4

Economic Analysis of Sanitation Technologies

ONCE THE TECHNOLOGIES that are technically infeasible for the site being considered have been eliminated by the project engineer, it is necessary to rank the remaining technically feasible technologies by some meaningful scale so that the most appropriate one may be selected.[1] Implicit in this is the need for a common basis for the objective comparison of the remaining technologies that reflects both the positive and negative consequences of adopting each of them.

Ideally, a cost-benefit analysis should be used to rank alternatives, but, as is true of many public services, it is impossible to quantify most of the benefits (such as those of improved health and user convenience) of a sanitation system. In general, there is no completely satisfactory way to get around this difficulty. Only in the case of mutually exclusive alternatives with *identical* benefits should one always select the one with the least cost. Where there are differences in the levels of service provided by the various alternatives, the least-cost choice will not necessarily be the one that is economically optimal. For this reason a least-cost comparison will not normally provide sufficient information to select the most appropriate sanitation technology. Nonetheless, if properly applied, it will provide a reasonably objective basis for comparison that reflects the cost tradeoffs corresponding to different levels of service. Once comparable cost data have been developed, the users or their community representatives can make their own determination of how much they are willing to pay to obtain various standards of service.

Economic Costing

The basic purpose behind the economic costing of sanitation technologies (or the economic costing of any other development activity) is to give policymakers a basis for their decisions by providing a price tag for a given level of service that represents the opportunity cost to the national economy of producing that service. Three principles must be followed in preparing estimates:

- All relevant costs must be included.
- Each cost must be properly evaluated.
- The assumptions used for costing different technologies must be mutually consistent.

The first principle of economic costing is that *all* costs to the economy, regardless of who incurs them, should be included. In comparing the costs of different sanitation technologies, too often only those costs met by the administrative (usually municipal or state) authority are considered in the cost comparison. The costs borne by the household or the costs of complementary services (for example, water for flushing) are often ignored. In the analysis of the *financial* implication for the authority of alternative technologies, such a comparison would be appropriate. For an *economic* comparison, however (that is, for the determination of the least-cost technology with respect to the national economy), it is necessary to include all costs attributable to a given alternative irrespective of whether they are borne by the household, the administrative authority, the national government, or whomever. Some financial costs should be excluded from the economic comparison. Examples of costs that should be ignored are subsidies and taxes, since these represent a transfer of money within the economy rather than a cost to it.

The determination of which costs to include should rest on a comparison of the situation over time both with and without the project. This is not the same as a simple "before and after" comparison. Rather than using the status quo as the "without" scenario, it is essential to estimate how the current situation would improve or deteriorate over the project period if the project were *not* to be undertaken. In addition, a broad enough view of the project must be taken so that all relevant costs will be included. For example, a cost that is often ignored when costing sewerage systems is the cost of the additional water that will be required for flushing.

Once the relevant costs have been identified, the second principle of economic costing concerns the prices that should be used to value these costs. Since the objective of economic costing is to develop figures that reflect the cost to the national economy of producing a good or service, the economist is concerned that unit prices represent the actual resource endowment of the country. Thus a country with abundant labor will have relatively inexpensive labor costs in terms of the alternative production possibilities of its labor. Similarly, a country with scarce water resources will have expensive water costs, in the economic sense, regardless of the regulated price charged to the customer. Only by using prices that reflect actual resource scarcities can one ensure that the least-cost solution will make the best use of a country's physical resources.

Because governments often have sociopolitical goals that may be only indirectly related to economic objectives, some market prices may bear little relation to real economic costs. For this reason it is sometimes necessary to adjust market prices in the economic costing exercise so that they represent more accurately "real" unit costs (in the sense of reflecting the effect of these costs on the national economy). This adjustment of market prices to reflect opportunity costs is sometimes known as "shadow pricing."

The calculation of these shadow rates, or conversion factors, is a difficult task that requires intimate knowledge of a country's economy. It is rarely (if ever) worthwhile for an economist or engineer involved with sanitation program planning to take the time to collect data and calculate conversion factors directly. Rather, he or she should check with the ministry of planning or economic affairs to see if the figures have already been determined.

