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AN ECONOMIC APPRAISAL OF SANITATION ALTERNATIVES

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Abstract

The theory of economic costing is briefly reviewed and applied to the analysis of alternative sanitation technologies. Using this method the costs from 44 systems in 12 countries are computed and compared. A value engineering approach is taken to analyze cost sensitivities and productive areas for future technical research.

INTRODUCTION

Comparative costing lies at the heart of the analysis of alternative sanitation technologies. A common denominator is needed to objectively compare diverse systems. That common denominator should reflect the positive and negative consequences of a given technology and indicate its overall "score" either on an objective scale or relative to other alternatives.

The scoring measure most commonly used in project evaluation is the cost-benefit ratio. (See note b.) It has the advantage of providing a single summary figure representing the net economic effect of a given project which can be readily compared with those of alternative projects. The disadvantages of cost-benefit calculations are that they do not easily accommodate non-economic costs and benefits (particularly if they are unquantifiable), they may give misleading results when applied to mutually exclusive projects and they may not reflect macroeconomic goals such as employment creation or increased savings. Fortunately, the latter two problems can be remedied by variations of the basic calculation. However, the difficulties of benefit measurement for sanitation projects cannot be overcome readily. Indeed, in the case of water supply projects, it has been concluded that the theoretical and empirical problems involved in quantifying incremental health benefits are so great as to make serious attempts at benefit measurement inappropriate as part of project appraisals (Ref. 2).

In general, there is no completely satisfactory scoring system for comparing alternatives with unquantifiable benefits. Only in the case of mutually exclusive alternatives with identical benefits can one apply a cost minimization rule. In such cases one should select the alternative with the lowest present value of cost when discounted at the appropriate rate of interest. For given levels and qualities of service the least-cost alternative should be preferred. But where there are differences in the output or service, the least-cost alternative often will not be the economically optimal one.

Alternative sanitation systems provide a wide range of benefit levels. While most properly selected systems can be designed to assure pathogen destruction (Ref. 3), the user convenience offered by an indoor toilet with sewer connection is hard to match with a pit privy. Many benefits exist in the mind of the user, and varying qualities of service result in varying benefit levels. For this reason a least-cost comparison will not provide sufficient information to select among sanitation alternatives. Nonetheless, if properly applied, it will provide an objective common denominator which reflects the cost trade-offs corresponding to different service standards. Once comparable cost data have been developed, the consumer can make his own determination of how much he is willing to pay to obtain various service standards.

Note a: The data used in this paper were collected as part of the World Bank's research project on Appropriate Technology for Water Supply and Waste Disposal. However, the views presented are those of the author and should not be attributed to the World Bank or any of its affiliates.

Note b: Variations of this calculation include the internal rate of return and the net present value. For a discussion of the set of conditions under which each is appropriate, see Squire and van der Tak (1).

Thus the economic evaluation of alternative sanitation technologies comprises three components: comparable economic costing, maximizing the health benefit from each alternative through proper technical design, and allowing the user to make the final cost-benefit determination. This paper deals with the first of these.

ECONOMIC COSTING IN THEORY

The basic purpose behind economic costing is to develop a price tag for a given good or service which represents the opportunity cost of producing that good or service to the national economy. Translated into practice, this purpose can be summarized in three principles to be followed in preparing cost estimates.

The first principle is that all costs to the economy, regardless of who incurs them, should be included. In comparing costs of public goods such as water or sanitation, too often only costs attributed to the public utility are considered in a cost comparison. The costs borne by the household are ignored or subsumed as being identical across alternatives. In analyzing the financial implications of alternative technologies such a comparison would be appropriate. However, for an economic comparison (i.e., for the determination of the least-cost solution) it is necessary to include all costs attributable to a given alternative whether borne by the household, the municipal utility, the national government, or whomever.

The determination of which costs to include should rest on a comparison of the situation over time with and without the project. This is not the same as a "before and after" comparison. Rather than using the status quo as the "without" scenario, one must estimate how the current situation would improve or deteriorate over the project period were the project not to be undertaken. In the case of sanitation systems for urban fringe areas, for example, the costs of groundwater pollution and the difficulty in siting new latrines are likely to increase over time as population pressure mounts. There is likely to be an optimum time to undertake a sanitation project. By acting too soon one may incur costs that could have been postponed. By waiting too long the per capita cost of the project could rise (in real terms) because of increases in population density, for example, which aggravate construction difficulties.

