part 2.

THE PREVENTION OF TROPICAL WATER-RELATED DISEASE

PROGRAMME

WEDNESDAY
13
DECEMBER

SESSION 7 (0900-1030)

22. Domestic water use in a village in Bangladesh: I. A methodology and a preliminary analysis of use patterns during the "cholera season": J. Briscoe, S. Ahmed and M. Chakraborty (p. 131)

23. Field studies on water sanitation and health education in relation to health status in Central America: M.A. Shiffman, R. Schneider, J.M. Faigenblum, R. Helms and A. Turner (p. 143)

24 Health problems connected with water sources and supply in Togo: R. Schubert (preprint not included)

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25 Design of water systems for developing countries: D.T. Lauria, P.J. Kolsky and R.N. Middleton (p. 151)

26, 27. Hand pump technology for the development of ground water resources: F. McJunkin ~~and Developments in village-scale slow sand filtration: E. L. P. Hessing~~ (pre~~prints not included)~~

28. Developments in village-scale slow sand filtration: L. Huisman (p. 159)

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DECEMBER

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Summary, Conclusion and Recommendations

ENGINEERING, SCIENCE AND MEDICINE IN THE PREVENTION OF TROPICAL WATER-RELATED DISEASE

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DOMESTIC WATER USE IN A VILLAGE IN BANGLADESH, I: A METHODOLOGY AND A PRELIMINARY ANALYSIS OF USE PATTERNS DURING THE "CHOLERA SEASON"

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Abstract - Using consumer behaviour theory, a method is developed for formally analyzing how people choose water sources for different domestic uses. A preliminary analysis of data collected in a Bangladeshi village during the months of November, December and January, the traditional "cholera season", is presented.

INTRODUCTION

It is widely believed that the health of people in rural Bangladesh (and other Third World countries) would be greatly improved if these people used increased quantities of water of a higher bacteriological quality for domestic purposes. Rural water supply programs are usually designed on the assumption that if access to an "improved" supply is easy and if the people are educated about the beneficial health effects of abandoning their traditional supplies and using this new supply, then existing water use patterns will change. Observations of the effect of such programs on the behaviour of rural people in many parts of the world (1) raise serious doubts as to the adequacy of this simple behavioural model. People frequently do not respond in the desired or expected manner to the availability of "improved" water sources. These failures are usually attributed to technical design deficiencies or to the lack of health awareness of the people; the solutions are thus better engineering and more health "education" (or, more accurately, health "propaganda" (2)).

Our approach is quite different. We assume that present water use habits are not the result of ignorance or the lack of availability of "safe" water. We know, since two of us are villagers ourselves, that villagers have well-formed opinions concerning the characteristics of available water sources. They know how far a source is from their home; whether there is likely to be a quarrel if they use the source; whether the water is clean, the colour good and the taste pleasant; whether the place is private and the ghat* of good quality; whether the water is deep. They choose water sources for different domestic purposes - drinking, cooking, washing utensils, washing clothes and bathing - in accordance with these perceptions. We expect the relative importance of these different factors to vary with social and economic status. The corollary of these assumptions is that only when we have a more subtle understanding of existing water use patterns and preferences will we be able to predict who will use a particular new source and for what purposes they will use it.

In designing water programs we are also hampered by our ignorance about how water-related behaviour affects disease. In an earlier paper we have shown (3) that we are often unable to relate the incidence of, say, cholera to water use patterns simply because we do not know how people actually use water. We thus need a better understanding of water use patterns and perceptions if we are to know both how people will respond to water supply programs and how this response will affect health.

THE THEORETICAL FRAMEWORK

Background

In 1972 Gilbert White published his pioneering study of how East African villagers choose among different water sources for domestic purposes (4). In White's study families were interviewed and for each accessible source their perceptions were elicited regarding the perceived quality of water, the economic feasibility of obtaining water and the technological feasibility of drawing water. For each accessible source the perceptions for each factor were

* A ghat is a structure providing access to a water source. The quality of a ghat may vary from a muddy embankment to a concrete structure.

recorded as "unfavourable", "neutral" or "favourable" and given rankings of 0, 1 or 2 respectively. A similar procedure was followed for assessing the effect of use of this source on relationships with other people. The scores were combined to produce an index of the "attractiveness" of each source to each user.

White's analysis was useful in several ways. It was an important step in drawing attention to the fact that user's reactions are based on their own perceptions of the situation and not the perceptions of scientists or government officials. The formal model was useful in guiding the systematic collection of data which, in the raw form, gave interesting insights into why some sources were preferred to others. The analysis is also a landmark in being the first attempt at formally understanding how people choose the water source they will use.

There are, however, three serious deficiencies in White's analysis. The first problem is that the model is ad hoc. The attractiveness index is obtained by multiplying the scores for quality, economic feasibility and technological feasibility and subtracting the score for "effects on others" from this product. The index is presented as "reasonable" but no attempt is made to relate the model to any rigorous theory of behaviour. The second problem relates to the simultaneous consideration of all types of domestic water use. In our study, where 65% of the families use more than one source of water for domestic purposes, and apparently in East Africa (5), each factor affects each type of water use differently. Water quality, for instance, may be a most important consideration when a person chooses a source of drinking water but may be largely irrelevant when the person chooses a place to wash clothes. The third problem is that while White's model was developed as an explanatory model, only a few illustrative examples are given and the predictive power of the model never tested on all of the data which were collected. The model presented in this paper is an attempt to build on that which White started but to avoid some of the problems which limit the usefulness of White's analysis.

The Model

The theory of consumer behaviour concerns the choice of a bundle of goods when the prices of these goods, the budget and the consumer's preferences (in the form of indifference curves or an ordinal utility function) are known. The "two-good" case is presented on Fig. 1. This theory is routinely used to examine the effects of changes in prices of the goods and income level on the demand for these goods. If we try to use this framework to understand the water choices exercised by villagers and to predict their response to a new water source, several problems are immediately apparent. Our case is different since we are trying to understand the choices, not among goods, but among different sources of the same good, with each source having a particular set of "characteristics". In our case there is no analogy to "prices" and "income" and use of a source is not divisible but a yes/no matter.

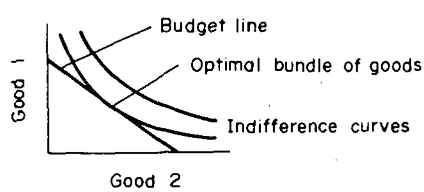

Fig. 1. The standard consumer paradigm.

In response to similar difficulties which have arisen in other areas - such as in estimating the demand for presently unavailable forms of transportation (6) - a "new" approach to consumer theory has been developed (7). In this view consumption goods, as such, are not immediate objects of preference or utility but have associated with them "characteristics" which are directly relevant to the user. The user is assumed to have a preference ordering over the set of all possible characteristic vectors, and her aim is to attain the most desired bundle of characteristics subject to the constraints of the situation. An example of the situation which faces a water user is presented graphically on Fig. 7 later in this paper.

The subsequent analysis differs from the standard approach in several important ways. A utility function is usually thought of as describing a consumer's preferences among different bundles of goods. In terms of the "new" theory, the standard utility function incorporates both preferential and technical considerations, the latter because the relationship between goods and characteristics is subsumed into the utility function. For this reason we cannot use this standard approach to predict the reaction to the availability of a new good or a new source of an existing good.

A feature of the "new" approach is the separation of technical and preferential issues.

After selection of the characteristics which are relevant to consumer or user choice, the goods-characteristic relationship and thus the efficiency frontier (the points "river 200", "tank 67"* and "tubewell I"** on Fig. 7) are specified without reference to the preferences of the user***. The indifference curves embody the people-characteristic relationship and are estimated by examining behaviour. In our graphical representation a "budget line" no longer exists: We now have an "efficiency frontier" which maps the vectors of available characteristics for a given set of prices and income. In this type of analysis real income differences may appear as scalar changes in the typical frontier or, in our case, as new options which embody a previously-unavailable vector of characteristics.

Understanding water-use choices is largely an exercise in elucidating ways in which users are willing to substitute one characteristic for another characteristic in order to maintain a given level of satisfaction. Each form of the ordinal user's preference function implicitly specifies the marginal rate of substitution (MRS) which is the rate at which this substitution takes place. Choosing an appropriate user's preference function is the art of striking a judicious balance between a simple form (which is analytically tractable but implies a restrictive set of substitution properties) and a complicated function (which implies few restrictions but requires the estimation of many parameters and is analytically intractable).

At the very least it seems reasonable to require that it becomes increasingly difficult to substitute one characteristic for another as the substitution proceeds, that is, we want the user's preference function to be convex to the origin. As an example of the implications of a choice of a particular form for the user's preference function let us consider the multiplicative function chosen by Gilbert White. Recalling that the function $Y=X_1^{\alpha_1}X_2^{\alpha_2}\ldots X_n^{1-\alpha_1-\alpha_2-\ldots\alpha_{n-1}}$ is the well-known Cobb-Douglas function, we note that the simple multiplicative form used by White is a special case of the Cobb-Douglas function, with $\alpha_1=\alpha_2=\ldots=\alpha_{n-1}$. (The fact that the exponents do not sum to unity in White's simple multiplicative form is irrelevant since behaviour is unaffected by a monotonic transformation of the preference function.)

Since MRS of 1 for 2 = $(\partial Y/\partial X_2)/(\partial Y/\partial X_1) = \alpha_2 x_1/\alpha_1 x_2 = x_1/x_2$ for a simple multiplicative function, the <u>ex ante</u> specification of the exponents by White was unnecessarily restrictive. No parameters are estimated from the data and thus the marginal rate of substitution between characteristics is uniquely and arbitrarily defined for the user's preference function.

Use of the Cobb-Douglas function has been restricted in the traditional theory of consumer choice since income elasticities (the relative change in the quantity of the good divided by the relative change in income) for all goods is unity and the elasticities of substitution between goods (which measures how fast the MRS increases) are unity. More general functional forms, in which these restrictions are relaxed, are available. In the Constant Elasticity of Substitution function, for instance, the elasticity of substitution is not specified <u>a priori</u> but estimated from the data.

Lancaster (7) has argued that these restrictive properties of the Cobb-Douglas function are mitigated if the standard concept of a "representative consumer" is abandoned and different preference functions are estimated at different income levels. If this is done a particular individual is no longer required to have the same preference parameters at different income levels. For the analysis of water-use choices the Cobb-Douglas form of the user's preference function appears to be an appropriate choice since it is analytically tractable but not unduly restrictive if the population is stratified by income level.

<u>Calibrating the Model</u>

In the standard consumer behaviour paradigm, consumers who have a given level of income and who are faced with a set of market prices choose that bundle of goods which maximizes their utility. In the standard paradigm it is reasonable to assume that individuals who have similar incomes will be reaching approximately the same utility level. Therefore the parameters of the utility function for a group of individuals who have similar incomes may be estimated by pooling all data on individual consumption choices.

Our case is quite different. We assume that individuals of the same economic status have similar preferences and thus the same indifference curve parameters. However, within an economic group individual water supply endowments may vary considerably and thus the utility levels obtained from consumption of water may be quite different for different individuals.

Since it is difficult to elicit useful data from questions on hypothetical situations - "If the water source which you presently use was not available, which source would you use for

* A tank is an artificial reservoir, usually excavated to obtain earth for flood-protecting house-mounds and for the houses themselves.

** A tubewell is a small-diameter cased well fitted with a cast-iron suction handpump.

***Ideally this relationship is "technical" and is measured objectively or by an engineer. In our analysis we use subjective evaluations, a procedure which introduces no theoretical difficulties if the evaluations are consistent. It is required, for example, that most users would agree that the colour of water from a certain source is "good", or that most observers would agree that a particular source is "far" from a particular family.

drinking? - we use the "revealed preference" approach to consumer behaviour. We obtain information on actual behaviour and from this information deduce certain properties of the underlying preference orderings. This approach restricts the available data set since we are unable to rank all of the water sources which are accessible to a family. The only justifiable ordinal comparisons are between the source which is chosen and each of the sources which are not chosen by the family. The resulting data are peculiar. We cannot make even ordinal comparisons between the preference levels of the individuals within the same economic group, and even within a single family we have an incomplete set of pair-wise comparisons of water sources. Because of these peculiarities we cannot use any standard statistical techniques for estimating the preference function parameters, and so adopt the following procedure for estimating the parameters of the Cobb-Douglas user's preference function for each economic group.

When a family chooses a source for, say, drinking water this implies that the family makes pair-wise comparisons between the chosen source and each of the rejected sources. For a given parameter vector our model assigns a value of the preference function to each source available to each family. We compare the results of the actual and predicted pair-wise comparisons and record the number of rankings which the model has predicted correctly. Our criterion for choice of a parameter vector is that we choose that vector which maximizes the proportion of/correct pair-wise comparisons.

THE FIELD STUDY

In investigating subjects about which knowledge is rudimentary the primary task of researchers is to formulate the correct questions, not to try to get a comprehensive set of answers. In-depth analyses of closely-observed samples has been the most fruitful method in this primary stage of most economic and sociological investigations (8). Since our knowledge of water-use perceptions and patterns is certainly no more than rudimentary our study was based on an in-depth study of a small number of families in the village of Panipur* for 1 year, followed by more rapid and superficial surveys of one month each in different ecological zones of Bangladesh. Due to unforseen circumstances we were able to collect only 9 months of data from Panipur and were unable to proceed with the second part of the study.

The village and domestic water sources

Panipur is located in the deep-water flooding plain of the Meghna River. For protection against inundation by the annual flood-waters the villagers build their homes on earthen mounds. Consequently the inhabited areas are flanked by depressions which fill with water during the monsoon. Where these depressions remain amorphous and unimproved they are known as "ditches"; where embankments are raised around a well-defined perimeter these water sources are known as "tanks". Many of the villagers also have access to one of the many natural water courses which criss-cross the active Ganges-Brahmaputra delta. In Panipur there are three such water courses. The largest of these is known as "the river" and the two smaller ones as "canals". The 1800 inhabitants of the village can also pump groundwater, which usually has an undesirably high iron content, through one of the eight handpump tubewells which have been installed by the government for public use. There are three private tubewells in this village.

The method

After spending two months learning Bengali, John spent one month in Panipur observing how people used water and listening to villager's opinions concerning their sources of domestic water supply. John then spent two months drawing up the theoretical framework for the analyis before returning to live in Panipur. For the next two months Shahana and Manisha, both of whom are local women, worked with John in specifying which factors should be included in the analysis and in developing a method for generating the required data. Careful and critical attention was paid to the hazard of failing to elicit complete replies.and to the converse risk of biasing the response through the mode of enquiry. After six preliminary formats had been tried and discarded we settled on one which proved to be satisfactory.

In living and working with the people of Panipur for a year we developed good relationships with many of its people. Shahana and Manisha, who did the interviewing, spent a substantial portion of their time helping women do their household work, looking after their children and telling stories, and were thus able to interview only two families each per day. It was essential that we inconvenience the study families as little as possible since we planned to interview them four times during the course of the year and a high degree of cooperation was necessary if we were to obtain accurate and complete information.

Our study families, which were selected randomly from the 365 families of the village, were divided into three groups of about 60 families each. Each family was to be interviewed at three monthly intervals. The first two days of each month were spent updating our map of the available water sources in the vicinity of the families who were to be interviewed that month.

*Panipur is a fictitious name meaning "place of water".

This was necessary because of the pronounced seasonal changes in the hydrology of the area. Each water source was given a code number and brief descriptions of the quality of the ghat and the water quality were recorded. Over the next two days the head female of each study family was asked which sources of water the family used at that time for each domestic purpose. Using the village map, the water use patterns of the family and its neighbours, and our knowledge of the village, we designated a number of sources - usually three or four - as "accessible" to the family. These sources always included all sources used by the family at that time.

Since the questionnaire was an important tool in this study we describe it in some detail. Before going to the field the interviewer, say Manisha, would record the date, the census numbers of the families to be interviewed, the name of the head male and female and the sources which the head female had said the family used at that time. She would also record the other sources which we considered to be "accessible" to this family. In the field Manisha would ask the woman again which sources she used for collecting drinking and cooking water, where she washed utensils and clothes, and where the different family members bathed. If there were any discrepancies between these answers and the information obtained earlier these were resolved. The distance of each source from the house was recorded.

Information was then collected on which water-related tasks were performed at home and which were done at the water source. The number, type and size of the kolshis* used for carrying water for drinking, cooking and other uses were recorded. The number of times each kolshi was filled with water over the last 24 hours was recorded as was the name of the person who carried the water, and the time of day when the water was carried. A brief set of questions was asked concerning the source of ablution water for different family members.

The heart of the questionnaire, and the part which was most difficult to develop, is the section designed to furnish information on the user's perceptions of the characteristics of each of the accessible sources. For each accessible source two pages of questions, as shown of Fig. 2, were asked.

Accessible water source (number and type): *101-b (tank)*	
(Left hand page)	(Right hand page)
1. Do you think this is a good source of drinking water? Yes__ No ✓. Why? *The tank is far from our house. There is rotting water hyacinth in the water so it does not taste good.*	1. ✓ distance. For any purpose, does distance affect your use of this source?
⋮	2.__ Colour. For any purpose, does colour of this water affect your use of this source? *The water is red so it is unsuitable for drinking, cooking and washing clothes.*
	⋮
8. Do you think this is a good source for mens bathing? Yes__ No ✓. Why? *My husband bathes here. The place is good because the water is deep, but is owned by others and so there are frequent quarrels.*	10. ✓ quarrels or friendship. For any purposes do quarrels or good relationships affect your use of this source?

Fig. 2. The questions on perceptions of accessible water sources.

Using the "left hand page" questions, we asked the user for her perceptions of that particular source for each of the domestic uses and recorded her answers in full (in Bengali). If she mentioned, for example, that the source was far (or close) then the question regarding "distance" on the "right hand page" was checked off. After the "left hand page" was completed, those "right hand page" questions which had not been checked off - there were usually one or two of these - were asked. We thus obtained perceptions regarding all of the factors - distance, colour, odour, taste, dirt, privacy, depth (or difficulty of pumping if the source was a tubewell), quality of ghat, and quarrels or friendship - which our earlier trials had suggested affected the attractiveness of a particular water source.

For each of the accessible sources a pair of pages were filled out. On a few occasions the respondents were not familiar with a source which we asked them about. These sources were

* A kolshi is a narrow-mouthed water carriage and storage vessel, usually made of pottery.

dropped from the list for that particular family. The questionnaire was concluded by asking whether any family members had had diarrhoea over the last 3 days and whether any were suffering from scabies.