In the economic costing of sanitation technologies there are four shadow rates that normally need to be incorporated in the analysis. These are:

- The unskilled labor wage shadow factor
- The foreign exchange shadow factor
- The opportunity cost of capital
- The shadow price of water, land, and other direct inputs.

Each is briefly discussed in turn.

Unskilled labor

Many governments enact minimum wage legislation. The usual effect of this is that unskilled labor is economically overvalued; that is, the paycheck of an unskilled laborer is higher than that he would receive in the absence of minimum wage legislation. Because his economic value is less than his wage, however, employers will be reluctant to hire him. Thus, where minimum wages are set above the real productivity of unskilled labor, unemployment generally results (of course, unemployment happens for other reasons as well). This means that, if a country has a very large pool of unemployed laborers, the shadow factor for unskilled labor wages might be close to zero because there is almost no cost *to the national economy* that results from employment of such people, since they would otherwise be unemployed and so be producing nothing. On the other hand, if a country has few unemployed unskilled workers, then the shadow factor would be 1, as this situation is an indication that the market wage fairly reflects economic value. Generally the shadow factor for unskilled labor in developing countries is in the range of 0.5 to 1.0.

Foreign exchange

Many governments do not permit free movement of the exchange rate of foreign currency for their national currency in the international money markets. Instead they fix its value, often in terms of the currency of a major trading partner such as the United Kingdom or Japan. As a result, the currency is sometimes overvalued; imports thus cost fewer units of the national currency than they would if the government allowed the currency to trade freely on the international market, and exports are overpriced in foreign currency value. Sometimes this same result is achieved not by an overvalued domestic currency but by a system of import restrictions, export taxes, or both. The foreign exchange shadow factor is the ratio of the shadow exchange rate (what the currency would be worth in a freely trading international market) to the official exchange rate fixed by the government; expressed in this way, the shadow factor is thus greater than 1 whenever the local currency is overvalued or import restrictions are high. Suppose a government fixes its official rate of exchange at 10 units of its national currency (UNC) to the U.S. dollar, but that in the free market 15 UNC would be required to purchase one U.S. dollar; the foreign exchange shadow factor is thus 1.5. Suppose further that a municipality in the same country wishes to import a night-soil vacuum tanker that has a direct foreign exchange cost at the border of $10,000. It would have to pay only 100,000 UNC for the tanker, but the true economic or "shadowed" cost to the country's economy is 1.5 times this amount (that is, 150,000 UNC), and this is the cost that should be used in evaluating the economic cost of the night-soil collection system the municipality wishes to adopt.

Opportunity cost of capital

This is defined as the marginal productivity of additional investment in its best alternative use. It can also be thought of as the price (or yield) of capital. In countries where capital is abundant, such as the industrialized countries of Europe, one expects the yield on capital to be relatively low. This is because capital has already been employed in its most productive uses and is now being substituted for labor or other inputs in less and less profitable areas. In many developing countries, however, capital is a scarce commodity and therefore has a high opportunity cost. A government might decide for sociopolitical reasons to make available loans to householders at a low rate of interest to enable them to build, say, ventilated improved pit (VIP) latrines. The economic cost of this decision is the yield that the government would have received had it invested its capital in the best alternative way; for example, by buying shares in a well-managed industrial enterprise. The opportunity cost of capital is thus expressed as a percentage; in developing countries it usually ranges from 8 percent to 15 percent.

Water, land, and other direct inputs

The prices of some inputs of sanitation systems are controlled by governments or incorporate government subsidies. For example, land for the construction of waste stabilization ponds may be owned by the government because it is near a public airport. The government may decide to transfer it to the sewerage authority for no financial cost. Its *economic* cost, however, should be calculated as what it would have been worth had it been sold on the market to a farmer or industry that wished to locate there. Usually a good approximation of this shadow cost can be obtained by reviewing recent sales records of similar land in the area.