Once the relevant costs to include have been identified, the second costing principle concerns the prices which should be used to value those costs. Since the objective of economic costing is to develop figures which reflect the cost to a given 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 labor's alternative production possibilities. Similarly, a country with scarce water resources will have expensive water costs, in the economic sense, regardless of the regulated price charged to the consumer. Only by using prices which 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 diverse goals which may be only indirectly related to economic objectives, some market prices may bear little relation to real economic costs. For this reason it is often necessary to "shadow price" observed, or market, prices to arrive at meaningful component costs of a sanitation technology. Calculating these shadow rates, or conversion factors, is a difficult task and requires intimate knowledge of an economy's workings. The shadow rates used in this paper were developed according to the method described by Squire (1).

The third principle of economic costing is that incremental rather than average historical costs should be used. This principle rests upon the idea that sunk costs should be disregarded in making decisions about future investments. In analyzing the real resource cost of a given technology, it is necessary to value the components of that technology at their actual replacement cost rather than at their historical price. In the case of sanitation systems this is particularly important in the treatment of water costs. Because a city develops its 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 gallon 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 water carried sewerage system will increase a given population's water consumption by around 50 to 70 percent. (See note a.) Thus in calculating the costs of such an alternative, it is extremely important to properly value the cost of the additional water required for its proper functioning.

Note a: Based on developed country data, the water used to flush toilets is around 40 percent of total domestic water use excluding garden watering.

SPECIAL PROBLEMS OF SANITATION PROJECTS

The application of these costing principles to sanitation projects is difficult for several reasons. The main one is the problem of finding a scaling variable that allows comparison among diverse technologies regardless of their design populations. On-site systems such as pit latrines are generally designed for a single family or household. The latrine's lifetime will depend on how many people use it. However, the life of some components, such as a vent pipe, may be independent of usage, so that the annuitized per capita construction cost of a latrine used by 6 people will probably not be the same as that of one used by 10 people. For this reason all costs presented in this paper are given in household rather than per capita units.

A further problem is that the construction cost of a sewerage system will vary considerably as the design population varies. In addition, it would be misleading to use the design population in deriving per capita costs to compare with those of a pit latrine since in the former case the benefits only reach a portion of the users during the early years, while the latrine's "design population" is served immediately upon construction. Any technology which exhibits economies of scale in production will result in a diversion of cost and benefit streams. With a facility such as a treatment plant or large interceptor all of the investment costs are incurred at the beginning of its lifetime while the benefits (leading to its full utilization) are realized gradually over time. Figure 1 provides a skematic representation of this diversion between cost and benefit streams.

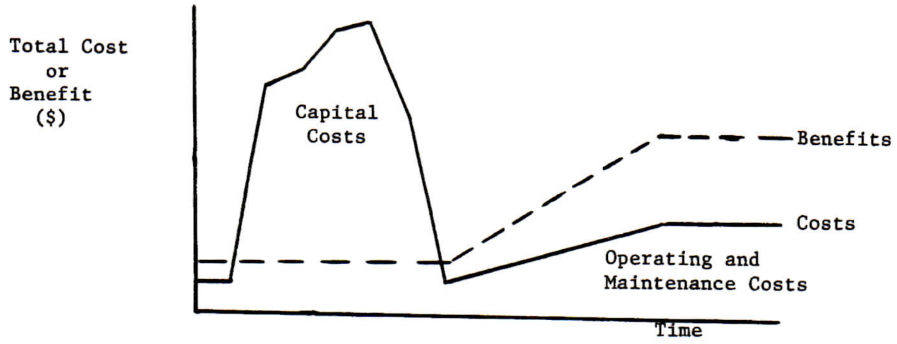

Fig. 1. Cost and benefit streams of an investment with economies of scale

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 case of deriving per capita (or 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 understate its real per capita cost when compared with that of a system that is fully utilized upon completion.