Each completed questionnaire was translated into English. In the first half of the study when this was done by John in consultation with Manisha and Shahana this led to informative discussions of what we were learning. In the latter part of the study, primarily due to John's commitment to another study in the village, we usually relied on others to translate and check the forms. Consequently we had fewer of these very useful discussions and our joint understanding of the situation as well as the quality of our data probably deteriorated slightly.

Our standard procedure was to collect all information from adult women in each family, since it is they who are responsible for all domestic work. Since there were legitimate questions as to whether adult males and children have similar perceptions of their water sources, we also interviewed a sample of men and children. We found their responses to be almost identical to those of the adult women.

For the quantitative analysis it was necessary to translate the verbal responses into "scores" - 1 if the individual's perception of the factor was "unfavourable", 2 if "ambivalent" and 3 if "favourable". Since this is obviously a risky procedure we cross-checked our assessments by asking the respondents another set of questions during our third 3-monthly round. For each accessible source they were asked whether they considered each factor to be "unfavourable, neutral or favourable". These responses were subsequently checked against the scores which we assigned on the basis of the verbal answers. There was close agreement, suggesting that our informal procedure for assigning scores to verbal answers was satisfactory.

We emphasize that we did not, and do not, see this short-hand method as a substitute for the more laborious verbal method incorporated into the main questionnaire. Throughout the study we placed a high premium on collecting information which did not fit into our structured scheme. We found that the verbal method encouraged the villagers to tell all that they thought about water. The short-hand method never elicited similar interesting responses.

WATER USE IN THE "CHOLERA SEASON"* BETWEEN NOVEMBER AND JANUARY

Due to the premature termination of the study we do not have land ownership data for all study families. The only available measure of economic status is the square foot of living area per capita. On this basis the population was stratified into a "rich" (more than 60 square feet per capita), a "medium" and a "poor" (less than 40 square feet per capita) group, containing respectively 54, 49 and 40 families. For each group the estimation algorithm was run three times.

In the first run all independent variables were included with the exponents of the characteristics specified by random numbers. The "% correct pair-wise comparisons" were computed for 200 parameter vectors. The optimal parameter vectors appear to be unstable for all groups and for all uses. An example of this instability is given on Table 1, where the four best predictor vectors for the drinking water patterns of the poor group are listed.

Table 1. Parameter values for the four best predictor vectors: The choice of drinking water sources by the poor

Distance	Colour	Odour	Taste	Dirt	Purdah	Quarrels	Depth	Ghat
0.179	0.000	0.071	0.321	0.107	0.107	0.179	0.000	0.036
0.146	0.146	0.171	0.122	0.049	0.049	0.146	0.024	0.049
0.158	0.018	0.140	0.158	0.123	0.123	0.140	0.070	0.070
0.026	0.237	0.211	0.211	0.079	0.079	0.211	0.000	0.000

In a standard statistical model this instability would be manifested in the form of high standard errors on the parameter estimates. The instability stems from two causes, namely the inclusion of independent variables with little explanatory power and multicollinearity among the independent variables. We return to these problems later in this paper.

Examination of the results of these random explorations of the complete sample space is nevertheless, revealing. It is clear that water uses divide into two sets of uses: the parameter vectors which give good predictions for drinking water give poor predictions for all other uses, while the parameter vectors which predict any of the "non-drinking" uses accurately predict all other non-drinking uses well but drinking water use poorly. This dichotomy is clear in all subsequent analyses. Including, as is done in these runs of the

* As has been the pattern since El Tor replaced Classical cholera in Bangladesh, cholera in 1977 occurred a couple of months earlier than this "traditional" time.

model, all of the independent variables, we find that the "% of correct predictions" is highest for drinking water and lowest for men's bathing with clothe washing, utensil washing, cooking, women's bathing, girl's bathing and boy's bathing (in that order) having intermediate "predictability". The "best" predictor of drinking water gets 89% of the eligible pair-wise comparisons correct, while the comparable figure for men's bathing is 80%. (On the basis of dominance alone we can specify the water use patterns for 28% of the study families only.) These maximum values of the "% of correct predictions" provide a standard against which to gauge the satisfactoriness of subsequent predictions in which the number of independent variables is limited.

In the second run of the estimation algorithm all characteristics were included with parameter values of 0.0, 0.5 or 1.0. This "screening model" was used to decide which variables should be used in specifying the dimensions of a smaller independent-variable sample space for subsequent, more thorough, exploration. As examples of what we learn and how we use the results of these apparently over-restricted runs we present the outcomes when each characteristic is used alone as a predictor of drinking water use (Fig. 3) and the predictive value of distance alone on each type of water use (Fig. 4).

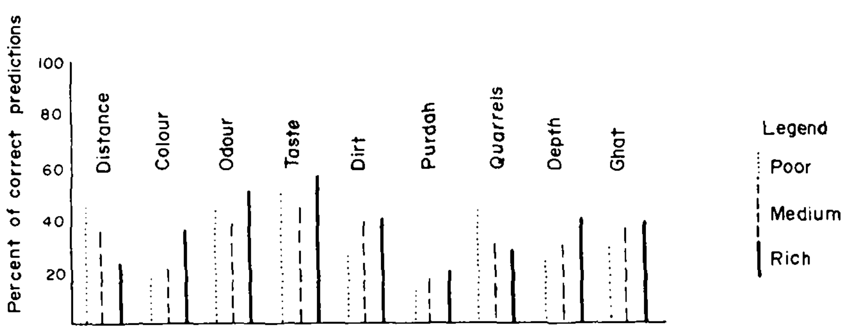

Fig. 3. Single characteristics as predictors.

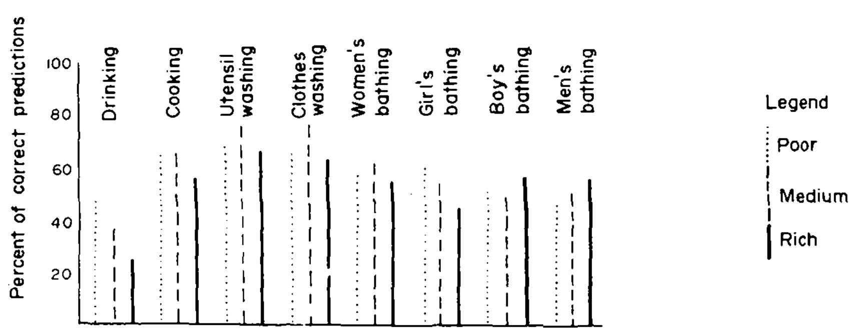

Fig. 4. The predictive value of distance alone.

From Fig. 3 we see: that distance and quarrels are powerful determinants for the poor but substantially less powerful for the rich; that odour and taste are the most important water quality variables; that all quality factors - colour, odour, taste, dirt, depth, purdah and ghat quality - are more powerful predictors for the rich than for the poor. From Fig. 4 we see: that distance is more important for all other uses than it is for drinking; that distance is a stronger determinant for poor than rich for all uses other than boy's and men's bathing; that distance is most powerful a predictor for cooking, utensil washing and clothes washing, that is, for the women's non-drinking water tasks. These results also show that single predictors are substantially inferior to predictors which incorporate two independent variables and that these, in turn, have substantially less explanatory power than models which include all nine of the independent variables.

Using the results of these runs in conjunction with the more intuitive knowledge acquired from both our field work and our examinations of the completed questionnaires, we are able to choose the most important independent variables for each purpose for further analysis. For example, from the field work we know that odour and taste are highly correlated and therefore eliminate one of them (somewhat arbitrarily, odour) despite its high predictive value; from our field work we though that purdah may be a significant determinant for uses like women's bathing, but our analysis shows that this is not the case for any purpose and it is therefore eliminated from further consideration.

The choice of the prescribed sets of independent variables proves to be surprisingly unambiguous. For drinking, it is clear that distance, quarrels and taste are important determinants; for all other purposes distance, quarrels and depth are unambiguously the variables which demand further joint exploration.

Using these limited sets of independent variables the algorithm was run again with the sample space systematically covered for parameter values of 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0. The sensitivity of the results to the exclusion of the excluded variables was tested in two ways: by comparing the "% of correct predictions" with the highest "% of correct predictions" in the first run of the algorithm (with all independent variables and random sampling); and by adding excluded variables and seeing whether they entered the optimal parameter vector. Both of these tests confirmed the validity of the method used for screening the independent variables.

The fact that only 3 independent variables entered any of our final prediction equations and that the parameters sum to unity meant that iso-prediction lines could be plotted on two-dimensional graphs and optimal parameter values chosen without recourse to further computer analysis. A typical response surface is presented on Fig. 5 and the optimal parameter values for all uses for each economic group presented on Table 2.

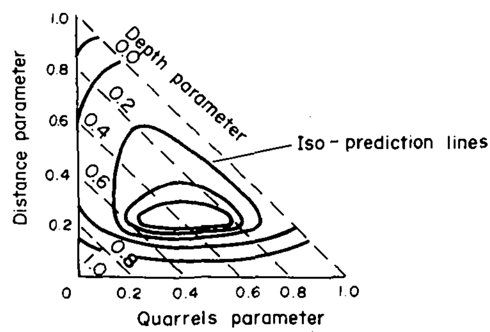

Fig. 5. Predicting the source of cooking water used by poor families.

Table 2. The optimal parameters for all groups for all purposes

	Poor			Medium			Rich		
	Taste	Distance	Quarrels	Taste	Distance	Quarrels	Taste	Distance	Quarrels
Drinking	0.55	0.21	0.24	0.62	0.20	0.18	0.66	0.14	0.20
	Depth	Distance	Quarrels	Depth	Distance	Quarrels	Depth	Distance	Quarrels
Cooking	0.38	0.22	0.40	0.20	0.28	0.52	0.29	0.25	0.46
Utensil Washing	0.39	0.21	0.40	0.10	0.60	0.30	0.31	0.25	0.44
Clothes Washing	0.36	0.22	0.42	0.11	0.63	0.26	0.25	0.25	0.50
Women's Bathing	0.39	0.21	0.40	0.30	0.30	0.40	0.27	0.23	0.50
Girl's Bathing	0.26	0.24	0.50	0.32	0.22	0.46	0.26	0.24	0.50
Boy's Bathing	0.30	0.22	0.48	0.38	0.26	0.36	0.22	0.25	0.53
Men's Bathing	0.26	0.28	0.46	0.22	0.22	0.56	0.28	0.22	0.50

If this analysis were performed on a data set with more conventional properties, the best estimates in Table 2 would be accompanied by a standard error of estimate. We convey information on the sensitivity of the response surface to different parameter vectors by specifying that the parameters associated with each of the included independent variables enter the equation with a value of at least 0.2 (the smallest positive value in our sampling frame) and comparing the lowest "% of correct predictions" in the resulting feasible region with the "% of correct predictions" at the optimal parameter values. These comparisons (listed on Table 3) suggest that for all uses other than drinking the results are quite insensitive to the particular parameter values. That is, as long as each of the included variables has an exponent of 0.2 or greater than the performance of the predictor is satisfactory. Only for drinking (and particularly for higher economic groups) do we need a more sophistocated specification of the preference function.

Table 3. The lowest % correct predictions in the "feasible region"

	Poor	Medium	Rich
Drinking	80%	74%	58%
Cooking	93%	86%	95%
Utensil Washing	98%	83%	95%
Clothes Washing	98%	84%	93%
Women's bathing	95%	94%	92%
Girls' bathing	94%	93%	86%
Boys' bathing	90%	93%	90%
Men's bathing	92%	93%	93%

The ratios of different parameters from the Cobb-Douglas function specify the marginal rates of substitution (MRS) between characteristics. On Fig. 6 we plot the values of the MRS of taste for distance and the MRS of taste for quarrels for the optimal parameter vector and for those parameter vectors which give 90% or more of the maximum number of correct pair-wise comparisons. Recalling that the MRS of taste for distance represents the additional "amount of taste" necessary to maintain utility when a small unit increase is made in the distance of the source from the user, we note that the MRS of distance for taste and the MRS of quarrels for taste both decrease as families become more wealthy. This means that if rich and poor families have the same water sources available to them, the poor families tend to choose sources which are of worse quality but which are closer and at which quarrels are less likely. These results accord with the less precise impressions conveyed by Fig. 3.

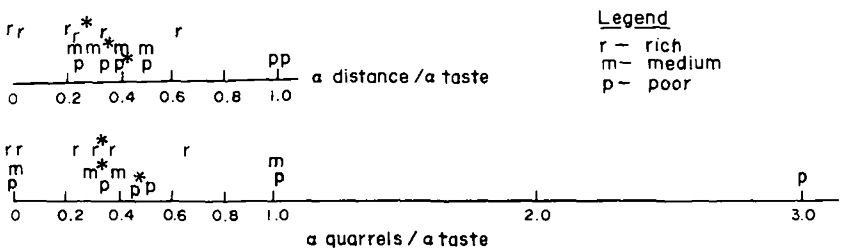

Fig 6. The marginal rates of substitution of distance for taste and quarrels for taste for optimal and near-optimal parameter vectors.

The purpose of our analysis is to assist planners in designing better programs for domestic water supply in rural areas of Bangladesh. In a later section of this paper we outline what further analysis of these data we are undertaking to fulfil this aim. Here we give an example of how this analysis equips us to predict the response of a particular family to different water supply programs.

Mosharaf Hossain is the head of a poor Muslim family of five people. All members of the family bathe at river ghat 200 which is several hundred yards from their house. Mosharaf's wife Nessa draws their drinking water from this ghat but brings cooking water from tank 67 which is about 100 yards away. She also washes clothes and utensils at this tank. Tubewell I, which is as far away as the river, is not used by the family but is perceived to be an alternative water source. They have no quarrels over the use of any of the sources - they are joint owners of the tank, the river-bank is a public place and the tubewell was installed by the government - and therefore the remaining characteristics relevant for drinking (viz. distance and taste) can be presented in a two-dimensional sketch. On Fig. 7 the available water sources and the preference function for this family (keeping "quarrels" constant) are plotted. Figure 7 shows that the choice exercised by the family in choosing a drinking water source is consistent with the preference function of their group.

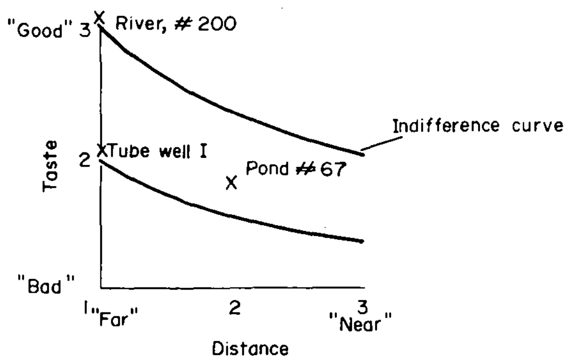

Fig. 7. The choice of drinking water by poor family (123).

Epidemiological studies (9) have shown that cholera rates are much lower in families who use tank water (pond water) for all purposes than in families where river water is used. In the present example there are two possibilities for getting the family to drink tank water. If there were a new tank close to the house and if this tank contained water of a quality similar to that in the existing tank, then the new tank would be about as attractive a water source for drinking as the river. Alternatively, if the taste of the tank water could be improved by some means, perhaps by removing water weeds or deepening the tank, then the family may use the tank and not the river.

The results are incomplete and analysis of the data will continue, but even at this early stage there are some policy implications. For example one of us has suggested (3) that a program for constructing ghats at ponds may induce beneficial changes in water use habits. Our formal analysis suggests that such a program would have little effect on water use patterns.

Some directions for future analysis

Further elaboration of water use choices along the lines developed in this paper will continue. More detailed descriptive material and an analysis of the determinants of the quantity of water used by study families will be presented.

Some outstanding problems in the present analysis.

1. The implications of using ordinal independent variables in a framework which is based on cardinal properties of the independent variables has to be investigated further.
2. A preliminary analysis of the inter-family consistency shows that the requirements for "subjective consistency" is not met adequately. (The standard error for taste is 0.77, for depth 0.69 and for ghat quality 0.49, for example). The implications of this violation will be explored further by repeating the analysis using the subjective evaluations of the investigators (which were recorded) and perhaps by using the modal valuations of the villagers.
3. As our analysis progressed it was clear that tubewells needed to be treated in a special way. For example the most frequent reason why people do not use tubewell water for cooking is that the iron content of the tubewell water is high and consequently rice turns black when cooked in this water. Our present analysis incorrectly suggests that no water quality variables enter the decision regarding cooking water. We plan to correct this by including a dummy variable for tubewells in further analysis.
4. Epidemiological studies (3) suggest that a precise understanding of casual water uses - a mouthful of water from a pond on the way home from school, for instance - is essential in elucidating the epidemiology of diseases like cholera which are primarily water-borne. Our study says nothing of these casual uses.

Beyond these technical questions our experience has caused us to question the validity of the neo-classical theoretical approach which we have used. Our experience has also given rise to serious reservations about the way in which we conducted this study: The project was of no direct benefit to the community in which we worked; the people were not involved in the formulation of the problem, the execution of the study or the interpretation of the data; and the research process did not assist the villagers in clarifying and de-mystifying social reality. We believe that this work may be useful in clarifying existing perceptions of reality but see that in the future we have to transcend rather than repeat this approach.

Acknowledgements

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FIELD STUDIES ON WATER SANITATION AND HEALTH EDUCATION IN RELATION TO HEALTH STATUS IN CENTRAL AMERICA

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The "Food Wastage/Sanitation Cost-Benefit Methodology Project" was conceived as one type of policy research. Policy research is usually predicated on the use of the skills and methods of diverse disciplines to provide insight into the multiple variables and linkages that characterize real-world problems and solutions. Under ideal conditions, policy research should offer the techniques that can make the assumptions explicit and the tests for establishing the validity of the assumptions. The Agency for International Development sponsored this policy research project on the relationship of water-related diseases and health benefits. The study was conducted in rural lowland Guatemala by the University of North Carolina at Chapel Hill and the Institute of Nutrition of Central America and Panama in Guatemala.

A conceptual scheme for pathways and linkages between water supply improvement, health behavior and economic change is shown in Fig. 1. The scheme is somewhat illusionary in terms of measurement potential, but it is helpful in understanding the hypotheses for the study. These hypotheses were:

A. A population living under unsanitary conditions will have an increased prevalence of diarrheal morbidity. Improvements in sanitation (with emphasis on water supply) will diminish diarrheal morbidity.

