,253**	**86,970**

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[a] *Total costs of serving all medium villages of 500 households. Figures in bold indicate least-cost options.*

[b] *DR = discount rate.*

Table 11. Large Villages: Present Value Analysis of Technology Costs

Technology		**Costs (millions US$)[a]**		
		DR[b] 10% for 10 years	**DR[b] 10% for 15 years**	**DR[b] 15% for 20 years**
A	Dug wells	359,893	430,213	363,300
B1	Rainwater harvesting + dug well	555,615	639,078	559,658
B2	Rainwater harvesting + deep tubewell	520,351	584,736	523,470
C	Deep tubewell	282,156	307,814	283,399
D	Shallow tubewell with arsenic removal	340,024	440,405	344,887
E1	Pond sand filter	394,971	448,092	397,544
E2	Pond sand filter (30 households/unit)	**49,737**	**56,426**	**50,061**
F	Deep production well, piped	144,354	166,438	145,424
G	Impoundment, piped	153,645	178,539	154,851
H	River abstraction, piped	**142,304**	**164,387**	**143,373**

[a] Total costs of serving all large villages of 1,000 households. Figures in bold indicate least-cost options.
[b] DR = discount rate.

In order to assess the total cost of providing the Bangladesh people with arsenic-free water, we need to make some further assumptions. These assumptions, which are listed below, are adopted solely for demonstration purposes and they do not reflect in any way the policy priorities of the World Bank.

- Technology is chosen according to the geographic population distribution.
- Deep tubewells are the optimal choice for small villages up to 100 households, while river abstraction (piped) is the optimal choice for medium and large villages of 500 and 1,000 households.
- 40% of the population is assumed to inhabit small villages, while the remainder of the population is equally divided between medium and large villages.
- Out of the total population (129 million), roughly 29 million people live in arsenic-affected areas. Moreover, we concern ourselves here with the rural population, which is approximately 99 million.[11]

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[11] There are very wide differences in the levels of exposure to arsenic throughout this rural population. Using data in Maddison, Luque, and Pearce 2004 we calculated an average exposure level for the entire rural population of 57 mg L^{-1}, which forms the basis of the analysis undertaken here.

- The methodology outlined can be implemented in a range of cases: for example, for one village, for a specific region, or for the whole region.

The rural population, approximately 99 million people, consists of around 18 million households. Given the geographic distribution of the population, we will assume for analytical purposes that 7,200,000 households live in small villages (72,000 villages of 100 households), 5,400,000 households live in medium villages (10,800 villages of 500 households), and 5,400,000 households live in large villages (5,400 villages of 1,000 households). Tables 12, 13, and 14 indicate the costs applicable to each of the three categories of village. Table 15 indicates total capital and operation and maintenance costs for the entire rural population. In this mode, total capital costs for the selected technology options range from US$0.6 to $6.4 billion, and total operation and maintenance costs range from $0.05 to $0.8 billion per year (table 15 see page 239).

Table 12. Small Villages: Total Costs of Mitigation Technology Options

	Technology	**Capital costs (million US$)[a]**	**Operation & maintenance costs (US$)[a]**
A	Dug wells	1,278.00	213.72
B1	Rainwater harvesting + dug well	2,441.75	253.67
B2	Rainwater harvesting + deep tubewell	2,544.15	203.00
C	Deep tubewell	1,552.37	77.98
D	Shallow tubewell with arsenic removal	573.56	305.08
E1	Pond sand filter	1,851.74	161.45
E2	Pond sand filter (30 households/unit)	274.33	23.92
F	Deep production well, piped	1,399.12	219.66
G	Impoundment, piped	1,399.12	244.07
H	River abstraction, piped	1,270.98	219.66

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[a] *Costs are for an estimated 72,000 small villages of 100 households each = 7,200,000 households.*

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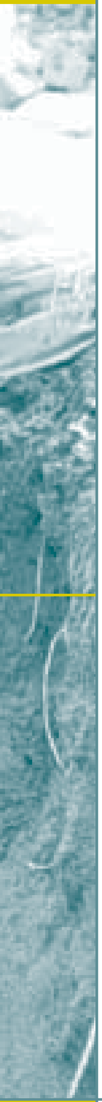

Table 13. Medium Villages: Total Costs of Mitigation Technology Options

Technology		**Capital costs (million US$)[a]**	**Operation & maintenance costs (US$)[a]**
A	Dug wells	958.50	160.29
B1	Rainwater harvesting + dug well	1,831.31	190.25
B2	Rainwater harvesting + deep tubewell	1,908.11	152.25
C	Deep tubewell	1,164.28	58.48
D	Shallow tubewell with arsenic removal	430.17	228.81
E1	Pond sand filter	1,388.81	121.09
E2	Pond sand filter (30 households/unit)	174.89	15.25
F	Deep production well, piped	508.61	73.22
G	Impoundment, piped	521.05	82.37
H	River abstraction, piped	480.97	73.22

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[a] *Costs are for an estimated 10,800 medium villages of 500 households each = 5,400,000 households.*

Table 14. Large Villages: Total Costs of Mitigation Technology Options

Technology		**Capital costs (million US$)[a]**	**Operation & maintenance costs (US$)[a]**
A	Dug wells	958.50	160.29
B1	Rainwater harvesting + dug well	1,831.31	190.25
B2	Rainwater harvesting + deep tubewell	1,908.11	146.76
C	Deep tubewell	1,164.28	58.48
D	Shallow tubewell with arsenic removal	430.17	228.81
E1	Pond sand filter	1,388.81	121.09
E2	Pond sand filter (30 households/unit)	174.89	15.25
F	Deep production well, piped	470.20	50.34
G	Impoundment, piped	481.00	56.75
H	River abstraction, piped	459.13	50.34

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[a] *Costs are for an estimated 5,400 large villages of 1,000 households each = 5,400,000 households.*