Other prices that may need adjustment to reflect real resource costs are those of publicly produced outputs such as water and power. It is usually not possible to estimate directly what a free market price would be for these items because the government normally has a monopoly in their production. Nevertheless, the shadow price of water or power can be approximated by calculating its average incremental production cost. A good method for doing this is described below and shown in the appendix to this chapter.

For most developing countries, where labor is abundant but capital and foreign exchange are scarce, the effect of shadow pricing is to decrease the cost of unskilled labor and to increase the cost of both capital and imported goods. Since shadow pricing removes distortions attributable to political decisions (for example, minimum wage legislation, overvaluation of local currencies, and the provision of development capital at low rates of interest), it is extremely valuable in the identification of the most appropriate sanitation technology for the actual resources of the country. An example of the use of shadow pricing in economic costing is given in the appendix to this chapter.

In addition to these adjustments for shadow prices, economic costs differ from financial costs in that they are based on incremental *future* investments rather than average *historical* investments. This principle rests on the idea that costs already incurred ("sunk" costs) should be disregarded in making decisions about future investments. Thus, in analyzing the real resource cost of a given technology, it is necessary to value the components of that technology at their replacement costs rather than at their actual historical prices. In the case of sanitation systems, this is particularly important in the costing of water. Because cities develop their least expensive sources of water first, it generally becomes more and more costly (even excluding the effect of inflation) to produce and deliver an additional liter of water as the city's demand grows. By using the average cost of producing today's water, one is often seriously underestimating the cost of obtaining additional water in the future. The decision to install a conventional sewerage system with high-volume cistern-flush toilets will increase domestic water consumption by around 50 to 70 percent. Thus, in calculating the costs of such an alternative, it is extremely important to value properly the cost of the additional water that will be required. The economic cost of this additional water is its average incremental production cost; it is *not* the cost charged to the consumers or its current average production cost.

The application of these costing principles to sanitation program planning presents several difficulties. The main one is the problem of finding a scaling variable that allows comparison among diverse technologies regardless of their design populations. Onsite systems such as improved pit latrines are generally designed for a single family or household. The latrine's lifetime or the intervals between fairly major maintenance work, such as desludging, will depend on how many people use it. The life of some components (such as the vent pipe), however, may be independent of usage, so that the annuitized per capita construction cost of a latrine used by six people will not be the same as that of one used by ten people. For this reason most costs should be calculated on a per household basis.

It is often difficult to calculate comparable costs when considering low-cost sanitation as an alternative to sewerage. The low-cost facility is fully used almost immediately by its "design population." Many of the components of sewerage, however, exhibit economies of scale and are therefore sized to meet a design flow that usually does not arise for many years. With such a facility all the investment costs are incurred at the beginning of its lifetime, whereas the benefits (services) are realized gradually over time. Just as costs incurred in the future have a lower present value than those incurred today, benefits received in the future are less valuable than those received immediately. In the derivation of per household costs, this means that serving a person five years hence is not worth as much as serving the same person now. To divide the cost of a sewerage system by its design population would greatly *understate* its real per household cost when compared with that of a system that is fully used upon completion.

One of the best methods to overcome this problem of the differing capacity utilization rates of different systems is the average incremental cost (AIC) approach. The per capita (or household) AIC of a sewerage system is calculated by dividing the sum of the present value of construction costs and incremental operating and maintenance costs by the sum of the present value of incremental persons (or households) served; the appropriate equation is:

$$\text{AIC}_t = \frac{\sum_{t=1}^{t=T} (C_t + O_t)/(1 + r)^{t-1}}{\sum_{t=1}^{t=T} N_t/(1 + r)^{t-1}}$$

where t = time in years

T = design lifetime in years (measured from start of project at $t = 0$)

C_t = construction costs incurred in year t

O_t = incremental (from year $t = 0$) operation and maintenance costs incurred in year t

N_t = additional people or households (from year $t = 0$) served in year t

r = opportunity cost of capital in percent times 10^{-2}.

It is essential that all costs used in the equation have been appropriately shadow priced. Note that, for a system that is fully utilized upon construction, the equation reduces to merely the sum of the annuitized capital costs and annual operating and maintenance costs divided by the design population.