This hypothesis was tested through the provision of a piped water supply to each house in the experimental village. At a later stage of the project, educational and community development programs were introduced to encourage the sanitation-related use of water and to promote improved sanitation behavior patterns. The objective of these inputs was to improve water quality, availability, convenience and utilization by the village population. A control village, where no inputs were introduced, was used for comparison. Florida Aceituno was the control village and Guanagazapa was the test village.

B. A population with a high prevalence of diarrheal morbidity may waste increased amounts of food as compared to a population with a lower prevalence of diarrheal morbidity. The food wastage is a consequence of repeated incidents of diarrheal disease which eventually tramatize the intestinal tract and results in malabsorption. There is reduced absorption during the diarrheal incident, however, this acute loss is considered separately from the losses due to chronic malabsorption.

Food ingested and then lost through intestinal malabsorption may constitute an economic loss and may be assessed in terms of wasted energy, non-utilized nutrients, direct food costs and losses in agricultural production.

The verification of these hypotheses required the assessment of inter-relationships and the measurement of a large number of variables. These variables included health status, dietary and nutritional status, anthropometry, intestinal efficiency, health behavior and other biomedical, economic, social and demographic characteristics of the village populations.

Policy research, because of its requirement for application to existing problem situations, is tied to the perception of these problem situations at a given time. Kuhn (1) proposes that scientific research at any given period is carried on within an instrumental and conceptual framework accepted by an entire scientific community. The resultant mode of scientific inquiry then leads to a point where current problems cannot be resolved within the accepted framework. The scientific community then proceeds to a new conceptual structure or paradigm to govern the search for new facts.

It may be useful to explore the changes in the "paradigm" for water supply/health benefits research from the 1960's to the present. The victories for disease prevention in the industrial countries based on treated water supplies led to the conviction that this pattern

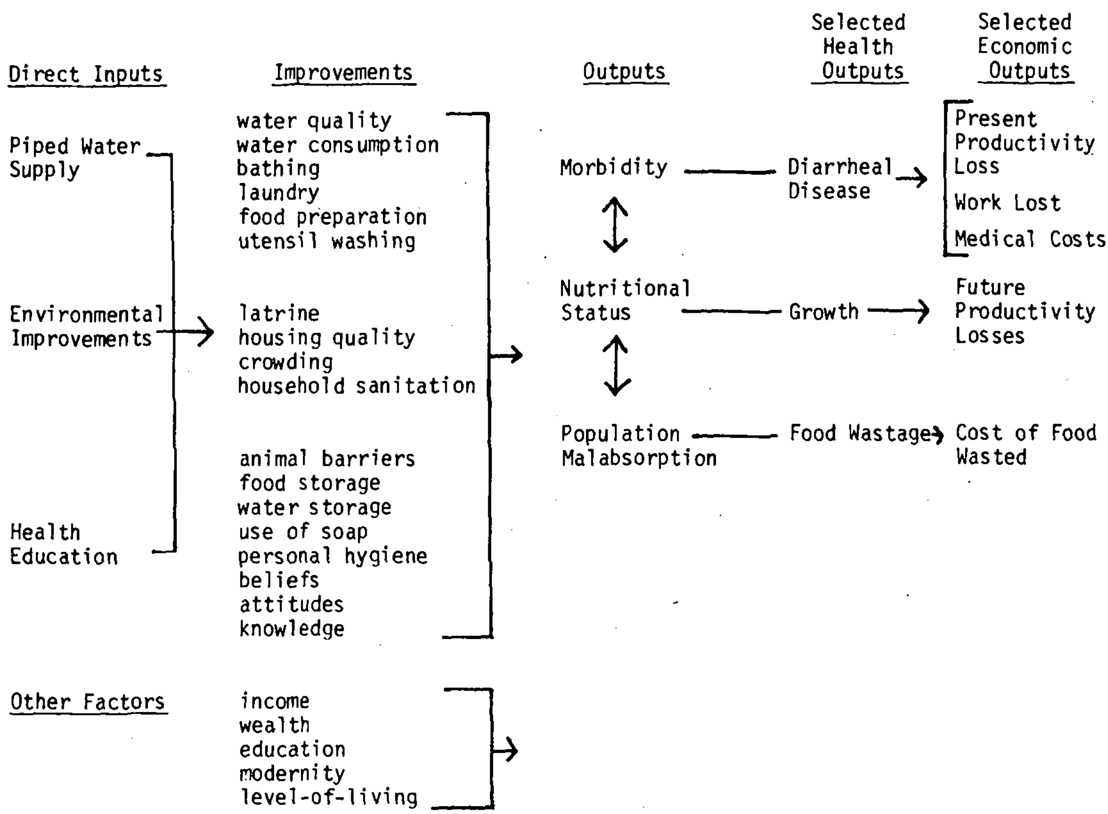

FIG. 1. Conceptual Scheme for Linkage Between Environmental Improvement, Health and Economic Change.

could be duplicated in the less developed countires through the introduction of piped water supplies of high quality. This view is still expressed with confidence and is historically demonstrable for the industrialized countries, however the demonstration must include all the other changes in housing, nutrition, and economics that also occurred in the industrialized countries during the same period. In any event, the experimental verification of the water supply/disease link has not been clearly demonstrated for the warm, poor, rural areas of the world. Confidence in establishing the project-impact link is lessened by difficulties in establishing the etiology of diarrheal disease and other "fuzzy" variables in the proposed equation.

The "classic" water supply project-impact was further questioned on the basis of economic justification for water supply projects. The UNC/INCAP project is a lineal discendent of several project-impact studies initiated by the economists' request for criteria for allocation of resources between water supplies and other sectors. The public health virtue of water supply investment was not considered sufficient for decision-making and investments in water supply were to be considered in the framework of economic analysis. During the late 1960's there were already doubts appearing in the literature about the feasibility of evaluating health, social or productivity outputs in terms of economic units. The emphasis on "food wastage" attributed to a diminished intestinal absorptive capacity seemed to offer a readily measurable system of inputs and outputs, definable in terms of energy and chemical constituents, which were calculable in terms of economic units.

RESULTS OF THE STUDY ON SANITATION, HEALTH EDUCATION AND MORBIDITY

The results of the study are presented with reference to individual variables and their relationships.

Demography

The objectives of the demography studies were to establish the comparability of the test and control villages. The villages were comparable in respect to their population sizes, age and sex distribution and family structure. Both villages showed a high degree of mobility. Villagers moved because of seasonal occupational requirements, however, there was also an extensive long term in and out migration. This finding is of some consequence since the usual perception of rural village populations is that they are static. A highly mobile population raises additional questions of time and concentration in respect to inputs. How long and for which periods were migrants exposed to the "beneficial" inputs; and obversely, what was the exposure outside of the "improved" village?

The population of each village in August 1976 was 1097 in Guanagazapa and 1006 in Florida. The populations under study were too small for any significance to be attached to the crude birth and death rates, infant mortality or vital index rates. However, the villages were comparable for demographic and other vital statistics and for morbidity and mortality. There were differences in family income, employment opportunities and land ownership.

An advanced technology water treatment and distribution system was installed to supply a rural village in the lowlands of Guatemala. This system consisted of a protected source (spring), chlorination facilities, adequate storage and water mains with faucets in the yards of 164 homes. It was designed for health and environmental appropriateness but not for functional appropriateness as defined by Pacey (2). This system provided high quality water (chemical and bacteriological), of unlimited quantity (but at a small cost), which was convenient and did not adversely affect the environment (breeding of vectors). However, it will be difficult for this village to adequately maintain this system without outside assistance in the future.

The primary purpose for installing this water system was to study the relationship of water to health, more specifically, to diarrheal morbidity and intestinal malabsorption. Functional appropriateness and cost were secondary considerations. The design and operation of the system met all the criteria for interrupting and/or reducing water-borne diseases (typhoid, cholera, amoebic and bacillary dysentery, gastroenteritis) and water-washed diseases (skin infections, otitis, conjunctivitis).

During the three year period after the installation of the water system, September 1973 to August 1976, the total morbidity of the population in this village was intensively investigated through monthly household surveys and a record of visits to the health post. Total as well as selected causes of morbidity were compared over seven periods of six-months each. The six-month periods were chosen to coincide with the rainy and dry seasons. Morbidity from all causes was not significantly different in the two villages, although there was more total illness in the control village during the last eighteen months of the study. No significant changes in morbidity were observed in the test village (Table I).

TABLE I. Selected Annual Morbidity Rates in Guanagazapa

Disease	Incidence Per 1000 Population* 1973	1976
Total morbidity	123	124
Diarrhea	39.7	39.5
Respiratory disease	53.7	52.7
Skin infections	12.5	9.1
Conjunctivitis & Otitis	3.5	4.3

*Incidence computed on two-weeks recall experience in each month. The true incidence will be higher than this for an entire month.

Diarrhea, respiratory disease, skin infections, otitis and conjunctivitis were analyzed by age, sex, season (dry and rainy), water usage, and family size. Monthly family morbidity rates were preponderantly zero. Only family size was correlated with any of these diseases and large families (more than five persons) had a disproportionately high morbidity rate. No attempt was made to isolate the agent(s) of diarrhea, thus the prevalence of salmonella and shigella in the village population could not be estimated. Stool cultures were collected on a small sample of the population in 1973, 1974 and 1975. Approximately 5% of the cultures were positive for salmonella and/or shigella. Children who were between one and two years old had more diarrheal disease than any other age group in the study. Children who were seven years of age and younger accounted for more than 80% of all diarrheal morbidity.

Diarrheal illness in the adult was low (<20/1000/fortnight) and was probably under-reported, especially for mild episodes. However, on the basis of study data, it can be stated that diarrheal illness was not a significant cause of disability in these adult populations. The relationship between season and illness is ambiguous when observed on a continuum. However, the rates for diarrheal morbidity were higher for the rainy seasons ($p < .05$) when differences in sanitation and family size were controlled for.

A review of the data on diarrheal morbidity leads to the conclusion that the introduction of water and the attempts to improve sanitation did not significantly affect diarrheal disease. Such a conclusion should not go unquestioned nor unchallenged. However, this conclusion is supported by the study data and criticism must be directed to study methods.

Improvements in Water Supply and Sanitation

Diarrheal morbidity leaves something to be desired as a criteria for the outcome of environmental improvements, however, it is "the only game in town." On the other side of the equation, water supply cannot be considered as a single point of reference but as a part of a delivery chain. In fact, this chain for the delivery of water of high quality was difficult to maintain.

It was apparent that "final-use" bacteriological water quality was inferior to source quality in both of the study villages. Even though 97% of the water samples collected from the distribution system in Guanagazapa were free of coliforms, only 65% of the samples collected from home water containers were satisfactory. Water samples from shallow wells in Florida Aceituno were contaminated 52% of the time while home water containers were contaminated 59% of the time. These results have implications for future studies which attempt to correlate water quality with morbidity and they also indicate the increased risk to a population from contaminated water containers. Assuming that final-use quality (consumption, bathing, handwashing, dishwashing) is the same as source quality (distribution system or well) could lead to erroneous conclusions.

There were some expected results. The installation of a convenient and plentiful water supply system did promote water usage. When the study concluded, the families in the test village were using two and a half times the water per person (69 liters/person/day) than were the residents of the control village. How this additional water usage translates into maintaining a sanitary home environment is discussed later. The maintenance of a clean home environment was difficult under the conditions that existed in the villages and the homes. Water supply is not an isolated change and some of the problems in assuring desirable outcomes from water inputs may result if sanitation improvements and the modification of health behavior are neglected.

relation with other diseases

Home Sanitation

Surveys were made throughout the period of the study to evaluate sanitary conditions in the home. It was assumed that the diarrheal diseases which were being recorded in the morbidity survey were mainly water-washed infections.

House construction and sixteen variables, indicative of sanitary behavior, were selected and monitored as indices of environmental quality. House construction and maintenance were surveyed annually and the sixteen environmental variables were monitored monthly. This array of variables is not exhaustive since it did not include information on food preparation practices, dishwashing, handwashing, infant feeding, the presence of insect vectors, and environmental quality outside the home (workplace, school, etc.). These latter variables are difficult and costly to quantify.

Crowding in the home is often felt to contribute to morbidity. Continuous measurements of total home crowding and number of persons occupying each bedroom were made. The mean and standard deviation of respiratory illness and diarrheal disease rates were plotted against crowding in bedrooms and for total home area for both the villages. Morbidity rates did not increase with more persons per bedroom or more persons per household area.

Health Education

The provision of a piped water supply to the test village was supplemented by a program for community health development. The objective of the health education program was to reduce fecal contamination in the home and surrounding areas and to promote the use of the piped water supply. In specific terms, this component of the study was directed to:

1. persuading the villagers to reduce human and fecal wastes in the home and the surrounding areas.

2. installing barriers to keep domestic animals out of the kitchen.

3. promoting the installation and sanitary maintenance of latrines.

4. improving food and water handling.

5. increasing water consumption for hygienic purposes; particularly for home and kitchen cleanliness, food preparation, and handwashing.

The community health development approach used in this study was found to be practical and useful, particularly for small communities. Since the comprehensive health education program was in effect for only one year, it is difficult to evaluate the potential impact which it might have had if it had been continued.

A health education scale was used to measure changes in attitude and perception after the initiation of the health education program. It was concluded that the program did influence the attitudes of the population relating to sanitation changes. Whether these changes in attitude are permanent is not known.

Several interesting observations were documented which have implications for future studies. Even with increased water availability and health education, the residents of Guanagazapa did not bathe more frequently nor did they wear clean clothing more often. However, they did report washing their hands more frequently. Handwashing and bathing practices were evaluated by questioning the female head-of-household and the validity of this data cannot be confirmed.

Improvement was documented in five environmental categories: removal of human and animal fecal matter from the home environment, protection of stored water, cleanliness of the yard, installation of latrines, and the exclusion of domestic animals from the kitchen and dining areas. These improvements, however, did not result in a decline in diarrheal or other morbidity during the study period.

Level-of-Living Indexes

A modification of Belcher's level-of-living index was used to evaluate socio-economic and socio-cultural variables and their relationship to morbidity. The Belcher scale contains fourteen household functions: construction of walls, floor, roof; water storage; water source; lighting; food preservation; eating utensils; sewage disposal; type of transportation; cooking facilities; floor cleaning equipment; and dishwashing facilities. These items are based on household functions and scaled according to the technological means employed in the accomplishment of the household function. Many of the functions represent sanitation facilities in the household.

The conclusion, based on this analysis, was that morbidity is associated with level-of-living [environmental quality as defined by Belcher (3)] but the association is weak and the level-of-living index is not a good predictor of the morbidity experience of a household.

Households were also characterized according to relative wealth status, occupational status of the head of the family, and levels of education and literacy of family members. Households were also described in terms of attitudinal modernity, cosmopoliteness, religion, and family size. Only family size was shown to be correlated with morbidity.

Observations

The data for census, morbidity and sanitation were examined extensively through the use of general linear and categorical models in order to determine if there were significant relationships between the four selected types of morbidity (diarrhea, respiratory diseases, skin infections and other infectious diseases) and water and sanitation. The data were adjusted for age, sex, size of family, season and village. In this way, sanitation effects on morbidity could be estimated without being influenced by these other factors, which also influence morbidity.

The results of these comprehensive analyses are disappointing in respect to policy research but do emphasize that answers to the water/sanitation/health question are still not resolvable through field studies. The variables which were "controlled for" did have discernable effects on morbidity. In contrast, there was no single sanitation variable which had a measurable effect on the morbidity rate. This statement is striking since the results also show no significant relationship between water supply and the morbidity rates. Of course, the measurements were taken over a study period of less than four years; a relatively short period for change to occur.

It is not reasonable to conclude from these results that there is no association between sanitation and morbidity. After all, diarrheal disease and death, especially in children, are clearly a problem in the Less Developed Countries. This issue will only be resolvable when reliable and pertinent measurement instruments are available.

We feel that future studies into the water/health relationship must be able to measure and deal with these multiple variables and to separate out the significant from the superfluous.

SUMMARY OF RESULTS OF THE STUDY FOR FOOD WASTAGE

An important objective of the study was to design and test a methodology through which the relationship between the improved water supply and food wastage could be examined and described in economic terms. The linkages between water supply/diarrheal disease/malabsorption were not known at the initiation of the study.

The choice of intestinal malabsorption as a measure of the health benefits of water supply was based on the assumption that it would provide a convenient economic measure of the benefits in terms of the reduced costs of food wastage. However, there were major difficulties in dealing with intestinal malabsorption as a variable in this study. This syndrome had been previously investigated only in the clinical setting. This study dealt with this condition on a population basis using community samples rather than individuals who were in a clinic setting. Further the use of accepted clinical standards for defining malabsorption was shown to be untenable for population studies and the concept of relative malabsorption for a given population was developed.

The role of malabsorption in diarrheal disease has been of interest in the last few years. Rosenberg, Solomons and Levin (4) have reviewed the combined effects of nutrition and infection on the diarrheal diseases. The need for field studies on intestinal malabsorption was reinforced by their observation that,

"In some populations, 20-25 percent of the presumed healthy adult population demonstrated some defect in intestinal absorption when tested and although there are far fewer studies in children, there is growing evidence that tropical enteropathy is seen in the first few years of life. The true quantitative implications of this phenomenon in terms of nutrient and food wastage by malabsorption are still uncertain. However, the possibility that a large proportion of the population in less developed countries, who are already on marginal nutrient intake, are failing to derive nutritional benefit from that intake because of a chronic malabsorption problem underscores the difficulty of projecting nutrient requirements based on research under sheltered ward conditions in developed countries."

Malabsorption

A basic objective of the study was to develop a methodology for assessing the extent of malabsorption in the village populations. This objective was based assessing long term losses in the adult and did not include food wastage due to diarrheal episodes. The adult malabsorption syndrome may result from a continued trauma to the intestinal tract as a consequence of multiple bouts of diarrheal disease, particularly during the early lifetime of the individual. Thus, measurements were designed to determine "subtle" rather than overt clinical changes. The subtle changes were then compared with a "normal" value which was derived from the study of a similar population who were free from repeated diarrheal disease for a sufficient period to allow for improvement in gastrointestinal tract efficiency.

The cycle of studies involved:

1. establishment of the absorption test methods, including the selection of the rural metabolic diet and metabolic ward procedures, laboratory procedures and the choice of the longitudinal sample.

2. determining the digestibility of the diet.

3. conducting the intestinal absorption study (balance studies).

4. food cost. Surveys were done in each month of the study to determine the cost of foods most commonly eaten by the village populations. The price information was based on the local markets in the communities.