Table 15. All Villages: Total Costs of Mitigation Technology Options

Technology		Capital costs (million US$)[a]	Operation & maintenance costs (US$)[a]
A	Dug wells	3,195.00	534.31
B1	Rainwater harvesting + dug well	6,104.36	634.17
B2	Rainwater harvesting + deep tubewell	6,360.38	502.02
C	Deep tubewell	3,880.93	194.95
D	Shallow tubewell with arsenic removal	1,433.90	762.71
E1	Pond sand filter	4,629.36	403.63
E2	Pond sand filter (30 households/unit)	624.11	54.41
F	Deep production well, piped	2,377.93	343.22
G	Impoundment, piped	2,401.18	383.19
H	River abstraction, piped	2,211.08	343.22

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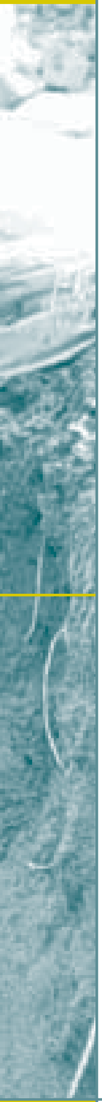
[a] *Aggregate costs for all small, medium, and large villages (tables 12, 13, and 14).*



4. Applying the Model

Methodology for the Model

The model developed in this chapter is a CBA model described by the following equation:

$$PV\,(B - C) = \frac{\sum_{i,t} \Delta I_{i,t}\,(\Delta X_t)}{(1 + s)^t}\; PV\,(Costs) \geq 0$$

We proceed by calculating the present value of costs and then estimating the relevant benefits.

Data and Estimates for the Model

Given our analysis of capital costs and operation and maintenance expenses in the previous chapter, we translate these figures into present values by using a 50-year horizon and a 5%, 10%, and 15% discount rate.[12] Moreover, we disaggregate these costs into costs paid by individuals and costs paid by the government based on the assumption that 20% of capital costs are paid by the individuals who bear the operation and maintenance expenses as well. This disaggregation is directly related to health benefits, as health expenditure is both private and public. As table 16 suggests, the present value of total costs is in the range US$1.6 billion to $15.4 billion for the 5% discount rate. Using the optimal choice, however, this cost drops to $0.5 billion for the government and to $1.1billion for individuals (total $1.7 billion). The respective figures for the 10% and 15% discount rates are $1.1 billion and $0.9 billion.

For a mitigation policy to result in a positive present value, the present value of benefits needs to exceed the present value of relevant costs, as these costs are calculated in table 16. In what follows we state the technique and basic assumptions made for the calculation of the relevant benefits.

Due to data nonavailability, we take into account only two sources of arsenic mitigation benefits. The first amounts to direct medical expense savings as reduced arsenic exposure dramatically improves people's health. The second amounts to indirect benefits of improved productivity and elevated output growth. Due to the lack of estimates on other social benefits, these are not included in our model. Our exact technique for calculating these benefits is defined negatively; that is, we estimate the costs the government would bear if no mitigation policy were undertaken. Hence, benefits are implicitly calculated as reduced costs and their present value is equal to the discounted cash flow of benefits for a 50-year horizon.

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[12] *In this chapter both costs and benefits are discounted at 5%, 10%, and 15%. Since health benefits should be discounted for a period of at least 50 years as they spread over a lifetime, we do the same with the costs. The relevant discount rate for benefits spread over the long run (more than 30 years) should be much lower than the one used on short-run projects. This is the reason the 5% discount rate is used in addition to the 10% and 15% discount rates. In the previous chapter only 10–15% was used as the focus was only on costs, and (a) 10–15% is the lending rate in Bangladesh; and (b) 10–20 years is a reasonable payout period given the financial market in Bangladesh.*

Table 16. Present Value of Costs of Arsenic Mitigation Options for Whole Population

Technology		Govt cost	Present value of private cost			Present value of total cost		
			5%	10%	15%	5%	10%	15%
A	Dug wells	2,556	10,393	5,937	4,198	12,949	8,493	6,754
B1	Rainwater + dug well	4,883	12,798	7,509	5,445	17,682	12,392	10,328
B2	Rainwater + deep tubewell	5,088	10, 437	6,249	4,616	15,525	11,338	9,704
C	Deep tubewell	3,105	4,335	2,709	2,075	7,440	5,814	5,179
D	Shallow tubewell/ arsenic removal	1,147	14,211	7,849	5,367	15, 358	8,996	6,514
E1	Pond sand filter	3,703	8,294	4,928	3,614	11,998	8,631	7,318
E2	Pond sand filter (30 households/unit)	499	1,118	664	487	1,618	1,164	987
F	Deep production well, piped	1,902	6,741	3,879	2,762	8,664	5,781	4,664
G	Impoundment, piped	1,921	7,476	4,279	3,032	9,397	6,200	4,953
H	River abstraction, piped	1,769	6,708	3,845	2,728	8,477	5,614	4,497
	Combined option	1,994	4,178	2,497	1,841	6,172	4,491	3,835

First, output benefits are calculated as foregone output for each person that becomes affected by arsenic-related diseases. In order to project the number of people who develop fatal cancer due to arsenic, we associate the level of arsenic in water with the risk of cancer. Specifically, the WHO (1993) set a provisional guideline value of 10 µg L^{-1} for arsenic in drinking water, which is associated with a lifetime excess skin cancer of about 6 per 10,000 persons. The Bangladesh standard of 50 µg L^{-1} is associated with a higher risk: 30 per 10,000 persons. Using the model developed by the United States Environmental Protection Agency and the distribution of population exposed to different levels of arsenic, the estimated total number of excess skin cancer victims is 375,000 if the present arsenic contamination level is maintained. If the Bangladesh standard is met, this figure drops to 55,000 and, if the WHO standard is met, it further drops to 15,000 (Ahmed 2003). However, skin cancer is not the only disease related to arsenic. Yu, Harvey, and Harvey (2003) estimate the number of people developing hyperpigmentation to be 1,200,000 and those developing keratosis to be 600,000. We project the number of people who die or become unable to work in the next 10 years to be approximately 50,000 per year (increasing by that number each year). This figure is derived by dividing the estimated 2.5 million people that are expected to develop arsenic-related diseases in the next 50 years, by 50 years (in order to get a per year estimate of affected people).