In practice it is often easier to calculate the AIC of a sewerage system on a volumetric, rather than a per capita, basis. The AIC per cubic meter of sewage is calculated from year-by-year projections of the total wastewater flow. The resulting volumetric costs can then be transformed into per capita (and per household) costs using the per capita wastewater flow. An example is given in the appendix to this chapter.

An additional problem in deriving comparable costs for different sanitation technologies is the differing abilities of the technologies to handle sullage. With conventional sewerage, most septic tanks and pour-flush (PF) and aquaprivy systems, sullage is disposed of with the excreta and toilet flushwater. With most of the on-site excreta disposal technologies, sullage must be disposed of into surface or piped storm drainage systems or into soakage pits. If stormwater drains are present (or would be constructed anyway), the incremental construction cost if sullage is to be discharged into them might be very small since they are usually designed to handle flood peaks. It would be necessary to include only the cost of any special modifications needed to enable the relatively small volumes of sullage to enter and flow in the storm drains without nuisance in the dry seasons, the maintenance costs of ensuring that they are not blocked (and so form breeding grounds for mosquitoes), and the environmental cost of the eventual disposal of the sullage into the receiving watercourse. If large amounts of sullage are left to soak into the ground, nuisance and possibly health risks may be created, and these costs should be evaluated and included. Alternatively, separate disposal of sullage may be considered a benefit where populations recycle kitchen and bathwater to irrigate gardens or dampen dust. In such a case, the removal of sullage through the introduction of a sewerage system would involve a cost. In any particular case it is best to compare alternatives that represent approximately the same benefit levels. Thus, if sewerage (including sullage collection) is one alternative, the cost of sullage disposal in, for example, road drains should be included in the cost of other sanitation alternatives *unless* the road drains would be built anyway for flood control, in which case it is necessary only to include the additional costs incurred as mentioned above. The guiding principle, again, is to compare the conditions with and without the project.

In general, the data necessary for the calculation of comparable economic costs can be collected fairly early in the design process, after preliminary designs have been prepared. This has the advantage of providing an early warning if, as is frequently the case, most of the alternative designs are too costly relative to the resources likely to be available. It thus saves the trouble of preparing final designs for those technologies that are outside the bounds of affordability. Economic costing should therefore be seen as an early screening of the various sanitation technologies that have passed the basic tests of technical and social feasibility.

Financial Costing

The purpose of deriving economic costs is to make a meaningful least-cost comparison among alternatives. Such a comparison is extremely useful to the planner and policymaker. The consumer, however, is much more interested in financial costs; that is, what he will be asked to pay for the system and how the payment will be spread over time. The difficulty in developing financial costs is that they are entirely dependent upon policy variables that can range widely. Whereas economic costs are based on the physical conditions of the community (for example, its abundance or scarcity of labor, water, and so forth) and therefore are quite objective, financial costs are entirely subject to interest rate policy, loan maturities, central government subsidies, and the like. For example, the financial costs of a sanitation system for a community can be zero if the central government has a policy of paying for them out of the general tax fund. Thus, financial costs cannot be used to make judgments about least-cost alternatives.

To promote the economically efficient allocation of resources, financial costs should of course reflect economic costs as closely as possible, given the government's equity goals and the degree of distortion in other prices in the economy. This could be accomplished with sewerage, for example, by setting a surcharge on the connected consumer's water bill that is equal to the AIC of sewerage per cubic meter of water consumed (that is, if 75 percent of water consumption reaches the sewers, the AIC of sewerage per cubic meter would be multiplied by 0.75 to arrive at the water surcharge). In the case of most of the on-site systems, the consumer would pay to construct the original facility (either in total or through a loan at the interest rate that reflects the opportunity cost of capital) and then pay a periodic sum to cover its operation and maintenance expenses, if any. In cases such as these, the financial cost would be identical to the economic cost except for any taxes and shadow pricing of those inputs that must be purchased in the market. To the extent that the latter account for a significant part of total economic costs, financial costs may be above or below economic costs.