The balance studies were performed over four years (1973-76) and participants were chosen from a pool (longitudinal sample) of adult males (15 years and older). Sixty participants from each village (120 a year) were subjected to the balance tests once each year for a period of at least six days. The tests were performed in a specially designed facility located midway between the two villages. The longitudinal sample was relatively stable in that 45 men from Guanagazapa and 37 men from Florida Aceituno particpated in all four years of the study. Replacements for dropouts came from an original pool of 97 men from Guanagazapa and 98 men from Florida. The data from these studies is voluminous (40,000 laboratory analyses alone) and cannot be dealt with in any detail in this paper.

The calculation of population malabsorption was based on the differences between the two population means (reference and village). The amount of calories, nitrogen, and fat lost in the stools was calculated from the difference between the average percentage absorption of individuals in the village longitudinal sample and the average percentage absorption of the reference group of soldiers. The extent of food wastage was assumed to be the difference between the stool loss of the average villager and an average soldier from the reference group. This average percentage loss (per person per day) was then applied to the daily food intake to derive the amount of food lost (per person per day).

The meaning of a "reference population" needs to be explained. The extent of malabsorption in a given population must be defined relative to a reference point. The reference population for this study was a group of soldiers who were born in the Pacific lowlands of Guatemala and who had been living during the previous 18 to 24 months in a military installation near Guatemala City. The level of sanitation in the military barrack was better and the diet quantitatively superior to that available to the rural population in the test and control villages. Therefore, this population was chosen and the absorptive capacity of a sample of this reference poulation was measured Malabsorption in the test and control villages was defined relative to this reference population. This reference population is an appropriate choice because they represent an absorption efficiency associated with a level of sanitation and nutrition which might be aspired to by the rural village populations.

The project investigators agree that the study data do not indicate that there was a real change in intestinal efficiency in Guanagazapa that could be interpreted as significant for the economic calculation of food wastage. There are a number of reasons:

1. The four year period was not sufficient time for improvement to occur.

2. There was significant and unpredictable variability within the same individualfrom year to year.

3. This study has expanded the understanding of some of the biological linkages between diarrheal morbidity and malabsorption, however, the primary linkages were not clarified.

Hypothesis A. Repeated diarrheal disease in childhood leads to enteropathy which in turn results in chronic population malabsorption and food wastage. There was not enough time to test this hypothesis. All that can be said is that there were no striking decreases in infant and childhood morbidity.

Hypothesis B. The enteropathy discussed in A above is reversible through improved water supply, sanitation and personal hygiene. The length of the intervention was not long, ranging from four years for water supply to one year for hygienic behavior modification. The observed changes in improved intestinal efficiency were in the right direction although there were no significant changes in diarrheal morbidity. The results do not fulfill the needs of policy research in providing a clear basis for planning, and particularly, for resource allocation. There is, however, sufficient reason to believe that the phenomenon of a small food wastage through population malabsorption is real when evaluated by reference to a comparable population living under improved sanitation conditions. In sum, these results do contribute to the scientific understanding of intestinal absorption and food wastage.

IMPLICATIONS FOR FUTURE STUDIES

The results of this study indicate: a) much must still be learned about the water supply/diarrheal disease/malabsorption linkage and b) losses from malabsorptive food wastage in a population does not lead to the loss of large amounts of food. However, scientific research in malabsorption, diarrheal morbidity and health status should be continued so that future policy research will be based on refined methods, information and knowledge. At present, policy research in this area is limited by difficulties in quantifying the economic variables, defining "normality" for food wastage in a population and explaining the biological variability in individuals in respect to malabsorption. Further constraints relate to the measurement of morbidity and sanitation.

The contributions of the study have not been to define the exact quantification of health benefits. The accomplishments have been in the developing and testing of methods, the development of indicators, and in results which provide an information base for further studies in policy and scientific research.

The field study, over the limited period of four years, did not demonstrate that a safe and available water supply leads to a decrease in diarrheal morbidity. This negative finding may be among the most significant of the study. Epidemiologists now have reservations about the usefulness of these field studies because of the difficulties in isolating the numerous variables involved. This study has helped in delineating the operational details of these difficulties and has led to new concepts, strategies, experimental designs and methods which may be used in future studies Limited studies are needed now to refine methods, information and data bases. Also needed are studies to add to the current knowledge of disease etiology and health benefits quantification. These are required before any further large-scale policy research is undertaken.

The complete study has been presented in a report to the United States Agency for International Development in three volumes I Methodology, II Results, III Assessment and Policy Implications.

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DESIGN OF WATER SYSTEMS FOR DEVELOPING COUNTRIES

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Abstract
This project is concerned with design standards for secondary water distribution networks. Based on field studies in the Middle East and Africa, mathematical equations were developed for predicting the length and mean diameter of network piping for given values of system variables. When coupled with local cost data, these equations enable prediction of system costs and hence provide a basis for deciding the spacing of public standposts, minimum network pressure and per capita flow.

INTRODUCTION

Recent estimates suggest that less than 300 million of the two billion people in the developing countries have access to adequate supplies of safe water and to proper sanitation (Ref. 1). Rapid growth of slums and squatter settlements in urban areas of the developing world present an urgent problem. The water and sewer systems of cities, already operating under considerable difficulties, are rarely expanded to meet even the most modest requirements of slum and squatter districts, whose inhabitants therefore resort to polluted water sources or to water purchased from vendors at rates much higher than those charged by the water utility.

One problem in extending water supply to cover these densely-populated and rather unstructured poor districts has been that designers tend to size the distribution networks by 'rule of thumb' methods rather than on the basis of rigorous analyses. The resulting networks are generally oversized and very expensive. Also, many designers are inclined to employ networks with house connections or yard faucets rather than simpler systems with public standposts, which are more affordable.

Recognizing the need for more appropriate water supply technology in developing countries, especially for migrants and the very poor, the World Bank commissioned a study in 1975 of minimum design standards (Note a). With principal emphasis on secondary distribution systems rather than major facilities like supply, transmission and primary networks, the Bank raised such basic questions as: how many persons should be served by each standpost? what is optimal standpost spacing? how much flow should be supplied per capita? what minimum pressure should be maintained in networks? and what is minimum acceptable pipe diameter?

As in the case of all standards, answers to these questions can in principle be obtained by benefit-cost analysis. Consider optimal standpost spacing, for example; it would be necessary on one hand to know the benefits associated with different spacings (they are essentially related to health and convenience), and on the other, information would be needed on costs (construction, operation, wastewater disposal, etc.). The optimal spacing, which maximizes net benefits, is that for which the marginal costs and benefits are equal.

In practice, the likelihood of quantifying the benefits of such things as the spacing of standposts, the amount of water supplied per capita, and minimum network pressure is not good. Consequently, this study focused primarily on costs, with the understanding that if accurate functions were available, they could be used to determine the incremental expense of changing

Note a: The work reported herein represents the views of the authors and not necessarily those of the World Bank, nor does the Bank accept responsibility for its accuracy or completeness.

such things as the per capita flow from, say, 25 liters per capita per day (lcd) to 50 lcd, or average standpost spacing from, say, 100 meters (m) to 60 m. Then it could be left to the user to decide whether his perception of the benefits associated with incremental changes was worth the cost.

The study methodology for developing cost functions comprised the following steps: (1) identify the decision variables (i.e., those items for which standards are sought); (2) select a variety of study regions in cities throughout the world; (3) design secondary systems for the selected regions using different values for the decision variables; (4) determine the quantities of materials and the costs of the alternative designs, and (5) determine the association between costs and decision variables to obtain the desired function.

A different approach for developing cost functions might have been to find areas for which water systems had already been designed, and then to analyze them in light of their stated criteria. Although this approach was considered, it was rejected when trial studies in Latin America indicated that the actual capability of systems did not in fact match the standards nominally used for their design (i.e., that the systems were overdesigned and hence technologically inefficient). Consequently, the former methodology was adopted.

DECISION VARIABLES

The principal decision variables over which the designer of secondary water distribution networks has control include (1) the quantity of water supplied per person, (2) the number of standposts to be employed, and (3) the minimum allowable pressure to be maintained in the system. If the standposts are more or less evenly spaced (as assumed in this study), the number N provided for a given area A is approximately related to the maximum walking distance R for carrying water by the relationship

$$R = 56\sqrt{A/N} \qquad (1)$$

where R, the radius of the circular area served by each standpost, is in m and A is in hectares (ha).

Clearly, the designer has control over numerous additional variables (for example, pipe materials, type of joints and the details of standpost design such as the number of faucets), most of which were either ignored or set to specific values in this study. It was assumed that systems would be continuously under pressure (although this is not true in many developing countries). Fire protection was ignored. In general, branched rather than looped systems were used in order to minimize pipe length, and the shortest possible routes were selected for connecting standposts to the primary distribution mains. The study included several designs that employed private yard or patio faucets instead of public standposts. Because of the need to serve each house with these systems, looped rather than branched layouts were used. Throughout the study, alternative designs for given regions were homogeneous in that a standpost network was never incorporated into a system with yard faucets, nor were two or more standpost spacings used in the same system.

STUDY REGIONS

The principal work in this investigation was done for two squatter areas in the Middle East and one in West Africa. Each of the areas was visited and outline designs prepared in the field, with detailed study being carried out on return. The Middle Eastern city has a population of 135,000 which is growing about 7% per year, divided more or less evenly between migration and natural increase. Most of the city obtains water from private wells, many of which are polluted. Vendors play a prominent role in distribution; they charge the equivalent of about US$ 8 per cubic meter (cm). The ground water table is falling at the rate of 3 m/yr. A new well field, treatment plant and primary distribution system are under construction.

The first study region (Zone 1) has an area of 29 ha and population of 10,000. The houses are large, with 4 to 6 storeys; the average number per ha is 52. The streets are narrow, winding, and cannot easily accommodate vehicles. The terrain is flat. Zone 2 in the Middle East has 40 ha and 4000 persons. The houses are lower and often detached; streets are wider and better able to handle traffic. The average housing density is 20/ha.

The population of the city in West Africa is about 200,000, with annual growth exceeding 6%. Nearly half the population is in squatter areas. The nonsquatters obtain water from a municipal system in quite good condition. About 35% have house connections and draw an average of 70 lcd; the remainder rely on standposts and vendors, using an average of less than 10 lcd. Vendors charge a price equivalent to US$ 3 per cm. The study region in this city (Zone 3) has 185 ha. It is a squatter neighborhood that is being upgraded and is expected to have a population of 22,200 residing in nearly 3000 single-storey dwellings. The terrain is flat.

SYSTEM DESIGN

The work of generating alternative designs began with Zone 1. Three different spacings were selected: standposts with approximate maximum walking distances of 100 m and 50 m, and individual courtyard connections. With A = 29 and R = 100, the number of standposts N from Eq. 1 (after rounding to the nearest whole value) is 9; similarly, with R = 50, N = 36. In fact, only 33 standposts were used for this spacing which resulted in maximum walking distance slightly in excess of 50 m. In the case of courtyard faucets, a total of 1475 were required which, from Eq. 1, implies a maximum carrying distance of about 8 m.

Three levels of average per capita consumption were selected for standpost service: 20, 50 and 100 lcd. The upper values are unrealistically large, but they were desirable from the standpoint of this exercise which sought water system characteristics and costs over a wide range of flows. For yard faucets, only 50 and 100 lcd were considered. A peak factor of 3 was assumed for network design.

The secondary network for Zone 1 was connected at only a single point to the primary main which supplies the area. The minimum head at the point of connection under peak demand conditions is known to be about 25 m. It was first assumed that the minimum allowable pressure at standposts and yard faucets was 15 m, thus allowing a head loss of 10 m across the distribution network. Later, the minimum pressure was raised to 20 m, reducing the available loss to only 5 m.

The design conditions in Zone 2 were similar to those in Zone 1. Maximum walking distances of about 100 m and 50 m were selected which resulted in 11 and 43 standposts, respectively. A total of 785 yard faucets were required which implied a walking distance of about 13 m. As before, average flows of 20, 50 and 100 lcd (corresponding to peaks of 60, 150 and 300 lcd) were used for standposts, with the smaller value deleted for courtyard connections. Maximum allowable head losses of 10 m and 5 m were assumed. For Zone 3, the design criteria were modified to reflect its lower economic status. Three standpost spacings with maximum walking distances between about 140 m and 240 m were investigated; courtyard faucets were not considered. Four different system head losses in the range of 5 m to 17.5 m were analyzed. Average flows in the range of 10 to 100 lcd were selected; systems were designed, however, for maximum demands assuming a peaking factor of 3. The basic data and design standards for all three zones are summarized in Table 1.

TABLE 1. Design criteria

Zone	1	2	3
Population	10,000	4,000	22,200
Area, ha	29	40	185
Houses	1,475	785	3,000
Population/ha	350	100	120
Houses/ha	52	20	16
Standposts (N)	9, 33, 1475	11, 43, 785	10, 17, 31
Service Radius (R)	101, 52, 8	107, 54, 13	241, 185, 137
Persons/Standpost	1110, 303, 7	364, 93, 5	2220, 1306, 716
Average Flow, lcd	20, 50, 100	20, 50, 100	10, 20, 30, 40, 50, 100
Peaking Factor	3	3	3
Head Loss, m	10, 5	10, 5	17.5, 15, 10, 5

After selecting design conditions and making network layouts to minimize pipe length, it was necessary to determine pipe diameters such that standards were satisfied at minimum cost. Analysis of construction bid prices showed that network piping costs (in 1976 US$ per m of length) could be approximated by (5 + 0.24 D) and (0.20 D) in the Middle East and West Africa, respectively, where D is diameter in millimeters (mm). Using these cost functions and a linear programming approach described by Robinson and Austin (2), optimal designs were obtained for the branched standpost systems in all three zones. In the case of networks for courtyard connections in Zones 1 and 2 where looped rather than branched systems were needed, the linear programming model could not be used because the flow in each pipe was unknown. Consequently, it was necessary to employ a simulation model which produced near-optimal designs; a computer program by Epp and Fowler (3) was used.

MATHEMATICAL MODELS

A total of 10 different designs in Zone 1, 10 in Zone 2, and 24 in Zone 3 were generated. Data were tabulated for each design on the average flow Q in lcd, the number of standposts or courtyard connections N, maximum allowable head loss across the system H in m, area of the region served A in ha, total population P, total pipe length L in m, average pipe diameter $\bar{D}$ in mm, total pipe cost Cp and total system cost C_T. Average diameter for each design was obtained from the relationship.

$$\bar{D} = \sum_i L_i D_i / \sum_i L_i \quad (2)$$

where D_i and L_i are the diameter and length of the ith piece of pipe in the network and the summation is made over all pipes.

The data for all 44 designs were pooled (i.e., no distinction was made between branched and looped systems), and mathematical models were fitted to them using linear regression analyses. The first model was for total pipe length L which was assumed to depend on only two variables, the area of the region served A and the total number of standposts or yard faucets N. The resulting equation is

$$L = 90\ N^{0.4}\ A^{0.6} \quad (3)$$

for which $R^2 = 0.98$. The fit of the model is excellent, with F (2,6) = 129; the partial F values for N and A are 162 and 97, respectively.

Next, a model was fitted to the data with mean diameter $\bar{D}$ as the dependent variable and the number of standposts or yard hydrants N, total population P, area A, average design flow Q, and system head loss H as the independent variables. The relationship is

$$\bar{D} = 3.9\ N^{-0.17}\ P^{0.22}\ A^{0.10}\ Q^{0.38}\ H^{-0.23} \quad (4)$$

Although Q is average design flow, this equation implicitly incorporates a peaking factor of 3. The statistics for Eq. 4 are $R^2 = 0.99$ and F (5,38) = 570, with partial F's from 100 to 1400; the fit is excellent. Deleting H from the model results in

$$\bar{D} = 3.6\ N^{-0.17}\ P^{0.21}\ A^{0.05}\ Q^{0.37}, \quad (5)$$

and deleting both H and A yields

$$\bar{D} = 4.5\ (P/N)^{0.21}\ Q^{0.39} \quad (6)$$

with R^2 values of about 0.95 and 0.9, respectively.

From the above expressions, it is possible to estimate total pipe length and mean diameter for selected values of the decision variables N, Q and H, and given values of A and P for the area served. Suppose now that the unit cost per m of length is known for pipe diameter $\bar{D}$. Multiplying this price by total length L from Eq. 3 results in an estimate of total pipe cost for the network. In mathematical symbols, let C(D) be the known cost per m of length for pipe with diameter D. Then total piping cost Cp is

$$Cp = 90\ N^{0.4}\ A^{0.6}\ C(\bar{D}) \quad (7)$$

where $\bar{D}$ is obtained from Eq. 4, 5 or 6. If the unit cost of standposts or hydrants C_s is also known, the total system cost C_T can be estimated from the following

$$C_T = 90\ N^{0.4}\ A^{0.6}\ C(\bar{D}) + NC_s \quad (8)$$

Thus Eq. 8 is the desired function that relates the total system cost to the decision variables N, Q and H.

APPLICATIONS

Before illustrating the application of the above equations to design, it is useful to make some observations about them. Note in Eq. 3 that for a given area, length increases as the number of standposts increases, but at a decreasing rate; the function is concave. Doubling the number of standposts, which is equivalent to halving the number of persons served per standpost, increases total pipe length about 30%. Note that N can be replaced by the maximum carrying distance R through use of Eq. 1. Making this substitution in Eq. 3, it follows that reducing the carrying distance by half increases network length about 70%.

All three equations for $\bar{D}$ give approximately equal results. Eq. 6 is particularly attractive because of its simplicity; it says that mean diameter depends on only two variables, the number of persons per standpost P/N and average design flow Q, $\bar{D}$ is fairly insensitive to both variables. A fivefold increase in flow, for example, increases mean diameter only about 85%, assuming P/N is constant. Similarly, for a given flow a fourfold increase in P/N results in only about 30% increase in mean diameter. These relationships allow one to explore the optimum diameter of pipes to be laid when a subsequent improvement in service (such as upgrading from public standposts to house connections) is anticipated. Of course the length of pipe is greater for networks with house connections than with standposts; the tradeoff can be seen by examining how L in Eq. 3 increases and $\bar{D}$ in Eq. 6 decreases as N increases.

Because Eq. 6 has only two independent variables, a graph can be made indicating the tradeoff between P/N and Q for networks of given mean diameter, as shown in Fig. 1. A network with $\bar{D}$ = 25 mm has capacity to deliver average flow of about 25 lcd at a peak factor of 3 to 10 persons per connection. Increasing $\bar{D}$ to 50 mm enables the supply to be increased to 150 lcd under the same conditions. A network of this same average size can also deliver 40 lcd average flow to 100 persons per standpost or 20 lcd to 350 persons perstandpost.