From a more detailed survey of the data currently available in the literature, Maddison, Luque, and Pearce (2004) estimate the annual impact on health from arsenic in Bangladesh as shown in table 17 (see page 242).

Table 17. Bangladesh: Estimated Health Impact of Arsenic Contamination of Tubewells

Impact on health/ type of illness	**Males**	**Females**	**Combined**
Cancer cases:			
Fatal cancers/year	3,809	2,718	6,528
Nonfatal cancers/year	1,071	1,024	2,095
Total cancer fatalities accumulated over 50 years	**190,450**	**135,900**	**326,400**
Arsenicosis cases[a]:			
Keratoses	277,759	74,473	352,233
Hyperpigmentation	654,718	316,511	971,230
Cough	21,823	68,887	90,712
Chest sounds	144,831	67,025	211,858
Breathlessness	93,247	176,874	270,122
Weakness	132,927	240,176	373,104
Glucosuria	67,887	63,551	131,439
High blood pressure	94,396	88,366	182,762
Total arsenicosis cases in each year	**1,487,588**	**1,095,863**	**2,583,460**

[a] *Figures indicate average number of cases occurring in each year (not number of* new cases*).*
Source: Maddison, Luque, and Pearce 2004, p. 32.

Estimates by Maddison, Luque, and Pearce (2004) suggest that 6,500 people die from cancer every year (a total of 326,000 people in a period of 50 years), while a maximum[13] of 2.5 million people develop some kind of arsenicosis. In our model, we add to the number of fatalities from cancer (6,500 people) an additional 1.7% of the total number of arsenic-affected people. This 1.7% represents the number of people that develop nonfatal diseases and become unable to work and produce.

Annual gross domestic product (GDP) is adjusted for the loss in output due to people becoming unable to work or dying. As a starting value for GDP, we take the 2002 GDP estimated at US$239 billion in purchasing power parity terms. We then assume that GDP increases by 4% each year over the next 50 years. The output lost is then calculated as the fraction of GDP the people

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[13] *Individuals suffering from keratosis can also suffer from cough, weakness, etc. Therefore, it is not possible to translate the sum of the people suffering from different symptoms, as shown in table 17, into a unique figure indicating the total number of people suffering from arsenicosis. The figures in the table, however, can be translated into a range of possible numbers. This range will vary from 971,230 (assuming that every person who develops arsenicosis will have all the symptoms) to 2,592,083 (assuming that each person has a unique symptom, in which case the number of people with arsenicosis is the sum of the number of symptoms).*

becoming ill would have produced. These output benefits amount to present values of $88.36 billion, $22.89 billion, and $8.77 billion for constant discount rates of 5%, 10%, and 15% respectively over a 50-year period.

Information from the National Institute of Preventive and Social Medicine (NIPSOM) of Bangladesh[14] indicates that the medical expenditure for treating mild to moderate arsenicosis is US$4 to $5 per month, and the treatment generally lasts from three to six months. As far as arsenicosis cancers are concerned, the medical expenditure ranges from $300 to $1,000 per patient. Using the information above, we calculate the direct medical cost of treating mild to moderate arsenicosis, as well as arsenicosis cancer. Referring back to table 17, 8,623 people (6,500 fatal cancers plus 2,095 nonfatal cancers) are expected to develop cancer per year, while 971,230 to 2,583,460 people will develop some other arsenic-related disease. In our calculations we use this range (971,230 to 2,583,460) as an approximation of the number of treatments of mild to moderate arsenicosis per year. Then, using the upper bound of the estimates of medical costs provided by NIPSOM, we find that the total cost of treating arsenicosis cancer amounts to US$8,623,000[15] and the cost of treating the rest of arsenic-related diseases is a number between $29,136,900 (= 971,230 x $30) and $77,503,800 (= 2,583,460 x $30). Using the average of the cost of treating noncancer arsenic-related diseases, and discounting the sum of medical expenditure on both cancer and mild to moderate arsenic-related diseases for a 50-year period at rates of 5%, 10%, and 15%, we get the present value of medical costs, which amount to $1.14 billion, $0.62 billion, and $0.41 billion respectively.

Before moving to section 4.3, where we calculate the net present value of different mitigation technologies, it is crucial to note that the calculated health expenditures in the previous paragraph represent lower bounds of the relevant magnitudes. That is, while these are the current actual expenditures made, they may not be really sufficient for the treatment of arsenic-related illnesses in Bangladesh. Thus it is likely that these are underestimates of the optimal level of the relevant health expenditure. This possibility is reinforced if one looks at the results of the contingent valuation study conducted by the Water and Sanitation Program, South Asia in December 2002 (Ahmad and others 2002). For rural Bangladesh, this study estimated the willingness to pay for arsenic-free, safe drinking water (that is, it estimated the value of avoiding arsenic-related health risks, which can approximate the value of avoiding the relevant health expenditure attached to these risks) to be equal to 0.2% to 0.3% of the average income of rural households. Although economic theory dictates that in a CBA one should use optimal levels of costs and benefits, we decided to use the lower bounds calculated in the previous paragraph in order to minimize the risk of exaggerating the health expenditure cost. Certainly our analysis shows that productivity losses due to illness are the primary component that drives the numbers, while the health expenditures are a secondary component to the net present value results.