In deriving financial costs in any particular case, it is necessary to talk with central and local government officials to determine their financial policies and noneconomic objectives. If the government places a high priority on satisfying the basic needs of all of its citizens, then it may be willing to subsidize part or all of the construction cost of a simple sanitation system. The general policy of international lending agencies such as the World Bank is that, if the cost of the minimal sanitation facility necessary to provide adequate health is more than a small part of the household income (say, 5 to 10 percent), then the central or local government should attempt to subsidize its construction to make it affordable. Any operation or maintenance costs should be borne by the beneficiary. If, however, some consumers wish to have better or more convenient facilities, they should pay the additional cost themselves. Similarly, if more affluent communities decide that, beyond meeting basic health needs, they wish to safeguard the cleanliness of their rivers or general environment by building a more expensive sanitation system, they should pay for that system either through direct user charges or through general *municipal* revenues. Since the majority of the poorest people in most countries live in rural areas, it is usually not appropriate to subsidize urban services from central tax revenues.

In general, it is necessary to calculate several sets of financial costs based on different assumptions about municipal or central government subsidies. The first set, which is hereafter called the base financial cost, is that which assumes no financial subsidy. For an on-site system with a short construction period and little requirement for municipal maintenance, the engineer's estimate of construction costs (in market prices) is simply annuitized over the life of the facility at the prevailing (market) interest rate. If self-help labor can be used for part of the construction, then the cost of hiring that labor should be subtracted from the total before annuitizing. To this annual capital cost must be added any operating and maintenance costs that will be required. Then this total base financial cost can be compared with household incomes to check affordability. If the technology is considered affordable by the target population, then the only financial arrangements that will be required at the outset are those necessary to aid consumers in securing loans from commercial and public banks. If the technology's base financial cost is not affordable by the households to be served, and if lower-cost solutions are infeasible or unacceptable, then various options involving increased self-help input, deferred or low-interest loans, partial construction grants, and the like should be used to compute alternative sets of financial costs. Before any of these are offered to the consumer, however, it is obviously necessary to obtain local government funding to cover the financing gap.

The development of financial costs is more difficult for technologies with off-site investments and the accompanying need for centralized management and operation. There is a large body of literature on accounting systems for public utility enterprises, and the subject cannot be fairly summarized in this brief chapter.

Costing of Community Support Activities

The construction cost figures used for both the economic and financial analyses do not include the cost of community organization, hygiene education and technical assistance, and government administrative support, which are not directly related to the construction of the facilities but which are normally provided to complement a water supply or sanitation program. Unless otherwise noted, it is assumed that assistance provided by government for health education and technical assistance is paid for from regular budgetary resources. Where additional assistance is required, the cost should be estimated and specific funding arrangements made. Needs for assistance vary too widely from community to community to permit the estimation of a useful average per capita cost figure.

Appendix. Examples of Economic Costing

Economic costing of a ventilated improved pit (VIP) latrine

Assume that all materials, except the vent-pipe, cement, and reinforcing steel (for the concrete squatting plate), are manufactured locally. Let the costs (in units of national currency, UNC) be:

Local materials	100 UNC
Imported materials	60 UNC.

Assume that skilled labor is used in building the squatting plate and superstructure and for general supervision, and that unskilled labor is used to excavate the pit, to mix the concrete, and generally to assist the skilled labor. Let the costs be:

Skilled labor	30 UNC
Unskilled labor	70 UNC.

Assume that the household can be expected to spend 10 UNC per year on minor repairs and cleaning materials, that the repairs are done by the householder, and that the cleaning material is manufactured locally.

Assume the following:

Unskilled labor shadow factor	0.7
Foreign exchange shadow factor	1.3
Opportunity cost of capital	12.0 percent
Official rate of exchange per U.S. dollar	2.80 UNC
Household size	6 persons.

Assume also that the pit latrine is designed to last ten years and that no items can be reused at the end of that period.