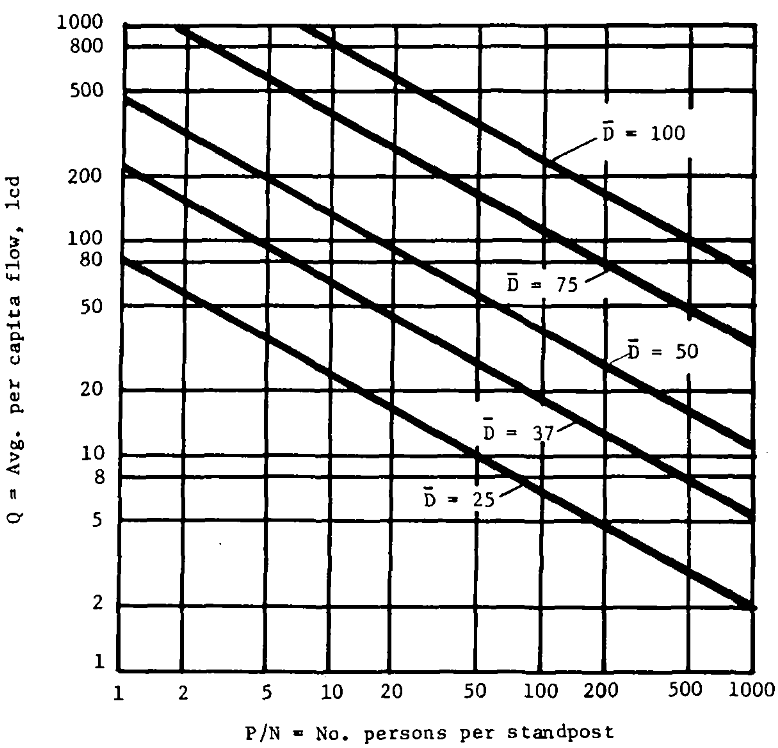

FIG. 1. Per capita flow vs. persons per standpost for various pipe sizes.

Eqs. 4, 5 and 6 only describe mean diameter, but an analysis was also made of the variation in pipe diameter as a function of length. For the branched systems, about 20% of total pipe length had diameters equal to or less than 0.65 $\bar{D}$, and 20% of the total pipe length had diameters equal to or greater than 1.35 $\bar{D}$. For looped networks, the equivalent diameters at the 20 percentiles were 0.45 $\bar{D}$ and 1.55 $\bar{D}$, respectively.

In the remainder of this section, only Eq. 6 is used for estimating $\bar{D}$. Assume that pipe cost per m of length C(D) can be estimated by

$$C(D) = 0.2\ D^{0.9} \qquad (9)$$

where D is diameter in mm. Further assume that the unit costs of standposts and yard faucets C_s are 500 and 100, respectively. Suppose a population P of 30,000 living in an area A of 100 ha is to be served by standposts. If the designer wants to limit maximum walking distance R to about 100 m, the number of required standposts from Eq. 1 is 30. The estimated length of the network from Eq. 3 is 5600 m, and average diameter from Eq. 6 is 47 mm, assuming an average per capita flow of 10 lcd. By Eq. 9, the cost per m of length for pipe of this size is 6.40 from which it follows that total pipe cost Cp is about 35,000. Adding the cost of 30 standposts (15,000) gives a total cost C_T of about 50,600 and per capita cost of 1.69.

Assume now that the designer wants to consider a somewhat better level of service. Instead of 1000 persons per standpost, 500 is preferred, with average per capita flow of 25 lcd at a peak factor of 3. The maximum walking distance for this number of standposts would be reduced from about 100 m to 70 m. Repeating the calculations, L = 7300, $\bar{D}$ = 58, C(58) = 7.73, Cp = 56,700 and C_T = 86,700. Thus the improved service has an incremental cost of 36,100 which is about 1.20 per capita. Whether the increase in benefits is worth this cost is for the designer to decide. If indeed the users are willing to pay at least this amount for the extra convenience and additional flow, then a still higher level of service should be considered, the iterations ending at the point where incremental benefits are judged to be just equal to incremental cost.

In the above example, the total per capita cost is 2.89. Suppose, however, that the total expenditure cannot exceed 75,000, which is equivalent to 2.50 per capita. To design within this constraint, assume that an average flow is selected, say, 25 lcd. The problem, then, is to decide the number of standposts N. From Eq. 3, the length of the network is 1426 $N^{0.4}$, from Eq. 6 the average pipe diameter is 138 $N^{-.21}$, and from Eq. 9, the unit cost of this size pipe is 16.8 $N^{-.19}$. The resulting expression for total cost is 23,957 $N^{0.21}$ + 500 N = 75,000 which yields N = 45. With this number of standposts, each will serve 670 persons on the average and will have a maximum carrying distance of 84 m.

A difficult problem for designers is to make an initial choice of pipe sizes to serve standpost networks that must later be compatible with the piping required for house connections after upgrading (compatibility here implies the use of pipe with sufficiently large diameter to avoid uneconomical replacement as the region switches from standposts to connections). One approach to design is the following. Suppose the area in the previous examples includes 3000 houses for which the ultimate target design flow is 200 lcd. From Eq. 3, the final length of pipe in the network is 35,100 m, with mean diameter 58 mm from Eq. 6. Assuming the standpost system is to be initially designed for an average per capita flow of 25 lcd, the number of standposts that can be supported by a network with the identical mean diameter of 58 mm can be found from Eq. 6 to be about 60, and maximum walking distance is about 70 m. From Eq. 3, the length of the initial standpost system is 7300 m. Thus it appears that if the initial system is designed for N = 60 and Q = 25, it will consist of pipe that will be essentially of the same diameter as that required to supply 200 lcd average flow after upgrading to house connections. However, care should be taken in designing the detailed layout of the initial system to ensure that the distribution of pipe sizes is compatible not only with the standpost layout but also with the eventual demands of the system with house connections.

In the previous example, it might be asked whether it would be preferable to initially construct only the 7300 m of pipe required for the standpost system, with network extensions to be made as required, or to build the ultimate system initially using only standposts that are gradually replaced by house connections. Assume for simplicity that the two alternatives are (1) construct in year zero 7300 m of $\bar{D}$ = 58 mm pipe plus 60 standposts; expand the system to total network length of 35,100 m with $\bar{D}$ = 58 mm and construct 3000 house connections in year 5 and (2) construct 35,100 m of $\bar{D}$ = 58 mm pipe plus 60 standposts in year 0; construct 3000 house connections in year 5. Because the identical facilities are required with both alternatives, the total construction cost is the same at 601,300. However, the present value costs of the alternatives are different because of differences in staging. With a discount rate of 6% per year, the present value costs of alternatives 1 and 2 are 471,200 and 525,500, respectively. With higher discount rates (appropriate to reflect the opportunity cost of capital in developing countries), the difference is even more marked. Thus it is more expensive to initially build the ultimate system and have it remain partially idle than to more carefully match the supply of facilities with the demand that is made upon them. Although this example is overly simplistic, its result will generally hold true.

This section has included illustrative examples of some of the uses that might be made of the equations resulting from this research. For a more complete description, the reader is referred to Ref. 4.

FUTURE STUDIES

The equations herein are preliminary and need to be verified. The work of verification consists of selecting additional areas and designing water systems using selected criteria. The characteristics of the systems (e.g., their mean diameter, length, and cost) then have to be compared with the predicted characteristics obtained by using the equations. If the agreement between actual and predicted characteristics is good, the models can be considered verified.

In fact, preliminary verification work has been started using selected regions in Asia. The results so far are generally satisfactory for the equations that predict mean diameter. However, the agreement between predicted and actual total pipe length needs improvement. It seems that Eq. 3 is overly simplistic because it includes only two independent variables, N and A, and purports to apply to both branched and looped networks. Work is being done to introduce street layout characteristics (for example by adding the number of blocks) into Eq. 3 as an independent variable.

The boundaries of this research need to be expanded to take account not only of secondary networks, but of primary facilities including source works, treatment plants, transmission mains and the primary distribution system. A complementary project is needed for the associated wastewater systems. Optimal design procedures are needed for appropriate wastewater technology in developing countries. Specifically, improved methods must be developed for designing sewers, especially the type that can be used with aqua privies or septic tank effluents, where flows are low and settleable solids are not a serious problem. Just as initial standpost networks must be compatible with final house networks, initial sewers for collecting aqua privy overflows must be compatible with final collection systems that will provide ultimate service. Work on these problems has begun by first of all developing an optimization model for the design of sewers. Application of this model to sanitation design in Latin America is currently underway. Also, work is proceeding there on a more general analysis of the effects on primary water facilities.

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DEVELOPMENTS OF VILLAGE-SCALE SLOW SAND FILTRATION

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1. PRINCIPLES OF SLOW SAND FILTRATION

Slow sand filtration is the process by which water is purified by passing it through a bed of fine sand at low velocities. Due to the fine grainsize distribution and the correspondingly small pores, the suspended matter present in the raw water is retained in the upper 0.5-2 cm's of the filterbed. This allows the filter to be cleaned and restored to its original capacity by scraping away this top layer of dirty sand. By the application of low rates of filtration, 0.1 to 0.3 m/hour under conditions of average daily demand, the interval between two successive cleanings is fairly long, varying from a few weeks to a few months. With one day necessary for cleaning and two days for the subsequent breaking-in period, this means an availability of 80 to 95%, for which a small number of reserve units is already sufficient.

The over-all removal of impurities associated with the process of slow sand filtration, is brought about by a combination of different processes of which the most important are mechanical straining, sedimentation and adsorbtion, and chemical and biological activity. Mechanical straining removes particles of suspended matter that are too large to pass through the interstices between the sand grains. As such it takes place almost entirely at the surface of the filter, where it clogs the upper millimeters of the filterbed, increasing the resistance against the downward movement of water. Periodically this deposition of material is removed by scraping, reducing the resistance to the original value of a new bed. By the action of gravity, sedimentation transfers suspended matter of fine sizes from the flowing water to the surface of the sand grains. By mass attraction and by attraction between opposite electrical charges, adsorbtion does the same for colloïdal and truely dissolved impurities. The matter accumulated on the sides of the sand grains, however, does not stay here unchanged. By chemical and bio-chemical oxidation ammonia is transformed into nitrite and subsequently nitrate, soluble ferrous and manganous compounds are oxidized into unsoluble ferric and manganic ones, forming a thin coating around the grains. With many steps in-between the organic matter is converted into inorganic salts, to be discharged with the filter effluent, meaning that these purifying actions will not result in a persistent clogging of the filterbed. The bacterial activity necessary for these break-down and conversion processes are most pronounced in the upper part of the filterbed, but they continue to a depth of 0.4 to 0.7 m, less as the temperature of the water is higher. With regard to the reduction in bed thickness by scraping in the meanwhile, the design thickness must be chosen 0.2 to 0.5 m larger.

The most important purifying action of a slow filter, however, is the removal of bacteria, including E-coli and pathogens when present in the raw water. By the mechanisms mentioned above, but also by their own movement, bacteria adhere to the surface of the filter grains, where their food is concentrated. For intestinal bacteria, the water environment is decidedly an unhealthy place, where the temperature is too low and insufficient organic matter of animal origin is available to suit their living requirements. In the upper part of the filterbed, moreover, several types of predatory organisms abound, feeding on bacteria. In the lower part of the filterbed bio-chemical oxidation has lowered the organic matter content so far as to starve the bacteria, which venture here. The over-all effect is a strong reduction in the number of bacteria, reducing the total bacteria count by a factor of 1000 to 10.000 and the E-coli count by a factor of 100 to 1000. Starting with an average quality of raw water it is usual to find E-coli absent in 100 ml samples of filtered water, thus satisfying normal drinking-water quality standards.

Slow filters may be built open or closed, the difference being the photo-synthetic growth of algae, which has advantages as well as disadvantages. As disadvantage must be mentioned a more rapid clogging of the filterbed, a variation in oxygen content of the supernatant water from day to night and in temperate climates the danger of anaerobic conditions when in autumn a massive die-away of algae occurs. The advantage is an increase in filter efficiency, a greater reduction in organic matter content and bacteria count. This is brought about by the presence of a thin slimy matting on top of the sand, consisting of

threadlike algae and numerous other forms of aquatic life, including plankton, diatoms, protozoa, rotifers and bacteria. This so-called Schmutzdecke is intensily active; the various micro-organisms entrapping, digesting and breaking down organic matter contained in the water passing through. Dead algae from the water above and living bacteria in the raw water supplied are likewise consumed within this filterskin, producing simple inorganic salts, while inert suspended matter is mechanically strained out.
Summing up, it may be said that the purifying action of a slow filter is promoted by two factors. The main body of the filterbed remains in place for years on end, allowing a favourable biotope to develop, while the detention time of the water to be treated is large, 5 to 10 hours in the depth of supernatant water and about 2 hours in the filterbed proper.

Slow filters for public water supplies were first used in 1829 by James Simpson for the Chelsea Water Company in London. The purpose of these filters was to obtain a clear water, free from the turbidity present in any river water. In this they were very successful, leading to applications elsewhere. The great increase in the use of slow sand filters, however, was brought about by the arrival of Asiatic cholera in Europe in 1830, causing many epidemics and innumerable illnesses of which nearly half the patients died. Around 1850 it had become clear that for the largest part cholera was spread by drinking water, but also that the contagious agent could be removed from polluted water by slow sand filtration. Up till about 1920 this process was practically the sole treatment available to transform surface water from rivers and lakes into a wholesome drinking water, free from pathogenic organisms. After the first world war, chlorine and chlorine compounds came to be used as disinfecting agents, able to kill all bacteria present in the water. In this way an even better protection against the spread of water borne diseases can be obtained, but their use requires technical expertise to operate and maintain the equipment and in particular to determine the right amount of dosing under varying conditions.

2. CONSTRUCTION AND OPERATION OF SLOW SAND FILTERS

The traditional slow sand filter, shown schematically in Fig. 1, is an open box, 2.5 to 4 m

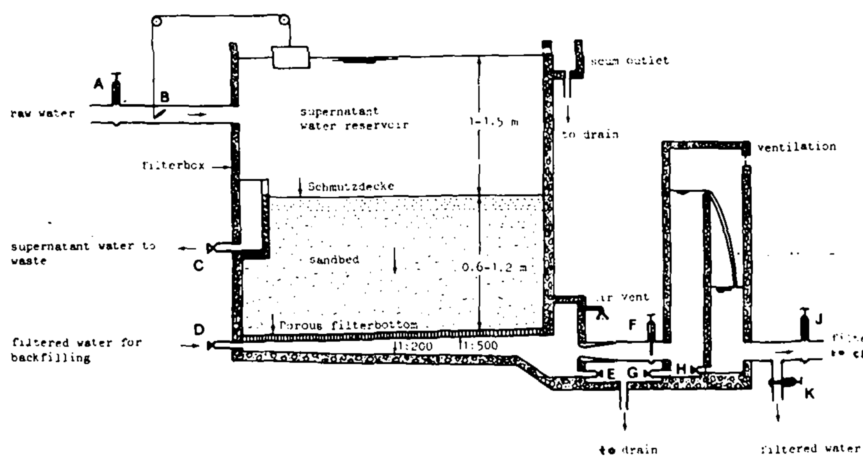

Fig. 1. Diagram of a slow filter

deep, rectangular in shape and varying in area from a few hundred to a few thousand m^2. Formerly this box was made of masonry on puddled clay with sloping sides, but nowadays it is constructed of (reinforced) concrete with vertical walls. On the bottom of this box the underdrainage system is present, serving the dual purpose of supporting the filter medium and allowing the passage of the filtered water. The filterbed consists of fine to medium sand and has a thickness of 0.6 to 1.2 m. On top of this bed the water to be treated is present to a depth of 1 to 1.5 m. In cold climates filters are covered to prevent freezing in wintertime, while in other climates covering is sometimes practised to keep algae from growing in the supernatant water.
During operation the raw water to be treated enters the filter through valve A and the regulating valve B, flows down the depth of supernatant water, the sandbed and the underdrainage system and flows through a venturi meter and the regulating valve F into a weir chamber. After overflowing the weir, the water passes through valve J towards the clear well, all other valves being closed. The regulating valve B is float controlled and keeps the level of the supernatant water constant, while by manual control of the regulating

valve F any rate of filtration, from zero up to the maximum allowable value can be obtained. The weir prevents the filtered water level to drop below the top of the sandbed, at the same time making the filtration rate independent of water level variations in the clear well. The weir also serves to aerate the water, raising the oxygen content and lowering the content of carbon dioxide, for which ventilation is an added necessity. This is also required for the filter proper, allowing air and other gases liberated in the underdrainage system to escape without hindering the movement of water. In case the composition of the raw water is such that larger amounts of scum accumulate at the water surface, scum outlets at the four corners of the filter are desirable for a regular scum removal after the water level has been raised by closing valve F over a short distance.
As the filtration process continues, a gradual clogging of the pores in the top layer of the filterbed occurs, increasing the resistance against downward water movement. This increase is compensated by opening the regulating valve F each day over a short distance, keeping the filtration rate at the desired value. When after some time of operation valve F is fully opened, a further increase in filter resistance would result in a lowering of the filtration rate and now the filter must be taken out of service for cleaning. Traditionally this is achieved by scraping away the upper 1 or 2 cm of dirty sand, for which the filter must first be drained to a waterlevel about 0.2 m below the top of the sand. This is obtained by closing valve A at the end of the day, allowing the filter to discharge over-night as much as possible in the normal way, through valves F and J. Early next morning the shallow layer of supernatant water still present in the filter is removed through valve C, connected to a box of which one wall is built up from stop logs, forming a weir of which the top can be kept near the surface of the sandbed, at whatever level this may be. The porewater in the upper 0.2 m of the sandbed finally is taken out by opening valve E for a short time, after valves F and J have been closed. When the cleaning operation has ended, valve C is closed and the filter is slowly recharged with filtered water from below, through valve D, to a level of about 0.1 m above the top of the sandbed, allowing all air accumulated in the pores of this bed to escape. The remaining depth is filled with raw water from above, through valve A, taking care not to disturb the surface of the sandbed when this is protected by only a shallow layer of water. Most simply this may be accomplished by locating valve A in the same vertical line as the discharge box connected to valve C. This box now acts as a stilling chamber from which the water flows with a small lateral velocity over the top of the upper stop log into the filter proper. When the raw water level in the filter has regained its normal level as determined by the regulating valve B, valve K is opened, keeping valve J closed. The regulating valve F is opened a short distance just so far as to have the clean filter operate at about one quarter of its normal rate. In the next 12 to 24 hours the filtration rate is slowly increased to the full value, after which a sample of the filtered water is taken and analysed in the laboratory. When the bacteriological quality satisfies the standards, valve K may be closed and valve J opened, bringing the filter back to normal operation. In case water quality is not satisfactory, valve J remains closed and the filtered water is carried to waste through valve K till further investigations show that the quality of this water is satisfactory for going into supply. After a normal cleaning, the ripening period necessary to restore the biological activity in the filterbed and the supernatant water lasts for 1 or 2 days. When the filter has been drained for a longer period, for resanding, repairs, etc, many weeks may be required, while after initial construction the breaking-in period may even last for several months. In case the filter remains out of operation for a longer period, it is drained completely with the help of valves E, G and H.