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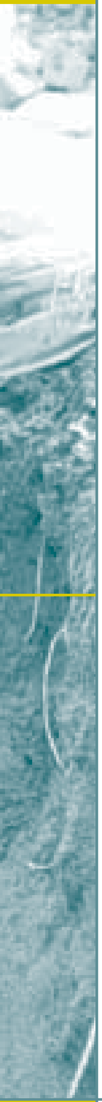
[14] *Private communication with Dr. Akhtar.*

[15] *This is calculated as ((6,528 + 2,095) x 1,000).*



Results for the Model

Taken together both output and medical costs generate a present value that ranges from US$9.18 billion to $23.51 billion to $89.50 billion as the discount rate ranges from 15% to 10% to 5%.[16]

The resulting net present value ranges from $8.2–1.1 billion to $22.3–11.1 billion to $71.8–87.9 billion as the discount rate ranges from 15% to 10% to 5% (while the variation under the same discount rate reflects varying costs of different technology options). The net present value arising from these calculations can be as large as 11% of current Bangladesh GDP. However, in estimating the benefits of the arsenic mitigation program it is unrealistic to assume that a mitigation policy will be fully (100%) effective in removing arsenic.

For this reason we further proceed in estimating the benefits under two scenarios:
(a) effectiveness of mitigation technology amounts to 70% of exposure reduction; and
(b) effectiveness of mitigation technology amounts to 50% of exposure reduction. Under scenario (a) the relevant net present value (discounted at 10%) amounts to approximately $9.5 (15–4) billion, which constitutes around 4% of Bangladesh GDP. Under scenario (b) the relevant net present value (discounted at 10%) amounts to approximately US$5 ((–0.6) – 10.6) billion, around 2% of Bangladesh GDP.

Tables 18, 19, and 20 (see page 246, 247 and 248) show analytically our results on the net present value of various arsenic mitigation policies, with different degrees of effectiveness, and discounted at different interest rates. The effect of a lower discount rate on the resulting level of net present value, and consequently the desirability of a project is obvious from these tables.

With the exception of the option of rainwater harvesting (+ dug well) when discounted at a 10% rate, all other considered mitigation technologies are welfare increasing (that is, they pass a CBA) under all three levels of effectiveness at both 5% and 10% discount rates. However, when discounted at a 15% rate many of the mitigation technologies do not pass a CBA at lower than 100% level of effectiveness. Moreover, rainwater harvesting (+ dug well) and rainwater harvesting (+ deep tubewell) are not welfare increasing even at 100% level of effectiveness. This result indicates that one needs to carefully evaluate what mitigation measures are implemented and that it is not true that any mitigation technology can be applied. Moreover, these results indicate that at the project level, one may want to carry out a least-cost analysis.

The use of pond sand filters (30 households per unit), taking account of the level of service, turns out to be superior to other technologies. However, even though our analysis concludes that pond sand filters are the most economically efficient option, two real-life caveats make this option less attractive. First, pond sand filters are often very polluted. To take this into account in a CBA one should ideally include in the methodology a risk-weighting factor, which will indicate the increase

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[16] *Using a different methodology, which relies on the estimation of epidemiological dose-response functions, Maddison, Luque, and Pearce (2004, p. 34) estimate the present value of benefits at US$138.7 billion, which is comparable to our total health benefit of $162.2 billion.*

of child morbidity and mortality due to water sources. The second caveat refers to the lack of space in Bangladesh for accommodating so many pond sand filters. In earlier years space was not an issue, but now there is either not enough land in any given village due to the high population density, or people actually use the ponds for fish farming, a significant source of income in rural Bangladesh. This situation makes the shadow price involved in using the pond very high, as it should include the price of the land where the pond will be situated. It can even be the case that the corresponding land has to be purchased through an actual money transaction, which makes the relevant price an explicit one.

Overall, no significant discrepancies among technologies are documented. The more dramatic effect on the desirability of different mitigation technologies emerges by the changes in the choice of discount rate of the future flow of cost and benefits. As expected, as the discount rate increases, the net benefits of mitigation policies are reduced, to the point that, with a 15% discount rate, we encounter negative net present value. This exercise highlights the significance of the choice of the discount rate, as well as the importance of the ability to predict the degree of effectiveness of a proposed policy.

The approach suggested and applied above is applicable to both cases: (a) the risk that arsenic might be found in an area where a project is planned; and (b) approaches regarding risk mitigation options where a project's stated purpose is arsenic mitigation itself. While the relevance of our approach to case (b) has already been demonstrated in this paper, below we clarify how the methodology can be applied to case (a).

The methodology can be applied in cases in which arsenic contamination is not as widespread as in Bangladesh and decisions have to be made about what needs to be done in advance of a project planned in an area with a high risk of being contaminated. More specifically, in such a case the policymaker should try to collect information (through hydrogeological surveys) on the existence and extent of contamination in the area under consideration. After acquiring this information, the policymaker should apply the suggested methodology in order to perform a rapid CBA, which will help decide whether it is affordable to mitigate arsenic and then complete the project under consideration, or whether arsenic mitigation is too expensive, possibly due to extensive contamination in the area. If the latter is true (that is, mitigation costs are significantly higher than benefits), then the relevant area should not be further developed through the other planned project, as development would attract people to the area, resulting in more people being exposed to arsenic in the future.

At this point it is worth mentioning that in order to establish the extent of contamination it is necessary to have a well-structured screening methodology and knowledge of the hydrogeology of the different areas in a country. This highlights the importance of investment in a screening program, as well as hydrogeological studies of high-risk areas. Both of these are necessary tools for acquiring knowledge about what is going on in a certain country, region, or area before mitigation measures or development plans are implemented. Although both of these tools are quite expensive (for example, the price of arsenic laboratory analysis is US$9, not taking into