Example

An example of costs calculated from these assumptions is presented in table 4-1. The following points also apply:

- The annuity or capital recovery factor (CRF) can most easily be obtained from a book of financial or compound interest tables or by using a financial calculator. It can also be calculated, however, from the equation:

$$\text{CRF} = \frac{r\,(1 + r)^N}{(1 + r)^N - 1}$$

  where r = opportunity cost of capital in percent $\times 10^{-2}$ and N = design lifetime in years. Here r = 12 percent and N = ten years, so that the CRF is 0.177.
- The annuitized annual cost (in UNC) of each capital item is obtained by multiplying its cost (in UNC) by the CRF and by the appropriate shadow factor, if any.
- The annual cost in U.S. dollars is calculated by converting the shadowed local cost at the *official* rate of exchange.

Table 4-1. *Annual Economic Costs of a Ventilated Improved Pit* (VIP) *Latrine*

Item	*Total cost* (UNC)	*Lifetime (years)*	*Shadow factor*	*Adjusted annual cost* UNC	*U.S. dollars*
Materials					
Local	100	10	None	17.7	6.3
Imported	60	10	1.3	13.8	4.9
Labor					
Skilled	30	10	None	5.3	1.9
Unskilled	70	10	0.7	8.7	3.1
Maintenance	10	1	None	10.0	3.6
Total					
Per household				55.5	19.8
Per capita				9.3	3.3

UNC Units of national currency.

Economic costing of a conventional sewerage scheme

Sewerage costs are divided into two types: household costs, and collection and treatment costs (although collection and treatment costs should be calculated separately, for reasons explained below).

HOUSEHOLD COSTS. These include all the toilet and plumbing fixtures, the connection to the street sewer, and the superstructure (in the case of a toilet located inside the house, this may be calculated as the toilet floor area times the construction cost per square meter—excluding from the latter the toilet and plumbing fixtures, to avoid including these twice). All these costs must be shadow priced, and it is thus necessary to determine separately the costs of unskilled labor and imported items. These capital costs are then converted to annual costs by multiplying by the appropriate CRF as described in the previous example.

Annual operation and maintenance costs are then calculated, using the AIC of water for the unit cost of the flushing water necessary.

Table 4-2. *Shadow-priced Collection and Treatment Costs of a Conventional Sewerage Scheme Constructed over Five Years*

Component	*Year incurred*	*Total cost* (UNC)
Collection		
Sewers, force mains, manholes	1–5 (evenly)	4,000,000
Pumping stations[a]	5	400,000
Engineering design	1–2 (evenly)	200,000
Operation and maintenance[b]	Annually	150,000
Treatment		
Land	1	2,000
Fencing	3	10,000
Engineering design	3	15,000
Treatment works	3–5 (evenly)	900,000
Operation and maintenance[b]	Annually	100,000

a. Includes mechanical and electrical installation.

b. Calculated assuming full capacity, beginning in year 11. (Because of initially incomplete capacity utilization, the costs upon completion of the system in year 5 would be 50 percent of the costs listed, increasing over years 6–10 to the full amounts shown.)

COLLECTION AND TREATMENT COSTS. These include all material and installation (labor) costs for the sewer network and its appurtenances (such as manholes and pumping stations) and for the treatment works (including land costs). Capital costs for collection and treatment should be calculated separately because they may be incurred at different times during the construction period and may also have different design lifetimes.

Example

Household costs are excluded from the example since they are calculated in the same way as those of the pit latrine. Note that the design lifetime of the household components is not likely to be the same as those of the collection system and treatment works.

Assume that the collection network and treatment works are constructed over a five-year period. Assume further that the shadowed costs are as listed (and incurred in the years stated) in table 4-2.