The construction of the filterbox with accessory pipelines and appurtenances follows common civil engineering rules and only the construction of the filterbottom and the composition of the filterbed deserves special attention here. For small filters, the most attractive underdrainage system consists of perforated pipes, connected to a main drain which leads the water out of the filter. The perforated laterals can be made of many materials, ranging from vitrified clay to cast iron, but in waterworks practise asbestic cement and PVC are most commonly applied, of the same type as used for the distribution system. Pipes with an inside diameter of say 0.08 m are set at intervals of about 1.5 m and are provided with holes 0.01 m diameter at the underside, about 5 per running meter. To prevent the fine filtersand from entering these holes, the laterals are covered with layers of graded gravel, for instance 4 layers, the lower one 0.15 m and the others 0.08 m thick, with grainsizes of 20-40, 8-16, 3-6 and 1.2-2.5 mm, topped by a layer of graded sand, 0.12 m thick with a grainsize of 0.5-1 mm. The main drain is commonly not perforated and should have a cross-sectional area about equal to the combined cross-sectional areas of the laterals connected to it. With larger filters and a greater distance of travel through the underdrainage system, larger passage ways for the filtered water are desirable. As shown in Fig. 2, this can easily be obtained by setting precast concrete slabs with open joints on precast concrete ribs. For somewhat smaller filters stacked bricks can be used to advantage, while for very large filters porous concrete poured in situ on retractable steel forms are better suited, also because this requires only 1 or 2 layers of graded gravel and sand to support the filterbed.
Sand for slow filters is commonly characterized by the sieve sizes passing 10 and 60% of the

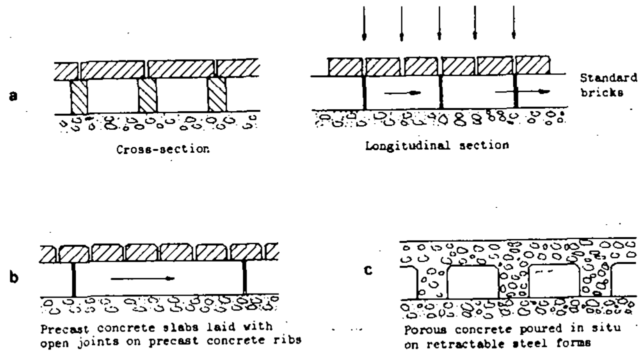

Fig. 2. Various types of filterbottom

material (Fig. 3). The 10% size is called the effective size and the ratio between the 60

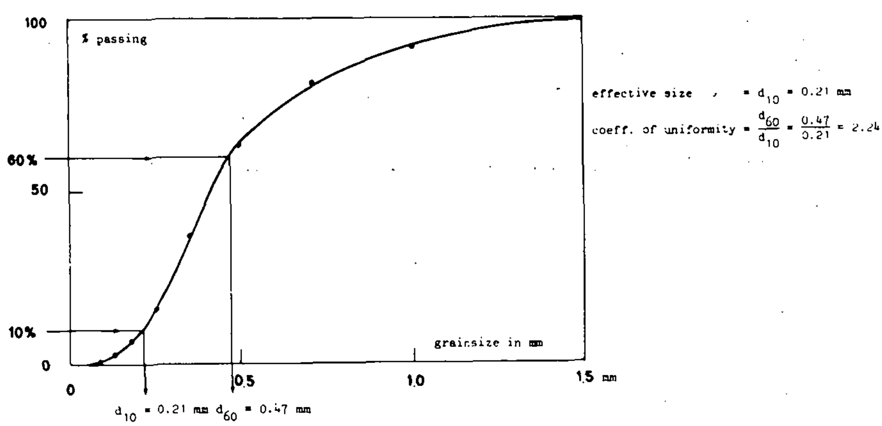

Fig. 3. Grainsize distribution of filtersand

and 10% sizes the coefficient of uniformity. For a large porosity this coefficient should be small, below 3 and preferably even below 2. When this cannot be obtained by sand as found in nature, the coarser particles have to be removed by sieving (builders grade sand). The most important factor in the meanwhile is the effective size, commonly between 0.15 and 0.3 mm, although in some cases values as low as 0.1 mm or as high as 0.4 mm have given satisfactory results. Again as much as possible natural sands should be used. In some cases the desired value of the effective size can be obtained by (thoroughly) mixing two types of sand, with the disadvantage, however, of a larger coefficient of uniformity. As last resort screening can be used, removing the fine particles to increase the effective size and the coarse particles to obtain a more uniform sand.

The effective size of the sand for slow filters must be chosen just so small that with the raw water at hand the quality of the filter effluent satisfies drinking water standards and that suspended matter present in the raw water does not penetrate the filterbed over a depth of more than 2 cm. The filtration rate has no influence on this quality, higher rates often giving better results, but it determines the length of filterrun, dropping a little more than corresponds with an increase of rate. Next to this, the length of filterrun will be larger as the turbidity of the raw water is smaller, while already a slight increase in the effective size of the filtersand greatly prolongs the interval between two successive filter scrapings. With a good quality of the raw water available, the requirements of effluent water quality and length of filterrun are easy to satisfy, allowing different combinations of effective size and filtration rate to be used. As standard may be suggested an effective size of about 0.2 mm and a design filtration rate of 0.2 m/hour under normal conditions, augmented to 0.3 m/hour for days of maximum demand and one filter out of operation for cleaning. When the raw water is turbid, contains larger amounts of iron and manganese or is polluted by organic matter and intestinal bacteria, standards designs can no longer be used. In particular for larger installations the design must now be based on the results obtained with experimental filters, using different types of sand, and operated for at least a whole year to take into account seasonal variation in raw water quality. In case the slow filter alone is not able to produce the desired results, pre-treatment must be used, ranging from settling as cheapest to rapid filtration as most effective method. In industrialized countries, slow sand filtration is often followed by chlorination to obtain a second line of defense. In those countries the large areas of land necessary for slow filters and the large force of unskilled labour required for the manual cleaning process are serious disadvantages. Here this has lead to the development of other methods for treating surface water from rivers and lakes, allowing a severe reduction in plant size and a fully mechanized and automated process, although of high complexity.

Since James Simpson built slow sand filters 1½ century ago, a number of modifications and improvements in design and construction have been incorporated. New building materials and building methods, covering of filters, mechanical cleaning, etc, have greatly changed the outward appearance of a slow sand filtration plant, but the underlying ideas and the principles of operation remained the same. As only change of importance may be mentioned the use of higher rates of filtration, 0.3 to 0.5 m/hour under conditions of average daily demand, made possible by both pre-treatment and post-chlorination.

3. VILLAGE SCALE WATER SUPPLIES IN DEVELOPING COUNTRIES

Public water supplies in rural areas of developing countries always suffer from lack of money, lack of technical and managerial skills, inadequate community participation and insufficient support from provincial authorities. Together with the absence of pathogenic organisms as most important water quality requirement, this means an outspoken preference for groundwater. By virtue of its origin, groundwater is safe in hygienic respect, while after constructing the means for abstraction, little supervision or maintenance is required. The use of surface water for public supplies is thus restricted to those cases where groundwater is not available, where the content of chemicals such as heavy metals would endanger the health of the consumer, when it is situated at a great depth below ground surface making abstraction expensive or when a complicated treatment is necessary. Surface water, however, is commonly polluted by suspended and organic matter and may always be contaminated with pathogenic micro-organisms. Before going into supply, this water must be purified for which in industrialized countries many systems are available. Treatments requiring a steady supply of coagulants, flocculants, disinfecting agents, etc, are bound to fail sooner or later in rural areas of developing countries. This leaves as only possibility the use of slow sand filtration with the added advantages of a simple construction, appropriate to local circumstances and a simple and fool-proof operation, doing away the need for expert supervision. With a relatively clear water from lakes, slow sand filtration may be the sole treatment to which the water is subjected. With a turbid water as found in rivers, preceding clarification by settling may be necessary. In rare cases slow sand filters are used to remove iron and manganese from groundwater.

When designing a slow sand filtration plant for village use, the smallness of the demand often comes as a surprise. Population numbers vary from a few hundred to several thousand, but taken over the whole of rural India (1971: 439 million people living in 576 thousand villages) the average amounts to only 762. Water use is also low as the large majority of the people have to carry the water from public standposts to their homes. Depending on the distance, the consumption will vary from 20 to 40 l.c.d., rising to perhaps 80 l.c.d. for yard connections. For the near future this means an average consumption of 50 l.c.d., including leakages. With small villages having less priority, the average population of communities to be served in the near future will be around 1500 people, giving a consumption of 75 m^3 on an average day and about 90 m^3 on days of maximum demand. With regard to the cost of labour and the lack of skilled personnel, operation of the plant is mostly limited to one shift, say for 10 hours, from 7 a.m. to 5 p.m. In the example given, this means a production between 7.5 and 9 m^3/hour. Assuming moreover a normal filtration rate of 0.2 m/hour, rising to 0.3 m/hour on days of maximum demand with one filter out of service for cleaning, the plant could best be composed of 3 units, each with a filterbed area of 15 m^2. In case they are built as one unit with common division walls, inside dimensions of each filter should be 3 x 5 m and overall dimensions 5.5 x 10 m (Fig. 4). When some time after

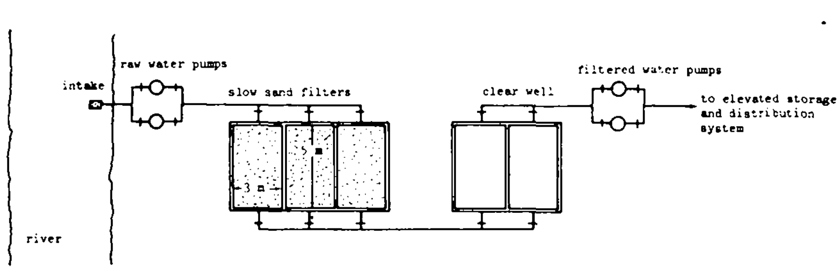

Fig. 4. Plan of slow sand filtration plant, serving 1500-3000 people

construction water consumption rises above the figures quoted above, the simplest solution is a gradual increase in the period of operation.
It goes without saying that design and construction of a village scale slow sand filtration plant should be as simple as possible, accepting the risk that under abnormal conditions water consumption has to be restricted. Keeping in mind that water from a river always needs pumping to bring it on top of the slow filter, this pump (capacity 9 m^3/hour or 2.5 liters/second in the example quoted above) may also be used to control the rate of filtration. Schematically this is shown in Fig. 5, where for normal operation valves C, E and

Somewhat complicated for ldc's

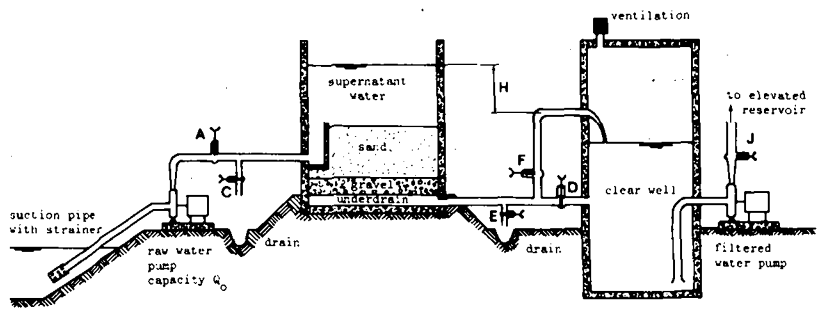

Fig. 5. Simplified operation of slow sand filter

D are closed. During filtration valves A and J are fully opened and valve F partially closed, so far as to maintain an adequate depth of supernatant water on top of the filterbed and so little as to prevent the filter from overflowing. When in periods of low demand, the latter phenomenon threatens to occur by a rise of the water level in the clear well, the operation of the pump is interrupted for a short period. At the end of the working day, valves A, F and J are closed and both pumps switched off, the filter and the clear well remaining full of water. This means, however, a fluctuation in filtration rate (Fig. 6a), lowering filtered water quality, which can be prevented to a large degree by leaving valve F open (Fig. 6b). For filter scraping, the sand bed must be drained, as much as possible in the

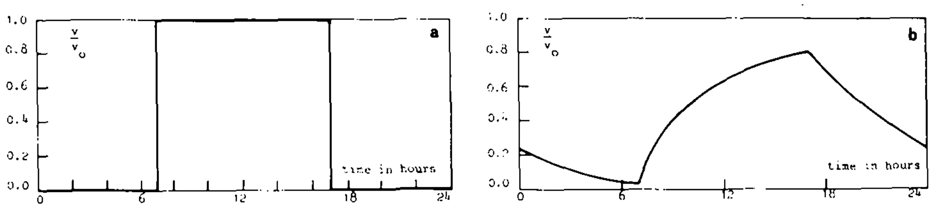

Fig. 6. Variation of filtration rate with time in case of interrupted operation

normal way through valve F and for the remaining part through valves C and E respectively. After cleaning, the filter is recharged through valve D to submerge the sandbed and through valve A to regain its normal water level. For at least one and preferably two days, the filter effluent is carried to waste through valve E, after which normal operation may be resumed. In tropical countries, slow sand filters are seldom covered. With a high water temperature the whole year round, a massive growth or die-away of algae will not occur, while this algae growth promotes the formation of a Schmutzdecke, increasing filter efficiency. Care, however, must be taken to prevent pollution of the raw water by birds, wind-blown dust, etc, as much as possible.
In rural areas of developing countries, water is mostly drawn for about 2 hours at the beginning and 2 hours at the end of the working day. To allow the filter to operate at a constant rate over the full working day, a rather large clear water storage is required, with a theoretical value of about 60% of total daily consumption for the case shown in Fig. 6a and about 40% for that in Fig. 6b. To allow maintenance and small repairs of pumping equipment, actual capacities must even be larger, rising to 100 and 65% of daily consumption respectively. In case the installation is built at some elevation above village level, the filtered water pumps can be dispensed with and the clear well acts as elevated storage reservoir.
As much as possible, piping, valves and mechanical equipment should be standardized for various capacities. The concrete structures housing filters and clear wells are built on the spot and may be adapted to local circumstances, provided that for structural details clear guidelines are available. Cement and reinforcing bars for concrete must be imported, but sand and gravel can usually be obtained locally. Instead of gravel, broken material from hard rocks or well fired bricks may be used, also to be applied for the underdrainage system of a

slow filter. Filtersand is most difficult to obtain as its effective size must be between narrow limits and the value of the coefficient of uniformity not too high. As much as possible sand as found in nature should be used, even when this entails transportation over some distance. The effective size may easily be changed by mixing two types of sand, but this increases the coefficient of uniformity. As last resort screening may be applied, removing the fine material to increase the effective size and the coarse material to lower the coefficient of uniformity. In case the filters are of small size, less than 7 m^2, the use of cylindrical steel tanks could be contemplated. Complete pre-fabrication is now possible, but transportation to the site is often difficult.

Summing up, the design of slow sand filters for use in rural areas of developing countries closely follows the rules developed in Europe during the past 150 years. As differences may be noted the smaller sizes, a simplification in construction and operation, a greater use of locally available materials and less instrumentation, but so-called appropriate technologies have not emerged. By experience gained during the last decades, the applicability of slow sand filtration for village use in developing countries has been shown beyond doubt, providing a clear water free from pathogenic organisms. The advantage of a water safe in hygienic respect, however, is often not understood by the people concerned, while the impact on public health remains small when it is not accompanied by an improvement in village hygiene.

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THE ENGINEER IN THE CONTROL OF SCHISTOSOMIASIS

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Abstract
The approach to schistosomiasis control in three irrigation schemes in Egypt and the Sudan is described. Engineering approaches which might have aided control but have not been adopted are discussed. These include redesign of minor canal sections and associated changes in project operation at field level. Reasons for the failure to consider these options are discussed. Design parameters for the guidance of engineers at scheme stage are proposed. A plea is made for experimental trials of engineering modifications in new irrigation schemes.

INTRODUCTION

The problem of schistosomiasis in certain less developed countries and its association with the extension of irrigation is well known. This association neccessarily involves the engineer in attempts to check the disease. As long ago as 1950, the World Health Organisation drew attention to the importance of taking precautions to ensure that the establishment of irrigation schemes did not bring with it the danger of the spread of the disease (1). Since then, the attention of the engineer has repeatedly been called to the danger of schistosomiasis and recommendations for appropriate action have been made (2, 3).

Despite this focus, the problem of schistosomiasis has not disappeared. Indeed, it appears to be worsening, with prevalence in irrigated areas in countries such as Sudan and Egypt reaching epidemic proportions. Yet in the extensive literature on schistosomiasis, there is little assessment of the efficacy of engineering controls. Given the serious nature of the problem, it seems appropriate to ask: To what extent do engineers take schistosomiasis into account in their design of new irrigation schemes ?

In the course of a short visit to Egypt and the Sudan and through subsequent discussions with technical consultants, I have investigated the preventative input in three large irrigation projects. In both countries, schistosomiasis is already a serious problem· in both attempts at control have been made and there is an awareness of the dangers. This may appear fertile ground for a coherent approach to control at the design stage of the projects. What I found however was either the rote application of a few misleading and probably ineffectual guidelines and a reliance on unproven chemical controls or a resigned acceptance that endemic schistosomiasis would be a fact of life in the new projects.

In this paper, the three projects and the consideration given to schistosomiasis control in them are outlined. The proposed cotntrols are assessed in the light of current knowledge and alternative approaches are discussed.