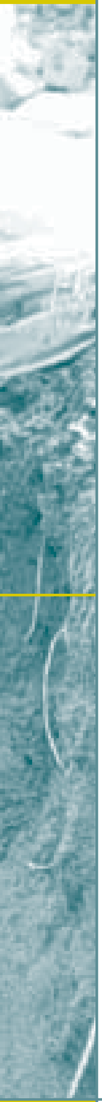

Table 18. NPV (in Billion US$) of Arsenic Mitigation Policies, Discounted at 5%

100% successful

	Technology	Costs (PV)[a]	Health benefits	Output benefits	Benefits (PV)[a]	NPV[b]
A	Dug wells	12.9	1.1	88.4	89.5	76.6
B1	Rainwater harvest + dug well	17.7	1.1	88.4	89.5	71.8
B2	Rainwater harvest + deep tubewell	15.5	1.1	88.4	89.5	74.0
C	Deep tubewell	7.4	1.1	88.4	89.5	82.1
D	Shallow tubewell / arsenic removal	15.4	1.1	88.4	89.5	74.1
E1	Pond sand filter	12.0	1.1	88.4	89.5	77.5
E2	Pond sand filter (30 households/unit)	1.6	1.1	88.4	89.5	87.9
F	Deep production well, piped	8.6	1.1	88.4	89.5	80.9
G	Impoundment, piped	9.4	1.1	88.4	89.5	80.1
H	River abstraction, piped	8.5	1.1	88.4	89.5	81.0

50% successful

	Technology	Costs (PV)	Health benefits	Output benefits	Benefits (PV)	NPV
A	Dug wells	12.9	0.6	44.2	44.8	31.8
B1	Rainwater harvest + dug well	17.7	0.6	44.2	44.8	27.1
B2	Rainwater harvest + deep tubewell	15.5	0.6	44.2	44.8	29.2
C	Deep tubewell	7.4	0.6	44.2	44.8	37.3
D	Shallow tubewell / arsenic removal	15.4	0.6	44.2	44.8	29.4
E1	Pond sand filter	12.0	0.6	44.2	44.8	32.8
E2	Pond sand filter (30 households/unit)	1.6	0.6	44.2	44.8	43.1
F	Deep production well, piped	8.6	0.6	44.2	44.8	36.1
G	Impoundment, piped	9.4	0.6	44.2	44.8	35.4
H	River abstraction, piped	8.5	0.6	44.2	44.8	36.3

70% successful

	Technology	Costs (PV)	Health benefits	Output benefits	Benefits (PV)	NPV
A	Dug wells	12.9	0.8	61.9	62.7	49.7
B1	Rainwater harvest + dug well	17.7	0.8	61.9	62.7	45.0
B2	Rainwater harvest + deep tubewell	15.5	0.8	61.9	62.7	47.1
C	Deep tubewell	7.4	0.8	61.9	62.7	55.2
D	Shallow tubewell / arsenic removal	15.4	0.8	61.9	62.7	47.3
E1	Pond sand filter	12.0	0.8	61.9	62.7	50.7
E2	Pond sand filter (30 households/unit)	1.6	0.8	61.9	62.7	61.0
F	Deep production well, piped	8.6	0.8	61.9	62.7	54.0
G	Impoundment, piped	9.4	0.8	61.9	62.7	53.3
H	River abstraction, piped	8.5	0.8	61.9	62.7	54.2

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[a] PV = present value. [b] NPV = net present value.

Table 19. NPV (in Billion US$) of Arsenic Mitigation Policies, Discounted at 10%

100% successful

Technology	Costs (PV)[a]	Health benefits	Output benefits	Benefits (PV)[a]	NPV[b]
A Dug wells	8.5	0.6	22.9	23.5	15.0
B1 Rainwater harvest + dug well	12.4	0.6	22.9	23.5	11.1
B2 Rainwater harvest + deep tubewell	11.3	0.6	22.9	23.5	12.2
C Deep tubewell	5.8	0.6	22.9	23.5	17.7
D Shallow tubewell / arsenic removal	9.0	0.6	22.9	23.5	14.5
E1 Pond sand filter	8.6	0.6	22.9	23.5	14.9
E2 Pond sand filter (30 households/unit)	1.2	0.6	22.9	23.5	22.3
F Deep production well, piped	5.8	0.6	22.9	23.5	17.7
G Impoundment, piped	6.2	0.6	22.9	23.5	17.3
H River abstraction, piped	5.6	0.6	22.9	23.5	17.9

50% successful

Technology	Costs (PV)	Health benefits	Output benefits	Benefits (PV)	NPV
A Dug wells	8.5	0.3	11.4	11.8	3.3
B1 Rainwater harvest + dug well	12.4	0.3	11.4	11.8	-0.6
B2 Rainwater harvest + deep tubewell	11.3	0.3	11.4	11.8	0.4
C Deep tubewell	5.8	0.3	11.4	11.8	5.9
D Shallow tubewell / arsenic removal	9.0	0.3	11.4	11.8	2.8
E1 Pond sand filter	8.6	0.3	11.4	11.8	3.1
E2 Pond sand filter (30 households/unit)	1.2	0.3	11.4	11.8	10.6
F Deep production well, piped	5.8	0.3	11.4	11.8	6.0
G Impoundment, piped	6.2	0.3	11.4	11.8	5.6
H River abstraction, piped	5.6	0.3	11.4	11.8	6.1

70% successful

Technology	Costs (PV)	Health benefits	Output benefits	Benefits (PV)	NPV
A Dug wells	8.5	0.4	16.0	16.5	8.0
B1 Rainwater harvest + dug well	12.4	0.4	16.0	16.5	4.1
B2 Rainwater harvest + deep tubewell	11.3	0.4	16.0	16.5	5.1
C Deep tubewell	5.8	0.4	16.0	16.5	10.6
D Shallow tubewell / arsenic removal	9.0	0.4	16.0	16.5	7.5
E1 Pond sand filter	8.6	0.4	16.0	16.5	7.8
E2 Pond sand filter (30 households/unit)	1.2	0.4	16.0	16.5	15.3
F Deep production well, piped	5.8	0.4	16.0	16.5	10.7
G Impoundment, piped	6.2	0.4	16.0	16.5	10.3
H River abstraction, piped	5.6	0.4	16.0	16.5	10.8

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[a] PV = present value. [b] NPV = net present value.