To overcome this problem of differing capacity utilization rates across systems the average incremental cost (AIC) calculation has been used. The per household AIC of a system is calculated by dividing the sum of the present value of construction (C) and incremental operating and maintenance (O) costs by the sum of the present value of incremental households served (H):

$$AIC_t = \sum_{t=1}^{T} \frac{\left[C_t + (O_t - O_{t_o})\right] \div (1 + r)^t}{(H_t - H_{t_o}) \div (1 + r)^t}$$

where r is the opportunity cost of capital and all costs have been appropriately shadow priced. Note that for a system which is fully utilized immediately this calculation reduces into the familiar annuitized capital and incremental operating and maintenance costs divided by the design (household) population.

In practice it is often easier to calculate the AIC on a volume (e.g., cubic meter) basis rather than per household served. For the sewerage costs in five of the case studies the AIC per cubic meter was calculated first for residential consumers since year-by-year projections of treated wastewater were available. Then these volumetric costs were transformed into per household costs using average household size and per capita demand figures.

An additional problem in deriving comparable sanitation system costs is the differing treatment of sullage wastes. With sewerage, most septic tanks, and some aquaprivy systems, sullage is disposed of along with excreta. With most of the on-site technologies sullage disposal must be accomplished separately through stormwater drains or ground seepage. If stormwater drains are present (or would be constructed anyway) then the incremental cost of disposing of sullage is very small since storm drains are usually designed to handle flood peaks. If sullage is left to soak into the ground, health and environmental risks may or may not be created depending on soil conditions and ground water tables. Alternatively, separate disposal of sullage may be considered a positive benefit by populations who recycle kitchen and bath water to irrigate gardens or dampen dust. In such a case, the removal of sullage through the introduction of a sewerage system would involve a negative benefit. In a particular case it is not difficult to decide how to treat sullage removal costs when comparing different sanitation systems. However, for the purposes of this paper where a more general comparison is required, a consistent assumption needs to be applied. Therefore, the costs in Tables 1 and 2 include sullage disposal only where the sanitation system itself is designed to accommodate it. This is true of all of the sewerage systems, all of the septic tanks and two of the sewered aquaprivies.

A final problem in designing comparable cost figures for sanitation systems concerns the approach to be used in gathering data. The study from which this data were abstracted was statistically based in contrast to a synthetic framework which develops an ideal model and tests the effect of varying assumptions. Both approaches have their advantages and disadvantages. Because so little is known about the technology or costs of non-conventional sanitation systems, it was decided that a broad-based study involving many systems in many different settings would provide the best overall framework for designing particular studies or, indeed, selecting "typical" technologies and settings to proceed with a synthetic model. The major disadvantage of a statistical approach, however, is that it is very difficult to identify the factors which result in increased or decreased costs since it is impossible to vary one factor at a time while holding all others constant. Cross-country comparisons can be misleading unless one is familiar with the background of each case. For this reason caution should be employed in generalizing the field results beyond their base or in using them for predictive purposes.

It is also important to note that the economic costs shown below do not represent average annual financial outlays. In general they will be higher than financial costs since sanitation projects usually have access to long-term finance (debt or equity), and financial interest rates are usually below the opportunity cost of capital. The focus of this paper is on a least-cost, economic comparison of alternatives rather than a financial appraisal.

FIELD RESULTS

The costs discussed below have been disaggregated in two ways: by function and by investment versus recurring costs. In disaggregating by function, the categories used are on-site facilities, collection, treatment and reuse. This distinction is made primarily because disaggregating by function allows one to broadly examine the cost effects of repackaging components (for example, many treatment alternatives can be linked with a variety of collection systems and/or on-site facilities). In addition this disaggregation is amenable to a "value engineering" approach by identifying the areas where the greatest potential for cost savings exists. It also provides a rough guide for the financial analyst to determine the proportion of system costs which must be borne by the utility as compared to that incurred directly by the household. The latter is a useful figure in estimating consumer willingness to pay utility rates since that willingness will be based in part on the costs to the household of obtaining the private facilities to enable it to make use of the utility's service.