THE SCHEMES

The three schemes investigated were the Rahad and the Kenana in the Sudan and the Upper Egypt Drainage Project. For all three, details of the schemes and the considerations given to schistosomiasis control at the design stage were obtained by personal contacts.

Rahad Irrigation Project

A 130 000 ha irrigation scheme supporting approximately 100 000 people. 100 cumec of water is supplied by pumping from the Blue Nile. A rotation of cotton, groundnuts and fodder will be grown with watering by a night storage system.

Client: Sudan Government

Finance: Principally Arab Development Funds and the International Development Association (World Bank).

Management: Rahad Corporation (a public corporation responsible to the Agriculture Ministry).

Consultants: Sir Malcolm MacDonald and Partners with specialist subcontractors.

Kenana Sugar Project
A 33 000 ha sugar estate with 42 cumec of water pumped from the White Nile. Estimated population in excess of 15 000.

Client: Kenana Sugar Company.

Finance: The Kenana Sugar Company is a private company financed jointly by the Sudanese Government and Arab finance houses.

Management: Originally by the Lonrho company more recently by an American sugar company.

Consultants: Howard Humphreys and Partners.

Upper Egypt Drainage Project
This involves the drainage of 400 000 ha of land currently under perennial irrigation from the Nile. The local population is approximately 300 000 families. The works include the provision of 30 000 km of 'tile drains', 1600 km of new and upgraded open drainage canals with total excavation estimated at 31 million cubic metres.

Client: Egyptian Government.

Finance: International Development Association (World Bank).

Management: Egyptian Public Authority for Drainage Works.

Consultants: World Bank and Egyptian experts.

SCHISTOSOMIASIS CONTROL INPUT

Rahad
Included in the project financing is provision for the supply of equipment and chemicals for the control of snails in the first few years of the project. Planning guidelines on the siting of homes at least 300m from canals have been observed. Villages for permanent dwellers in the scheme area have been provided with drinking water either from boreholes or from small treatment plants.

Kenana
Planning guidelines are being followed as in the Rahad. The use of chemicals for snail control was being considered but no decision had yet been taken. Water supplies are being provided for all permanent labour.

Upper Egypt
A US$8 million (1975) control programme for 350 000 ha is allowed for in the US$124 million project finance agreement. This involves treatment and snail control using molluscicides over a period of 3 years. The engineering works are used to justify the programme:-

> "As the open drains to be installed would increase the already serious transmission of bilharzia (schistosomiasis), the project provides for bilharzia control to be undertaken in a 900 000 feddan (350 000 ha) area where conditions are conducive to its success." (4)

ASSESSMENT OF CONTROL APPROACHES ADOPTED

Planning considerations
The planning considerations adopted in the Sudan are of dubious efficacy. Commenting on the siting of villages to minimise the spread of schistosomiasis, Satti (5) says:

> "The distance from the canal must be about 2km if not more. The distance advocated for the Gezira of 300 yards from the canal proved inadequate."

This point has been clearly demonstrated by Greany (6).

In both the Kenana and the Rahad, the planning guidelines are being applied in letter rather than in spirit. Thus spacing of housing from canals is being maintained at 300m. In both schemes however, the 300m gap is being used to site schools, public buildings and markets. It must be assumed that these will themselves generate the water contact that the separation is intended to prevent.

Water supplies to the farm tenants on the Rahad and the labourers in Kenana are basically standpipes. Additional facilities which have been shown to reduce water contact with canals - wash houses for instance - have been considered but ruled out because of cost. One serious outstanding problem in both schemes is provision of water for the temporary labour force required at harvest times. In neither scheme are adequate supplies for this large group provided. For them, it must be assumed that the canals will remain an important source of water for all domestic needs. The resulting contact with untreated water must promote the transmission of schistosomiasis.

Chemical Control of Snail Hosts

The reliance on chemical contrbl in both the Rahad and Kenana is based on schistosomiasis control efforts currently underway in the nearby Gezira Irrigated Area. Here, a pilot project has since 1973 attempted to control the snail population in a 1000 sq km portion of the scheme. It is hoped that by reducing snail population sufficiently, the current epidemic transmission of schistosomiasis can be significantly reduced.

The methodology of this effort is based on the successful control which has been achieved in smaller schemes (7). On the Gezira, it has proved much more difficult to reduce the snail population to satisfactory levels (8). And although latest results have been more encouraging, the associated reduction in transmission of the disease has been disappointing. Cost of chemical control on the Gezira has been estimated at £1.40 per hectare (1976). Most of this represents the foreign exchange cost of the chemicals. This cost may be an underestimate since it has been suggested that prices are being held artificially low during the development period.

Despite its cost, control of schistosomiasis by chemical means remains an unproven method in the Sudan. Similar considerations apply in Egypt. A combination of treatment of infected persons and snail control in the Fayoum area has significantly reduced the disease but the high recurrent cost is probably too high to allow control to be introduced throughout the country.

Engineering Considerations

In the area of the Egyptian scheme, schistosomiasis is already established, largely as a result of the switch from flood to perennial irrigation made possible by the Aswan High Dam and other Nile management projects. In this case however, the engineering justification given for control appears to be spurious. The introduction of a few hundred kilometre of new open drains may marginally increase the risk of water contact and thus transmission of the infection. The drains will also provide new habitats for the host snails. The project's objective however is to lower the water table and reduce the waterlogging which threatens agricultural productivity. So overall, the project is likely to both reduce snail habitats and water contact. Drainage is in fact widely regarded as a useful control activity in itself. Indeed, in the Nile Delta, similar drainage projects have demonstrably reduced snail populations (9).

Thus while a schistosomiasis control programme in Upper Egypt is doubtless neccessary, its association with the drainage works should be regarded purely as a matter of convenience - perhaps to facilitate the flow of finance. This is implicitly acknowledged in the project design since the schistosomiasis control area does not coincide particularly closely with the drainage project area.

As in the Sudanese projects, no specific engineering controls are to be implemented

TOWARDS ENGINEERED CONTROLS

Objectives

The principal objectives for engineers designing to limit the spread of schistosomiasis in new irrigation works should be:-

1. To minimise the extent of human contact with potentially infected water.

2. To minimise the extent of habitats suitable for the snail host.

Further, since no single control method is likely to eradicate the disease in endemic regions,

3. To ensure that the design chosen permits the most effective and economic control of the host by other - e.g. chemical - means.

Alternative Techniques for the Sudan
To illustrate these objectives, it is useful to look at engineering measures which could havebeen adopted in the two Sudanese schemes to meet these objective.

Night Storage. One important engineering option which could have greatly assisted schistosomiasis control was given no serious consideration. This is the adoption of a continuous watering system at field level rather than the night storage/day watering system that has in fact been adopted. Night storage has been categorically defined as a schistosomiasis hazard:

> "The practice of using small reservoirs for overnight collections and storage with distribution the following day is condemned by all authorities. Such reservoirs tend to have fantastic densities of snails and cercariae and disseminate highly contaminated water over the area irrigated." (3)

The reasons for this are two-fold. In night storage schemes such as the Rahad (and the Gezira upon which its canalisation is modelled) the minor canals are effectively longitudinal reservoirs. They are much larger than would be the case if they were designed simply to carry water. The excess size of the canals creates virtually stagnant water flow and provides excellent habitats for the snail hosts of schistosomiasis. Second, the night storage regime creates an irrigation system which contains a larger volume of water than a continuously operated scheme. Any control operation which aims to kill snails by delivering a specified concentration of the chemical molluscicide will thus be more expensive in terms of the quantity of chemical required. Further, the velocities in over-size canals are so low that they inhibit mixing and require proportionately more molluscicide to ensure the penetration of the chemical throughout the canal margins. Stagnant reaches cannot be treated by a main canal drip feed, the most convenient technique. Instead, expensive manual or aerial spraying must be adopted.

In construction terms, continuous irrigation systems are cheaper than night storage since they require less excavation to deliver the same flow of water. Their prime disadvantage for the engineer is that they are less easy to operate, lacking the buffer capacity of night storage systems with which to absorb the consequences of operational errors.

The main objection is usually on agricultural and social grounds however. A continuous system, by its nature, requires more intensive management. But this need not neccessarily mean 24 hour round-the-clock watering as is sometimes implied.

Fluctuations of water level. An engineering technique which has demonstrably reduced snail populations is the operation of an irrigation system so that water levels in it fluctuate rapidly (10). The complete draining of canals can also reduce though not eradicate snail populations even if it is done for short periods only. Both these options could have been explored on the Rahad and Kenana by making provision to drain the tails of minor canals. In the Kenana, weirs have been built at the end of each canal, overflowing into drains. Simple gates were considered but ruled out. These would have allowed rapid draining.

This type of operational control is unlikely to eradicate snail populations on its own. It could however offer great advantages in combination with other techniques of control. Since snail ecology varies between species and localities, experimental trials could help to determine the most effective operating regime.

Other engineering controls. Other design methods for the control of schistosomiasis have been recommended (3). They include:
1. Increasing water velocities in canals to a level at which the snails are immobilised or dislodged.
2. Lining canals with materials such as concrete which do not create habitats suitable for the snail and have economic benefit since they also reduce seepage losses.
3. Building canals with steep or vertical sides.
4. Covering canals and drains - piped systems.
5. Providing physical barriers to prevent access to canals.
6. Ensuring adequate drainage to reduce waterlogging and the resulting snail habitats. Drains should however be designed with the same care as canals to avoid creating a new hazard.

In the Sudan, the first three considerations are ruled out by site conditions and topography on the two schemes considered. The impermeable clays require no lining and very gentle slopes make high velocities impractical.

SOME NUMBERS TO WORK TO

It is not realistic to expect engineers to understand the nuances of schistosomiasis control programmes when their primary task is the design of irrigation schemes. So it is important for health workers to give clear, simple and appropriate guidance. Unfortunately, health workers rarely understand the constraints under which the engineer works. Too often, the suggestions they make are already ruled out by site conditions or economics. Recommendations that on the Rahad, drains be covered and canals lined come into this category. It is also unhelpful simply to brief engineers on the nature of the disease and allow them to take appropriate action. On Kenana, engineers found the literature on schistosomiasis very interesting but "too biological" to be of much assistance during the rushed two month design programme.

There is thus a real need for more general guidelines. For the purpose of illustration, I propose two parameters which, suitably elaborated, could usefully help engineers to compare different design approaches at early scheme stages of a project for their schistosomiasis control potential.

Snail Habitat Created

Irrigation is associated with schistosomiasis because it creates habitats suitable for the parasite's snail intermediate host. So a reasonable design parameter would be the extent of habitat created. This could be represented as follows.

$$H = \sum (Aw \times Fm \times Fv \times Fo) \; / \; Ai$$

H is the habitat created per unit area of scheme
Aw is the canal area
Ai is the scheme area
Fm relates to the material of construction ranging perhaps from .1 for concrete to 1 for natural earth
Fv relates to mean water velocity in the canal ranging linearly from 1 (below .3m/sec) to .1 at 1.5 m/sec and above
Fo is an operation factor, perhaps the proportion of time drained every year.

Chemical Control Cost

Another parameter which would help to design for control is the cost of chemical control. This assumes the regular use of chemicals for snail control and enables potential savings on this recurrent operating cost to be assessed. It is given by:

$$X = C \times (Vs + Vf) \times S \times L \times N$$

X is the annual control cost
C is the required concentration of chemicals for kill
Vs is the volume of water in the system when operating
Vf is the volume of water used in the scheme over 8 - 24 hours (depending on the control chemical used) on an annual average basis
S is a stagnation factor, perhaps given by Vs/Vf
L is the unit cost of the chemical
N is the number of chemical treatments required per year

These parameters, if applied to the Rahad and Kenana schemes, quickly indicate modifications which could be made to facilitate schistosomiasis control.

EXPERIMENTAL WORK

There is an urgent need for experimental work to determine the efficacy of the various engineering methods that have been proposed for the control of schistosomiasis. At present, many engineers rightly regard these as academic prescriptions with little proven basis. The need for experimental work was recognised at the 1975 Cairo Conference on Schistosomiasis where the sub-committee on environmental control concluded:-

> "Because of the emphasis placed on molluscicides as a control method in the past 10 - 15 years, other possible methods of control have received little encouragement although they have shown potential value. The urgency for the control of schistosomiasis will require in many instances that all available methods be used in an integrated programme .... it is recommended that schemes be set up to demonstrate the efficiency of control by these environmental and habitat management methods." (11)

There are two distinct approaches to this kind of experimentation. The one, as outlined by Agamieh (12), is to start with existing irrigation schemes and answer the simple question: 'Why does one canal have a thriving snail population while the next is snail free ?' . This can be done by surveys of snail populations combined with an analysis of the physical and operational characteristics of each canal. The other approach is to incorporate design features aimed at control in new irrigation schemes schemes. This could have been done in the Rahad , with a trial portion designed to operate on a continuous flow rather than night storage regime: gates rather than weirs could have been built at the tail of the Kenana minor canals and cycles of watering-draining instituted. The effect on snail populations - and the cost of their chemical control - could then have been assessed.

CONCLUSION

It is doubly unfortunate that the World Bank should invest considerable resources on chemical control in Egypt while neglecting the valuable opportunity to incorporate experimental engineering controls offered by the Rahad. The first is a short term palliative, the second a true investment promising cheaper control methods of wide application. The ground was fertile in the Rahad since the Bank's experts insisted on a radical agricultural change - from the basin irrigation system traditionally used in the Gezira scheme to the more modern long-furrow system. Continuous flow watering rather than the night storage system could have been introduced with this innovation aided by the fact that tenant farmers in the Gezira have already - if unofficially - switched to a continuous watering system (13).

One lesson here is simple. The basic design choice on the Rahad was made before the health impact of the scheme had been assessed in one of the socio economic studies that the World Bank rightly insisted upon. But any failure to take all practical steps to control schistosomiasis on the Rahad cannot be attributed to poor timing alone. There is a more deep-rooted malaise. Many of the engineers and health workers I spoke to expressed a deep sense of pessimism. "education and rising standards of living are the only long-term answer" was an opinion voiced repeatedly. This reliance on economic development as the answer to schistosomiasis - and other health problems - is no longer acceptable. As the World Health Organisation's director, Dr Halfdan Mahler has emphasised:-

> "Improved health care will not 'trickle down' to the majority of the people as a natural consequence of economic growth or by reinforcing present structures or techniques .... Planners should not be asking : 'To how many people can we provide good health care ?' but 'Given these resources how do we use them to provide health care to everyone ?'"

The World Health Organisation's strategy for Primary Health Care (14) is based on the concept that the health of a community is the concern for all its members not just its doctors. The need for preventive action on schistosomiasis is specifically singled out as an example of the broad approach needed. Engineers guide the use of scarce resources. They, and their funding agencies, have a responsibility to guide them well. As illustrated in this paper, they can contribute far more to the fight against schistosomiasis than they do at present.

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ASPECTS OF ENVIRONMENTAL HEALTH IMPACTS OF THE ASWAN HIGH DAM ON ON RURAL POPULATION IN EGYPT

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Abstract

An environmental and epidemiological survey was completed in 41 Egyptian villages from which 15,334 persons were examined. Samples were taken in the Nile Delta, Upper-Middle Egypt, Upper Egypt, and in the resettled Nubian population. The findings of this survey and of past surveys clearly indicated a steady decline in the prevalence of the most important parameter of this study, schistosomiasis. Since the 1930's this trend has been continuous, with the exception of localized minor increases, which most likely occured just prior to the construction of the Aswan High Dam (AHD). Schistosomiasis prevalence also fell in the Nubian population following resettlement, from 15.7% to 8.8%. The wide-spread speculation that schistosomiasis would be greatly increased as a result of the Aswan High Dam construction or the related irrigation expansion has been premature. However, general estimates of schistosomiasis show that this disease has continued to affect the health and well-being of millions of Egyptians over the past forty years. Sporadic cases of S. mansoni were seen in villages 150 km south of Cairo. Population growth has been responsible, in part, for an increase in the number of positive cases.

INTRODUCTION

Egypt is made up of several geographically distinct sectors: the eastern and western deserts, the Nile Valley, Lake Nasser, and the Suez Canal region. The Nile Valley, in which 99% of the population resides, is divided into the Nile Delta, Upper-Middle Egypt (south of the delta to Assyut), Upper Egypt (south of Assyut to Aswan), and resettled Nubia.

Dams and irrigation schemes in Egypt date from the pharaonic periods. Calcified ova of S. haematobium were found in mummies of the XXth Dynasty (Ruffer, 1910), and hieroglyphic inscriptions have been found which describe haematuria and its curative magic formula. Schistosomiasis has long been a health problem in Egypt.

Accurate information on the prevalence of schistosomiasis in the Egyptian population did not exist until Scott's studies in the 1930's. A number of other studies have been completed since that time; however, no review of these studies has been made. This research included an extensive review of all investigations of schistosomiasis on incidence, prevalence, and distribution in Egypt in an attempt to piece together an overall pattern of the disease since the 1930's in Egypt. The review in its entirety has been published elsewhere (Miller, et al., 1978). Table 1, taken from this review, shows the author, date, and location of prevalence studies which have been made since the turn of the century. More studies were listed for Qalyubia than for any other governorate, most likely because this governorate is one of the few in the Nile Delta that can be easily reached from Cairo.

TABLE 1. Summary of prevalence surveys for bilharziasis in Egypt by area, year, and author

Area of Survey	Year	Author
Country-wide	1935	Scott
Country-wide	1955	EMPH-Wright
Nile Delta	1866-1935	Azim
Qalyubia	1936	Khalil and Azim
Qalyubia	1952	Weir
Qalyubia	1954	Chandler
Qalyubia	1956	Dimmette
Qalyubia	1958	van der Schalie
Qalyubia	1959	Abdallah
Iflaka	1963	Sherif
Beheira	1966	Farooq, et al.
Beheira	1966	Bell, et al.
Kafr El Sheikh	1972	Hussein
Beheira	1973	Gilles, et al.
Qalyubia	1977	Alamy and Cline
Upper-Middle	1866-1935	Azim
Giza	1949	Khalil
Giza	1955	Zawahry
Assyut	1968	Hamman
Giza	1970	Abdallah
Beni Suef	1972	Hussein
Fayoum	1976	EMH
Giza	1977	Abdel-Salam and Abdel-Fattah
Upper Egypt	----	----
Kom Ombo	1935	Khalil and Azim
Sohag	1954	Nooman
General	1955	EMPH
Aswan	1966	Tuli
Aswan	1970	Satti
General	1972	Dazo and Biles
Old Nubia	----	----
General	1951	Dawood
General	1958	Rifaat and Nagaty
General	1964	Zawahry
New Nubia	----	----
General	1972	Dazo and Biles
Lake Nasser	----	----
Fishermen	1970	Satti
Fishermen	1971	Dazo and Biles
Fishermen	1972	Dazo and Biles
Fishermen	1974	Scott and Chu
Desert Areas	----	----
Dakhla Oasis	1952	Abdallah
Dakhla Oasis	1957	Rifaat, et al.
Dakhla Oasis	1964	Rifaat and Nagaty
Wadi El Natrun	1964	Rifaat, et al.
Mersa-Matruh	1964	Rifaat

The objectives of this study were:

1. To provide current information on the prevalence and distribution in rural Egypt on a country-wide basis;
2. To evaluate changes in the prevalence of schistosomiasis in the Nubian populations following their resettlement in Kom Ombo;
3. To examine the relationships between schistosomiasis prevalence and selected environmental variables; and
4. To analyze current and past data to determine the effect of the Aswan High Dam on the prevalence of schistosomiasis in rural Egypt.