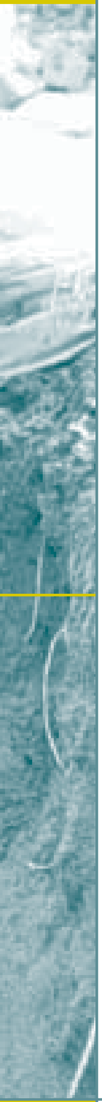

Table 20. NPV (in Billion US$) of Arsenic Mitigation Policies, Discounted at 15%

100% successful						
Technology		**Costs (PV)[a]**	**Health benefits**	**Output benefits**	**Benefits (PV)[a]**	**NPV[b]**
A	Dug wells	6.8	0.4	8.8	9.2	2.4
B1	Rainwater harvest + dug well	10.3	0.4	8.8	9.2	-1.1
B2	Rainwater harvest + deep tubewell	9.7	0.4	8.8	9.2	-0.5
C	Deep tubewell	5.2	0.4	8.8	9.2	4.0
D	Shallow tubewell / arsenic removal	6.5	0.4	8.8	9.2	2.7
E1	Pond sand filter	7.3	0.4	8.8	9.2	1.9
E2	Pond sand filter (30 households/unit)	1.0	0.4	8.8	9.2	8.2
F	Deep production well, piped	4.7	0.4	8.8	9.2	4.5
G	Impoundment, piped	5.0	0.4	8.8	9.2	4.2
H	River abstraction, piped	4.5	0.4	8.8	9.2	4.7
50% successful						
Technology		**Costs (PV)**	**Health benefits**	**Output benefits**	**Benefits (PV)**	**NPV**
A	Dug wells	6.8	0.2	4.4	4.6	-2.2
B1	Rainwater harvest + dug well	10.3	0.2	4.4	4.6	-5.7
B2	Rainwater harvest + deep tubewell	9.7	0.2	4.4	4.6	-5.1
C	Deep tubewell	5.2	0.2	4.4	4.6	-0.6
D	Shallow tubewell / arsenic removal	6.5	0.2	4.4	4.6	-1.9
E1	Pond sand filter	7.3	0.2	4.4	4.6	-2.7
E2	Pond sand filter (30 households/unit)	1.0	0.2	4.4	4.6	3.6
F	Deep production well, piped	4.7	0.2	4.4	4.6	-0.1
G	Impoundment, piped	5.0	0.2	4.4	4.6	-0.4
H	River abstraction, piped	4.5	0.2	4.4	4.6	-0.1
70% successful						
Technology		**Costs (PV)**	**Health benefits**	**Output benefits**	**Benefits (PV)**	**NPV**
A	Dug wells	6.8	0.3	6.1	6.4	-0.3
B1	Rainwater harvest + dug well	10.3	0.3	6.1	6.4	-3.9
B2	Rainwater harvest + deep tubewell	9.7	0.3	6.1	6.4	-3.3
C	Deep tubewell	5.2	0.3	6.1	6.4	1.2
D	Shallow tubewell / arsenic removal	6.5	0.3	6.1	6.4	-0.1
E1	Pond sand filter	7.3	0.3	6.1	6.4	-0.9
E2	Pond sand filter (30 households/unit)	1.0	0.3	6.1	6.4	5.4
F	Deep production well, piped	4.7	0.3	6.1	6.4	1.8
G	Impoundment, piped	5.0	0.3	6.1	6.4	1.5
H	River abstraction, piped	4.5	0.3	6.1	6.4	1.9

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[a] PV = present value. [b]. NPV = net present value.

account transportation costs, while the price of a field kit is $0.5 per test) they are a necessary first step of any decision about project implementation.

The logic behind this necessity is the following. The long-run nature of project-specific developments means that initial screening costs will be discounted over a long-run horizon; hence, these costs will be relatively small in net present value terms irrespective of their absolute initial value. On the contrary, the effects of arsenic contamination could be detrimental to both the economy and health of the inhabitants of an area over a much shorter horizon. Moreover, it should be kept in mind that the decision to develop a particular area is irreversible in practical terms. This characteristic of irreversibility necessitates great caution about the decision to develop or not, hence such decisions should be taken under minimum risk conditions. The combined result of these three effects increases the net potential benefit to society that can be achieved through gathering information regarding the existence and extent of arsenic contamination prior to any other project-related appraisal.

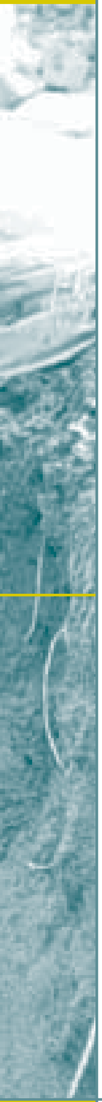
This discussion indicates that an option value underlies the development of particular projects in high-risk areas. Option value is a measure of people's (society's) risk aversion to factors that might affect future access to use of environmental or biological assets. More precisely, the option value relevant to our discussion is the premium that society is willing to pay to avoid having to face the effects of arsenic contamination in the area where economic and social development is planned. In our case, this premium is the money that the society (the government) will spend on screening and hydrological studies in order to gather enough information to allow the choice of a development area with a minimum risk of arsenic contamination. This allows society to reduce the risk (variance) associated with future welfare.

In conclusion, as long as society is risk averse and the development horizon is long, screening and hydrological studies that enable such risk reductions are likely to be welfare increasing.

5. Summary and Conclusions

This paper reviews existing studies and data on arsenic contamination, related health effects, and the costs of mitigation in those countries where it has been undertaken. Then it introduces an approach which provides a quick and readily applicable method for performing a CBA of different arsenic mitigation policies. In particular, our suggested approach estimates benefits of mitigation activities as the sum of foregone medical costs and saved output productivity achieved through the reduction of arsenic exposure. The present value of these benefits is then compared with the present value of costs of various mitigation measures in order to determine when and which mitigation policies pass a CBA (that is, produce a positive change to social welfare).

The paper applies this approach in order to provide some estimate of costs and benefits of arsenic mitigation in one case study country, Bangladesh. This case study serves as an applied example of a rapid socioeconomic evaluation and is also used as a basis for discussing trade-offs in decisionmaking with respect to the allocation of financial resources. Our approach is applicable to the following cases: (a) where there is risk that arsenic might be found in an area where a project is planned; and (b) in regard to risk mitigation options where a project's goal is arsenic mitigation per se.