The second type of disaggregation is the separation of capital and recurrent costs. The difference between high capital cost and high recurrent cost technologies generally parallels that of capital intensive versus labor intensive technologies. This is because investment costs of most systems are mainly capital while recurrent costs are mainly labor. The distinction is made in this paper between investment and recurrent rather than between capital and labor partly to focus on the main cause of the difference and partly because of the important institutional implications of managing a high recurrent cost system.

Cross-technology cost comparison

The single most useful figure for cross-technology comparisons is the total annual cost per household (TACH). It includes both investment and recurrent costs, properly adjusted to reflect real opportunity costs and averaged over time by the AIC method. The use of per household rather than per capita costs is appropriate for those systems whose on-site facilities are designed for use by a single household. However, TACH is misleading when applied to communal facilities or cases where several households share one toilet. In those instances an adjusted TACH has been calculated by scaling up per capita costs by the average number of persons per household.

Table 1 summarizes the TACH obtained for the ten technologies studied. Several summary statistics are shown due to a wide variation in the number of cases studied and the range of costs.

TABLE 1. Summary of total annual costs per household (1978 $)

	Mean TACH	Number of Observations	Range	Mean Investment Cost	Mean Recurrent Cost
Waterseal Pit Latrine	18.7	3	13.2	13.2	5.5
Pit Latrine	26.4	7	48.6	26.3	0.1
Communal Waterseal Latrine	34.0	3	34.2	24.2	9.8
Bucket Cartage	49.5	3	57.0	28.0	21.2
Composting Latrine	55.0	3	40.3	50.4	4.8
Aquaprivy	87.7	1	-	79.8	7.9
Vacuum Truck Cartage	104.2	9	184.7	67.0	37.4
Japanese	187.7	4	38.6	127.7	60.0
Others	37.5	5	28.1	18.1	19.3
Sewered Aquaprivy	180.0	3	120.6	141.2	38.7
Septic Tanks	204.0	4	345.3	130.8	73.1
Japanese and Taiwanese	348.2	2	84.3	216.7	131.5
Others	59.7	2	29.5	45.0	15.0
Sewerage	395.8	8	499.1	272.0	122.7

Contrary to expectation, when ranked according to cost the technologies do not divide cleanly into community and individual systems. The most expensive group (those with TACH greater than $300) includes sewerage and Japanese and Taiwanese septic tanks. The middle range technologies (those with TACH between $150 and $200) are Japanese cartage systems and sewered aquaprivies. The low cost technologies (those with TACH less than $100) include both community systems such as buckets and non-Japanese cartage and most of the individual systems. The division between high, middle and low cost-technologies is fairly sharp with large buffer areas available for system upgrading. The fact that variations of septic tanks and vacuum truck cartage appear in two categories indicates the potential for installing a low-cost technology at an early stage of development and improving its standard as development proceeds.

Within the low-cost technology group, there is a fairly large variety of systems, ranging from aquaprivies and simple septic tanks to pit privies and waterseal latrines. Vacuum truck cartage (non-Japanese) and bucket cartage, with TACHs in the $30 to $50 range, fall in the middle of this group. However, the cartage figures are derived mostly from Taiwanese and Korean case studies which exhibit a degree of labor efficiency that might be difficult to replicate in other parts of the world. Bucket cartage figures are mostly from Africa and represent poorly functioning systems that probably should not be replicated without upgrading. Thus the TACHs of community systems in the low cost group are likely to understate their cost of construction and operation in other countries. Of course, since all of the costs in Table 1 are derived from particular case studies, none can be considered an accurate representation of what it would cost to build a particular system in a different country. However, there is no reason to suspect that the individual system costs are biased either upward or downward because of country selection.

Cross-country cost comparison

Before examining the cost data for each technology it is useful to consider the overall variation of costs across countries. The magnitude of the total variation is quite large, as is indicated in the third column of Table 1. In nearly all cases the range is at least as large as the mean TACH. In the case of the pit privy the range is nearly double the mean. In a statistical study of this type such a wide variation is to be expected and does not present a major problem since the figures are meant to be informative rather than predictive. Further, the relatively wide margins between the grouping of technologies into high, medium and low cost systems indicates that the groupings are probably accurate even though the means may be 50% too low or too high.