Assume also that: the design population is 250,000; the wastewater flow is 200 liters per capita daily; 50 percent of the design population is served upon completion of construction, increasing linearly to full utilization by the beginning of the eleventh year from

Table 4-3. *Costs (in Constant Base-year Prices) and Wastewater Flows for Conventional Sewerage Scheme* (UNC)

	Collection		*Treatment*		
Year	*Capital*	*Operation and maintenance*	*Capital*	*Operation and maintenance*	*Wastewater flow (thousands of cubic meters)*
1	900,000	0	2,000	0	0
2	900,000	0	0	0	0
3	800,000	0	325,000	0	0
4	800,000	0	300,000	0	0
5	1,200,000	0	300,000	0	0
6	0	75,000	0	50,000	9,125
7	0	82,000	0	55,000	10,038
8	0	90,000	0	60,000	10,950
9	0	97,500	0	65,000	11,863
10	0	105,000	0	70,000	12,775
11	0	112,500	0	75,000	13,688
12	0	120,000	0	80,000	14,600
13	0	127,000	0	85,000	15,513
14	0	135,000	0	90,000	16,425
15	0	142,500	0	95,000	17,338
16	0	150,000	0	100,000	18,250
17	0	150,000	0	100,000	18,250
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
44	0	150,000	0	100,000	18,250
45	0	150,000	0	100,000	18,250

Table 4-4. *Present Values* (PV) *of Costs (in Constant Base-year Prices) and Wastewater Flows for Conventional Sewerage Scheme* (UNC)

	Collection		*Treatment*		
Year	*Capital*	*Operation and maintenance*	*Capital*	*Operation and maintenance*	*Wastewater flow (thousands of cubic meters)*
1	900,000	0	2,000	0	0
2	803,571	0	0	0	0
3	637,755	0	259,088	0	0
4	569,424	0	213,534	0	0
5	762,621	0	190,655	0	0
6	0	42,557	0	28,371	5,177
7	0	41,543	0	27,864	5,085
8	0	40,711	0	27,140	4,953
9	0	39,378	0	26,252	4,791
10	0	37,864	0	25,242	4,606
11	0	36,221	0	24,147	4,407
12	0	34,497	0	22,998	4,197
13	0	32,597	0	21,817	3,981
14	0	30,938	0	20,625	3,764
15	0	29,158	0	19,438	3,547
16	0	27,404	0	18,269	3,334
17	0	24,468	0	16,312	2,976
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
44	0	1,147	0	764	139
45	0	1,024	0	682	124
Present value of column	3,673,371	612,689	665,277	408,702	74,575

Note: AIC (average incremental cost) = (3,673,371 + 612,689 + 665,227 + 408,702)/74,575,000 = 0.07 UNC per cubic meter of wastewater.

completion; the design lifetime of both the collection system and treatment works is forty years (measured from completion); and the opportunity cost of capital is 12 percent. Note that the costs given in table 4-2 are assumed to have been shadow priced already for unskilled labor and foreign exchange components. Operation and maintenance costs are assumed to vary with the population served, being 50 percent of the figures given upon completion, increasing to 100 percent of the figures by the beginning of the eleventh year from completion.

Given these assumptions, the costing procedure is:

- Construct a table, similar to table 4-3, in which all the costs incurred and the total volume (in cubic meters) of wastewater generated in each year are entered under the various headings as shown. The effect of inflation should be ignored in this calculation so that all costs are in constant prices.
- As shown in table 4-4, convert these costs and volumes to their present values (PV) by using a set of financial tables, a financial calculator, or the equation:

$$PV_t = \frac{C_t}{(1 + r)^{t-1}},$$

where C_t = cost incurred (or total wastewater volume produced) in year t; and r = opportunity cost of capital in percent times 10^{-2}.
- Calculate the AIC of the collection and treatment components by adding together the sums of the PV of the capital and operation and maintenance costs for both components and then dividing by the sum of the PV of the wastewater volumes as shown in the last line of table 4-4. This gives the AIC of collection and treatment in UNC per cubic meter, from which the annual per capita AIC can be calculated because the per capita wastewater flow is known to be 200 liters per capita daily (73 cubic meters per year). In this example the AIC per cubic meter is 0.072 UNC, or 5.2 UNC per capita annually. The total AIC of the whole sewerage scheme in UNC per capita annually is then obtained by adding in the shadowed annual per capita household capital and operation and maintenance costs. This may be expressed in U.S. dollars by converting at the official exchange rate.

Note to Chapter 4

1. For a more detailed treatment of the issues in this chapter, see Kalbermatten, Julius, and Gunnerson (1982).