With the exception of the option of rainwater harvesting (+ dug well) when discounted at a 10% rate, all other considered mitigation technologies are welfare increasing (that is, they pass a cost-benefit analysis) under all three levels of effectiveness at both 5% and 10% discount rates. However, when discounted at a 15% rate, many of the mitigation technologies do not pass a CBA at lower than 100% level of effectiveness. Moreover, rainwater harvesting (+ dug well) and rainwater harvesting (+ deep tubewell) are not welfare increasing even at 100% level of effectiveness. This result indicates that one needs to carefully evaluate what mitigation measures are implemented and that it is not true that any mitigation technology can be applied. Moreover, these results indicate that, at the project level, one may want to carry out a least-cost analysis.

It is also worth mentioning that (a) in our calculation we did not take into account the environmental benefits of mitigation strategies (mainly due to lack of precise data); and that (b) the health expenditures only represent a lower bound. That is, the calculated net benefits from arsenic mitigation are underestimates of the true benefits and should be used as a very conservative figure of welfare increases to be derived from implementing the various mitigation policies.

Finally, these figures indicate the imminent need for facing the arsenic crisis in Bangladesh, but also the clarity with which our approach can answer the difficult question on the balance of relevant costs and benefits of various mitigation policies.

Annex 1

Detailed Technology Costs

The tables below itemize the costs of each technology for a village of 500 households.

Average Village Model: 500 Households

	Nos.
Homesteads (clusters)	50
Households @ 10 per homestead	500
Population @ 5.5 per household	2,750

Income Categories

	High	Medium	Low	Total
Proportion	10%	20%	70%	100%
Households	50	100	350	500
Population	275	550	1,925	2,750

Option A: Dug Wells

Capital costs	Unit	Qty	Rate (US$)	Amt (US$)
Excavation: depth 12.5 m	m^3	10	10	102
Pipe rings supply	m	12.5	20	254
Pipe rings install	m	12.5	8	106
Handpump supply & install	no.	1	68	68
Transport	sum	1	85	85
Contingencies and handover/training	sum	1	34	34
Platform + other core components work	sum	1	102	102
			Total	750
Operation & maintenance costs annual	**Unit**	**Qty**	**Rate (US$)**	**Amt (US$)**
Chemical: disinfection	kg	15	2	25
Labour	days	24	2	41
Spares/parts	sum	1	17	17
Water quality monitoring	sum	5	8	42
			Total	125
Infrastructure required	**Income**			
	High	**Medium**	**Low**	**Total**
Proportion	10%	20%	70%	100%
Households	50	100	350	500
Households/dug well	1	3	10	n.a.
No. of dug wells	50	33	35	118
Financial costs				
Capital				88,750
Annual operation & maintenance				14,842

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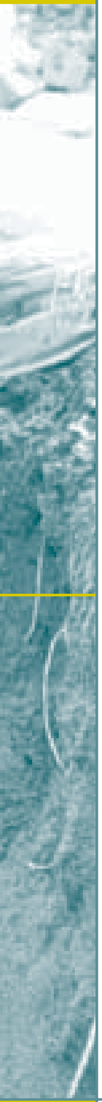
n.a. Not applicable.



Option B1: Roof Rainwater Harvest/Household (60 sq m) + Dug Well

Capital costs: roof catchment	**Unit**	**Qty**	**Rate (US$)**	**Amt (US$)**
Roof gutters	m	36	3	107
Pipework	m	7	5	36
Tank 3.2 m3 on platform/3 month storage	no.	1	105	105
Handpump supply and install	no.	0	n.a.	n.a.
Transport	sum	1	17	17
Contingencies and handover/training	sum	1	8	8
Roof rainwater harvest capital cost			Total	273
Dug well capital cost	sum	1	750	750

Operation & maintenance costs annual (roof catchment)	**Unit**	**Qty**	**Rate (US$)**	**Amt (US$)**
Chemical: disinfection	kg	0.25	2	0
Labour	days	7	2	12
Spares/parts	sum	1	3	3
Water quality monitoring	sum	1	8	8
			Total	24
Dug well	months	12	10.45	125

Infrastructure required	**Income**			
	High	**Medium**	**Low**	**Total**
Proportion	10%	20%	70%	100%
Households	50	100	350	500
Households/rainwater harvest	1	1	1	n.a.
No. of rainwater harvest systems	50	100	350	500
Households/dug well	3	10	20	n.a.
No. of dug wells	17	10	18	44

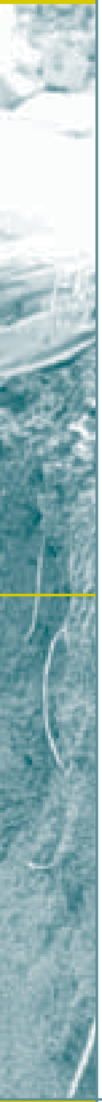
Financial costs	
Capital	169,566
Annual operation & maintenance	17,616

n.a. Not applicable.

Option B2: Roof Rainwater Harvest/Household (60 sq m) + Deep Tubewell

Capital costs: roof catchment	**Unit**	**Qty**	**Rate (US$)**	**Amt (US$)**
Roof gutters	m	36	3	107
Pipework	m	7	5	36
Tank 3.2 m^3 on platform/3 month storage	no.	1	105	105
Handpump supply and install	no.	0	n.a.	n.a.
Transport	sum	1	17	17
Contingencies and handover/training	sum	1	8	8
Roof rainwater harvest capital cost			Total	273
Deep tubewell capital cost	sum	1	911	911
Operation & maintenance costs annual (roof catchment)	**Unit**	**Qty**	**Rate (US$)**	**Amt (US$)**
Chemical: disinfection	kg	0.25	2	0
Labour	days	7	2	12
Spares/parts	sum	1	3	3
Water quality monitoring	sum	1	8	8
			Total	24
Deep tubewell	months	12	4	46
Infrastructure required	**Income**			
	High	**Medium**	**Low**	**Total**
Proportion	10%	20%	70%	100%
Households	50	100	350	500
Households/rainwater harvest	1	1	1	n.a.
No. of rainwater harvest systems	50	100	350	500
Households/deep tubewell	3	10	20	n.a.
No. of deep tubewells	17	10	18	44
Financial costs				
Capital				176,677
Annual operation & maintenance				14,097

n.a. Not applicable.