The total variation is due in part to differences in the costs of basic inputs such as labor and in part to differences in the input combination used (e.g., different types of treatment processes among the sewerage systems). To some extent these two factors are off-setting since a country with high capital costs would be expected to choose a less capital-intensive treatment process, for example. For two of the systems, vacuum truck cartage and septic tanks, the difference in input combinations seems to be very important since the case studies' costs exhibited a bimodal distribution which could be directly traced to differences in the technologies employed in different countries. In no two case studies is the exact design of a system replicated; i.e., no two pit privies are exactly alike. However, for most of the technologies the variation in cost across countries parallels the general price levels of the countries.

Investment and recurrent costs

The distinction between investment and recurrent costs is an important one for both financial and technical reasons. A city or community with very limited fiscal resources at present but with a good growth potential might find it impossible to raise the investment finance to build a system with large initial capital requirements, whereas it could build and maintain another system (with the same TACH) whose recurrent expenses were relatively high. Conversely, a major city in a developing country which has access to external sources of funds might prefer to build an expensive system initially with the help of grant or low-interest loan capital and thereby reduce its need for recurrent funds. (See note a.)

From the technical viewpoint high recurrent costs generally stem from large or sophisticated operating and maintenance requirements. In those developing countries where skilled labor is scarce or where the management necessary to coordinate large numbers of unskilled workers does not exist, it may be unwise to opt for a system with high recurrent costs. However, an offsetting argument is that the employment benefits arising from a high recurrent cost system such as vacuum cart collection may be large enough to justify importing the management skills necessary.

The final two columns of Table 1 present the investment and recurrent cost breakdown for the 10 technologies studied. One interesting conclusion that could be derived from these columns is that as one moves from the most expensive to the least expensive system, recurrent costs as a percent of the total first increase and then decrease. The two high cost and the two medium cost technologies exhibit recurrent costs amounting to between 20 and 36 percent of TACH. The highest recurrent cost systems (as a percent of the total) are in the middle of the low-cost technology group, non-Japanese cartage and buckets, with 52% and 43% recurrent cost, respectively. As one moves to technologies such as composting latrines and pit privies the porportion of recurrent cost drops to less than 10%.

This somewhat surprising pattern is due in part to the make-up of the recurrent cost figure. Because economic rather than strictly financial costs are used in this study, a major item is included in recurrent cost which typically does not appear in engineering cost estimates: the water used to flush some systems. In order to see how the inclusion of flushing water cost affects the investment versus recurrent cost breakdown, separate calculations excluding water costs were made for those six systems which require water.

If one excludes flushing water from recurrent costs, only vacuum truck cartage and bucket systems show recurrent costs of more than 30%. The overall conclusion is that nearly all of the sanitation systems studied are relatively high in investment as opposed to recurrent cost. Only in the case of non-Japanese cartage do recurrent costs represent more than half of TACH. In ten of the twelve systems (treating the two varieties of septic tanks and cartage as separate systems) investment costs account for more than 60% of TACH.

There are several implications of this concentration on investment costs. One is that it will probably be necessary to set up financing arrangement for the utility regardless of which technology is chosen by a particular city or community. High initial costs almost invariably require some sort of financial mechanism to smooth payments so that they are more in line with benefits delivered to (and paid for by) the consumers. A second implication is that where funding constraints are binding, the size of the initial investment requirement may be the most important determinant of technology choice. There is relatively little scope for substituting a higher recurrent cost system. In that sense, the distinction between the relative importance of investment and recurrent costs of different systems becomes moot. While sewerage and waterseal latrines both entail recurrent costs of about 30% of their respective TACH, the important point is that the investment cost (per household, per year) of the former is more than 20 times larger than that of the latter.

On-site collection, and treatment costs

The separation of TACH into its functional components is useful in determining where to

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Note a: This would not be an economically efficient solution since the opportunity cost of capital does not depend on the source of the funds or the terms of a particular loan package.

focus the design effort in attempting to reduce costs. For most of the individual systems, of course, all (or greater than 90%) of the cost is on-site. Thus an investigation of the cost reduction potential for them must center on the materials and methods used to produce and install them. In one African case between 40 and 60 percent of the TACH for pit latrines, composting latrines, and aquaprivies went for the superstructures which were made of concrete blocks. If these units were built using local materials such as clay brick or straw matting their costs could be reduced significantly.