Option C: Hand Deep Tubewell

Capital costs	**Unit**	**Qty**	**Rate (US$)**	**Amt (US$)**
Sinking	m	250	0.3	64
35 mm pipe supply + stainer	m	250	1.7	424
Pipe install	m	250	0.8	212
Handpump supply & install	no.	1	127.1	127
Transport	sum	1	33.9	34
Contingencies and handover	sum	1	16.9	17
Platform + other core components work	sum	1	33.9	34
			Total	911

Operation & maintenance costs annual	**Unit**	**Qty**	**Rate (US$)**	**Amt (US$)**
Chemical: disinfection	kg	0	n.a.	n.a.
Labour	days	12	1.7	20
Spares/parts	sum	1	16.9	17
Water quality monitoring	sum	1	8.5	8
			Total	46

Infrastructure required	**Income**			
	High	**Medium**	**Low**	**Total**
Proportion	10%	20%	70%	100%
Households	50	100	350	500
Households/deep tubewell	1	3	10	n.a.
No. of deep tubewells	50	33	35	118

Financial costs	
Capital	107,804
Annual operation & maintenance	5,415

n.a. Not applicable.

Option D: Existing Shallow Tubewell with Household Arsenic Removal

Capital costs	**Unit**	**Qty**	**Rate (US$)**	**Amt (US$)**
Arsenic removal supply & install	no.	1	50.8	51
Transport	sum	1	3.4	3
Contingencies and handover/training	sum	1	25.4	25
			Total	80

Operation & maintenance costs annual	**Unit**	**Qty**	**Rate (US$)**	**Amt (US$)**
Chemical: disinfection	kg	0	n.a.	n.a.
Labour	days	0	n.a.	n.a.
Media/spares/parts	sum	1	25.4	25
Water testing (for arsenic)	sum	2	8.5	17
			Total	42

Infrastructure required	**Income**			
	High	**Medium**	**Low**	**Total**
Proportion	10%	20%	70%	100%
Households	50	100	350	500
Households/arsenic removal unit	1	1	1	n.a.
No. of arsenic removal	50	100	350	500

Financial costs	
Capital	39,831
Annual operation & maintenance	21,186

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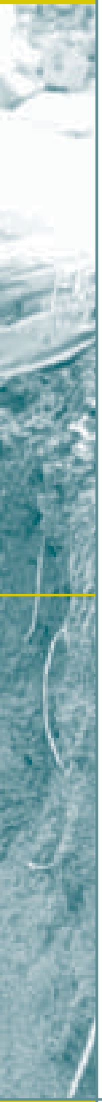
n.a. Not applicable.



Option E: Pond Sand Filter

Capital costs	Unit	Qty	Rate (US$)	Amt (US$)
Excavation	m^3	6	3.4	20
Reinforced concrete including formwork	m^3	4	1.7	7
Block wall	m^2	48	11.9	569
Handpump supply & install	no.	1	67.8	68
Transport	sum	1	33.9	34
Contingencies and handover/training	sum	1	254.2	254
			Total	953

Operation & maintenance costs annual	Unit	Qty	Rate (US$)	Amt (US$)
Chemical: disinfection	kg	15	1.7	25
Labour	days	24	1.7	41
Spares/parts	sum	1	16.9	17
			Total	83

Infrastructure required	Income			
	High	Medium	Low	Total
Proportion	10%	20%	70%	100%
Households	50	100	350	500
Households/pond sand filter	1	2	10	n.a.
No. of pond sand filters	50	50	35	135

Financial costs	
Capital	128,593
Annual operation & maintenance	11,212

n.a. Not applicable.

Option F: Piped Scheme Deep Production Well (Domestic)

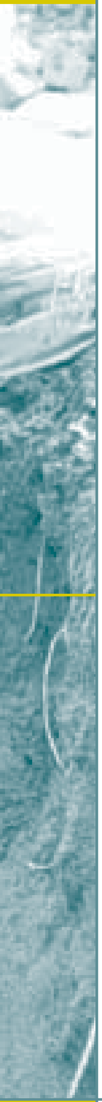
Capital costs	Unit	Qty	Rate (US$)	Amt (US$)
Production wells	sum			3,627
Sinking/drilling and core samples	m	300	3.2	966
Pumping facilities	sum			6,356
Masonry/concrete storage tanks	sum			8,305
Trunk main/transmission main	sum			847
Distribution system	sum			18,271
House connections	sum			8,720
Capital costs			Total	47,093
Operation & maintenance costs annual			Total	6,780

Option G: Piped Scheme Impoundment: Engineered Pond

Capital costs	Unit	Qty	Rate (US$)	Amt (US$)
Impoundment	sum			4,237
Intake/infiltration gallery	sum			1,508
Pumping facilities	sum			6,356
Masonry/concrete storage tanks	sum			8,305
Trunk main/transmission main	sum			847
Distribution system	sum			18,271
House connections	sum			8,720
Capital costs			Total	48,246
Operation & maintenance costs annual			Total	7,627

Option H: Piped Scheme Surface Water: River Abstraction/Infiltration Gallery

Capital costs	Unit	Qty	Rate (US$)	Amt (US$)
Intake/infiltration gallery	sum			2,034
Pumping facilities	sum			6,356
Masonry/concrete storage tanks	sum			8,305
Trunk main/transmission main	sum			847
Distribution system	sum			18,271
House connections	sum			8,720
Capital costs			Total	44,534
Operation & maintenance costs annual			Total	6,780



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VOL II TECHNICAL REPORT

Notes

Notes

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