Table 2 presents the functional breakdown of costs for the ten systems. Even among the six community systems, on-site costs account for at least 45% of the total. Japanese and Taiwanese septic tanks have the highest on-site costs of over $320 per household per year. The large role that the costs incurred by the household play in total system costs shows the importance of finding ways for funding on-site facilities. The very low connection rates of many sewer systems in developing countries (often in the face of legal requirements to connect) probably is at least partly due to the large household expenditure involved.

With the exception of the bucket systems, collection costs and treatment costs make up about equal proportions of the TACH of the various community systems. In the bucket systems covered in this study the only "treatment" practiced was trenching so that it is not surprising that treatment costs represented only 8% of the total.

Table 2. Average annual on-site, collection, and treatment costs per household (percent)

	On-site	Collection	Treatment
Waterseal Latrine	100	-	-
Pit Privy	100	-	-
Communal Waterseal Latrine	100	-	-
Bucket Cartage	48	44	8
Composting Latrine	85	-	15
Aquaprivy	100	-	-
Vacuum Truck Cartage	64	22	14
Japanese	68	18	14
Others	45	37	18
Sewered Aquaprivy	54	23	23
Septic Tanks	94	4	2
Japanese and Taiwanese	93	5	2
Others	100	-	-
Sewerage	49	21	30

An additional functional category was included in the original study to represent any economic benefits accruing from reuse of treated nightsoil or sewage effluent. Unfortunately, it was very difficult to locate working examples of human waste disposal systems with a sizable reuse component. A few of the sewerage systems produced small amounts of methane from their digestors which was used to heat the plants. There was some demand from orchard farmers in the Far East for the nightsoil collected by vacuum truck but the municipalities made no effort to set up a delivery system or to charge a market-clearing price. The composting latrines built in Africa were too new to yield useful data on reuse. All except one of the biogas units observed ran on animal rather than human waste. In short, while there is much experimental and theoretical data on the economic potential of reuse technologies, there is a dearth of actual experience. (See note a.)

COST SENSITIVITIES

It may be useful to summarize the broad conclusions from this review of cost data from a total of 44 sanitation systems studied in 12 countries. Precise calculations of the sensitivity of system costs to changes in particular parameters are impossible to undertake within the framework of an empirically based study such as this one. However, it is possible to discern areas of relatively greater and lesser importance.

The two most outstanding influences upon total household costs are factors which have often been ignored in engineering analyses: on-site household costs and the cost of flushing water for water-carried systems. The former is important in all systems and never accounted for less than 45% of TACH. The latter is most important for sewerage and septic tank systems. Where the economic cost of water is high, the payoff from designing systems with low requirements for flushing water is large.

Note a: The obvious exception to this statement is the experience of mainland China, but scientifically documented information on it is rare, and it was not possible to include first-hand observation in this study.

A second conclusion relates to those aspects of sanitation systems which do not significantly influence costs but can make a big difference in benefits. Two components of individual systems, ventilation pipes and water seals, aid greatly in reducing odors and fly breeding without adding noticeably to system costs. In one of the case studies it was found that people were very concerned about the color of the floor of their latrines. While this is an aesthetic concern without technical importance, it may make the difference between a facility that is kept clean and regularly used and one that isn't. In another case, in an effort to cut costs the latrine designers had used pre-cut sheets of zinc for the superstructure siding. However, this meant that the siding did not reach all the way to the floor which provided easy access for rodents and scorpions during the night and embarrassment for the people (whose feet could be seen while using the latrine). Such unimportant details from the cost viewpoint are often very significant in enhancing health and aesthetic benefits (both of which generate a willingness to pay on the part of the user).

A final caution is appropriate in the interpretation of these case study costs. In very few cases were the systems optimally designed. This was true of the overdesigned superstructures of the experimental African latrines, the reuse components found in the Far East, some sewered aquaprivies in Zambia (which fed into conventionally sized collectors designed for a full sewerage system), and many of the other cases. Nonetheless the broad ranking of technologies, the cost sensitivity patterns, and the method used to arrive at appropriate figures for a least-cost comparison are believed to have general applicability.

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