Methods

The research approach of this study included a thorough analysis of historical data collected on all aspects of schistosomiasis transmission in the Egyptian population. This has been prepared as a review and is published separately. Particular attention was given to methodology in order to maximize the validity of comparisons drawn between this study and historical data.

Rural Egyptian villages were selected to represent the three major geographical areas of the Nile Valley (Upper Eypt, Upper-Middle Egypt, and the Nile Delta), and included the new Nubian villages in Kom Ombo, Upper Egypt. Five study sites, each of which encompassed one or more villages, were selected in the Kafr El Sheikh governorate. Kafr El Sheikh is located in the north central delta. Five study sites were also selected in both the Beni Suef and Aswan governorates which are located in Upper-Middle and Upper Egypt, respectively. In the Nubian villages of Kom Ombo, five more sites were selected, making a total of twenty sites comprising 41 villages. The study sites selected in Nubia included the same villages previously surveyed by Zawarhy in 1964. Later in 1964, the Nubians were moved from the area that is now inundated by Lake Nasser.

At each study site a list of every family and its members was compiled. The list was frequently checked for completeness. From the list, or sample frame, approximately 200 families were selected systematically at each study site. Since the population differed from site to site, the sampling was not proportional and required that the findings first be adjusted for the samping fraction before selection probabilities could be calculated for a given study area.

All members of each selected family were requested to attend the examination at a nearby rural health unit. Urine and stool specimens were obtained at the health unit. This measure was taken to assure the proper identification of the individual who provided the specimen.

Data on age, sex, height, weight, occupation, and education were also obtained at the health unit. The dwelling of each selected family was examined, and types of water and wastewater practices were noted. Environmental aspects of the villages were recorded and included: irrigation practices, water and wastewater schemes, and the general setting of the village in respect to agricultural practices and water use practices.

Urine specimens were examined at the rural health units using the sedimentation technique described by Farooq and Nielsen (1966). This is a more traditional technique for the detection of schistosome ova, but it was the technique most frequently used in past studies with which comparisons were desired. Stool specimens were coded and preserved in MIF solution. All stool specimens were then shipped to a central laboratory at the High Institute of Public Health where they were examined for parasites and ova using the MIFC procedure (Blagg, et al., 1955).

Field activities started in April, 1976, and were completed by November, 1976. All specimens were examined by May, 1977. The coded results were key punched and the data transferred to magnetic computer tapes. The data on these tapes, which contained over three million characters, have been analyzed at the University of Michigan computer facilities.

Overall prevalence figures and age-sex curves combined from all study sites in a given study were adjusted for sampling fraction.

Results

In the villages located in the Nile Delta, Upper-Middle Egypt, and in Upper Egypt, 12,933 persons were selected and 93.2% attended the examination. Of those who attended, 6% did not give a specimen (11,555 specimens in all were examined for these sites). In the Nubian sample, 3,275 persons were selected and all attended the examination. However, only 2,782 gave a specimen, or 85% of the total. The age distribution curves of the sample were remarkably similar from site to site, and also paralleled age curves drawn from the 1960 Egyptian census. This is a good indication that the sampling techniques used were consistent and representative of the population from which the sample was drawn. Figure 1 is the age curves from the five study sites in Aswan (Upper Egypt). Figure 2 shows the relationship between the sample from Kafr El Sheikh (North Central Delta) and corresponding census data. Both graphs show typical results.

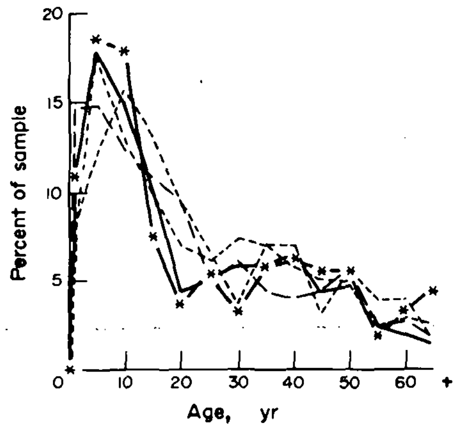

Figure 1. The age distribution by study site in the Aswan study area. Each line represents a study site.

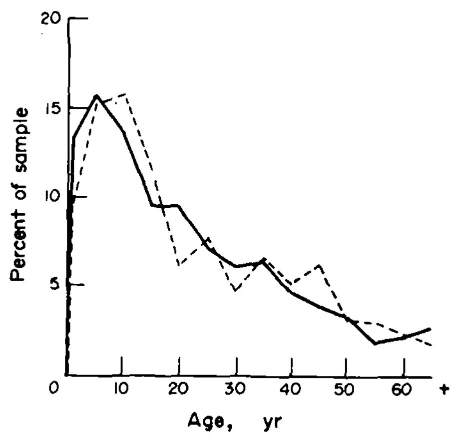

Figure 2. The adjusted age distribution from the Kafr El Sheikh study area and compared to the age distribution for this same rural area according to the 1960 census data (CAPMAS, 1960). The solid line represents the data from CAPMAS (1960); the dashed line, from the sample.

Figure 3 shows the age and sex distribution of schistosome infection in the four respective study areas (including the Nubians). Prevalence figures, adjusted for sampling fraction and age structure, were highest in the north central delta study sites (42.1%). This included all those infected with either or both species. Generally, S. haematobium prevalence was higher than S. mansoni.

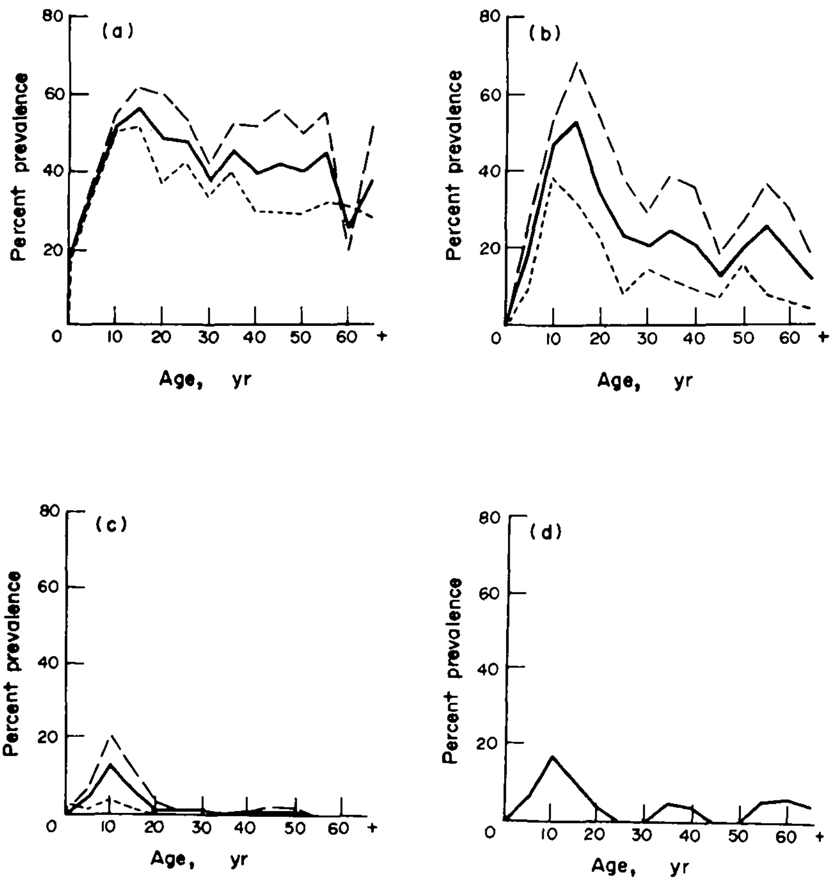

Figure 3. The age-sex prevalence of schistosomiasis in (A)North Central Delta; (B) Upper-Middle Egypt; (C)Upper Egypt; (D) Nubia. In (A), the prevalence curve represents all those infected with either or both species. In (B), (C) and (D), the prevalence curves represent S. haemotobium infections. The broad dashed line represents males; the solid line, both sexes; and the short dashed line, females.

The predominant schistosome infection found in the Upper-Middle Egypt study sites was S. haematobium. The overall prevalence was lower than in the Nile Delta (26.7%). Sporadic S. mansoni infections were noted. Seven cases were observed in children under fourteen years of age, and one case was seen in a male infant. The total number of cases with S. mansoni infections was twenty, less than one percent of the sample. This is the first evidence that S. mansoni infections have been acquired outside the Nile Delta.

Prevalence in the study sites of Upper Egypt varied according to the location of the village. Villages built on high, dry, barren ground, typically seen in the narrow confines of the Nile Valley in the Aswan region, had a very low prevalence (4.1 after adjustments). These villages were labeled "desert villages". Villages sampled in the Kom Ombo plain, about 60 km north of Aswan city, were surrounded by cultivated fields. In these villages, called "agricultural villages", the prevalence of S. haematobium was over five times greater (24.8%).

The difference in prevalence between the sexes was greatest in Aswan and least in the Nile Delta study areas. The prevalence in males from the Upper Egypt sites was four times higher than females, 2.1 times higher in Upper-Middle Egypt, and 1.4 times higher in the Nile Delta. The prevalence of S. haematobium for males alone in Upper-Middle Egypt was actually higher (37.7%) than for males in the north central delta (33.2%).

The source of water for domestic use and the prevalence of schistosomiasis was highly related. Prevalence decreased as the quality of the water source improved. Those who had indoor taps had a lower prevalence of schistosomiasis than those who obtained their water from an outdoor public fountain or standpipe. The prevalence was highest in those who obtained their water from canals or drains. The availability of protected water has greatly increased in the rural Egyptian villages over the past twenty years. There is now at least one standpipe, supplied by a deep well or water treatment plant, in every village, and the majority of the population studied used the protected supply as a source of water.

The overall adjusted prevalence of schistosomiasis in the resettled Nubian population was 7.2%. This is a reduction by half in the overall prevalence of schistosomiasis in the Nubians since the 1964 study by Zawarhy before their relocation.

Discussion and Conclusion

An environmental and epidemiological survey was completed on 15,329 rural Egyptians who were selected from the three major geographical regions of the Nile Valley and from the resettled Nubian population. Estimates based on these findings suggest that a minimum of 6.9 million Egyptians are infected with either S. haematobium or S. mansoni or both. Prevalence of infection was highest in the Nile Delta and decreased from north to south.

Data on the prevalence of schistosomiasis from Scott (1937), Wier et al. (1952), Farooq et al. (1966), Alamy and Cline (1977), and our current results show that S. haematobium infection in the Nile Delta has declined over the past forty years. S. mansoni has also been declining in the northern parts of the delta, but the recent findings of Alamy and Cline indicate that the once limited distribution of S. mansoni infections are now expanding southward. We observed locally acquired infections of S. mansoni 150 km south of the Nile Delta. This is the first time that S. mansoni infections have been see outside the Nile Delta, but the prevalence remains very low in this area. There is no doubt that the distribution of S. mansoni is in transition.

It is tempting to cite the Aswan High Dam as the causative factor of this change in distribution. However, until evidence is available to show why S. mansoni has not always been found in parallel distribution with S. haematobium in Egypt this explanation is only speculation. It is doubtful that the distribution of the snail vector for S. mansoni can be explained by changes in river hydrology alone. Furthermore, a decline in the prevalence of S. haematobium can be shown for the study sites in Upper-Middle Egypt. Table 2 shows a dramatic increase over a period of forty years in this area.

TABLE 2. Upper-Middle Egypt: Percent prevalence of S. haematobium by selected years.

Year	Percent Prevalence
1937 (Scott)	82
1955 (EMPH)	36
1968 (Hamman, et al.)	35
1976 Upper-Middle Egypt (Beni Suef)	27

In Upper Egypt, the prevalence of schistosomiasis was generally low in the 1930's (Scott, 1937) but where there were irrigation schemes as in Esna, Idfu, Naga Hammadi, and Kom Ombo, prevalence figures paralleled those found in Lower Egypt (Khalil and Azim, 1938). Although the data on the prevalence of schistosomiasis for Upper Egypt is more limited, there is evidence that S. haematobium infections had risen sharply in both Aswan and Sohag by 1955 (EMPH). Inferences to explain this change must be drawn from irrigation data. Information from the Egyptian Ministry of Agriculture (Shindy, 1977) shows that all three governorates of Upper Egypt, Aswan, Qena, and Sohag, had developed irrigation schemes fed by pumps installed on floating platforms before Lake Nasser began to fill in 1964.

There is no collaborating data from this period to show what changes occured in the prevalence of S. haematobium. In Sohag, pumps and canals were apparently installed before 1955 as the prevalence had increased from 3% in the 1930's (Scott, 1937) to 42% (EMPH) by 1955. The findings of this study from the agricultural village types of Upper Egypt suggest that 1) the prevalence in Upper Egypt now parallels that of Upper-Middle Egypt; 2) there was a burst of infection in Upper Egypt in the 1950's and early 1960's as pumps and canals were installed followed by a gradual drop in prevalence to current levels; and 3) that all future work in Upper Egypt must include a measurement of prevalence in the desert type villages as well, before truly accurate estimates can be made. In regard to the last point, we have already begun new surveillance studies in the Qena province where information on the prevalence and distribution of schistosomiasis is most limited.

Two epidemiological surveys were made of old Nubia before relocation in 1974, one in 1958 by Rifaat and Nagaty (1970) and one by Zawahry in 1964. Both found perennial irrigation schemes at various locales. Zawahry based his study on a multi-stage stratified random sample of the entire Nubian population in Egypt. Although the Nubians are now compressed into a much smaller area, resettlement did not disrupt tribal and village patterns. Often neighbors were resettled beside neighbors. These two factors - precise sampling techniques and an orderly resettlement, greatly facilitated this follow-up study. Zawahry had found an overall prevalence of 15.2% with S. haematobium. We examined the same villages that Zawahry had selected but increased the sample size by four times. As pointed out, the overall adjusted prevalence was 7.2%. This is a strong indication that the Nubians have benefited, as far as schistosomiasis is concerned, from resettlement.

There are several possible explanations for this drop. One, the Nubians were resettled in villages strategically located away from the canals and fields of Kom Ombo. Two, treated water supplies were provided in every village. Three, the resettled Nubians were compensated by the government with land in the Kom Ombo plain. As landowners, the Nubians can and do hire locals to till and tend the fields. Four, schools, clubs, social centers, electricity, and more importantly, rural health units were all built into the resettled sites. The real question concerning the Nubians is "Why is the prevalence of S. haematobium, at 8.8%, still so high in these villages?"

In conclusion, we feel that there is sufficient historical and current data to firmly disregard any role of the Aswan High Dam in causing an increase in schistosomiasis in rural Egypt. Indeed, all available data points to an overall decrease rather than an increase and this includes the resettled Nubians. The decreases in prevalence over the past forty years can best be explained by the improvement in the domestic water supply to the villages, the development of health care and delivery (there are now 2140 rural health units and centers), the improved distribution and availability of pharmaceuticals, and also by an increase in the general awareness by the population at risk of how to avoid infection and how to get treatment. It should be borne in mind that forty years ago the environmental conditions in rural Egypt were optimal for transmission and in many areas the prevalence in the population had reached a maximum level.

Nevertheless, schistosomiasis is still found in an estimated minimum of 6.9 million rural Egyptians. Furthermore, the doubling of the population over the past three decades has resulted in a continued increase in the number of new cases. Population growth is a frequently ignored but important aspect of schistosome transmission. There still remains such aspects as new areas, land yet to be reclaimed for agricultural expansion, and the new lake, where schistosomiasis can still spread. Also, the potential change in distribution of S. mansoni infections into areas south of the Nile Delta poses possible future problems. Surveillance programs are strongly recommended in order to detect early changes.

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WATER SUPPLY AND SCHISTOSOMIASIS IN ST. LUCIA

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INTRODUCTION

The need for rural water supply, whether for political, social or health reasons is receiving greater attention in developing countries today. Such rural water supplies can be effective in disease control such as schistosomiasis provided certain design criteria are given consideration.

The transmission of schistosomiasis requires low level sanitation and frequent contact (Fig. 1).

Reduction of water contact through the provision of a safe and convenient water supply and its effect on transmission was one of the approaches investigated in St. Lucia. Evidence that the provision of a safe potable water supply could help in reducing transmission came from S. Africa (1, 2) and Brazil (3).

DESCRIPTION OF PROJECT

Five rural communities in the southwestern part of Riche Fond Valley in St. Lucia with a total population of about 2000 were provided with a household water supply designed to deliver a convenient and reliable water service. The main objective of the water supplies, which became operational in 1970, was to make it unnecessary for villagers to contact infected rivers and streams.

The comparison area includes six settlements in the same valley, but on the opposite northern side. In this area a standard government rural water scheme was introduced in 1969 with communal standpipes at intervals along the main road and at various points in the villages.

To evaluate the benefits of water supplies on the health of the community, especially the effects on transmission of schistosomiasis, it is necessary to plan for adequate quantities of water conveniently available at all times.

As the settlements were all near the rivers and streams the project was designed to provide a hydrant near each house (Fig. 2). In addition laundry-shower units (Fig. 3) and simple swimming pools (Fig. 4) were located at strategic locations in the communities.

The laundry-shower units contain six or eight sinks and four or six shower stalls depending on population density.

All household and laundry-shower outlets were fitted with fordilla valves. These spring-loaded valves close automatically after a few seconds and discharge a fixed amount every time they are reactivated. Thus reducing waste without significantly reducing the beneficial consumption. These were modified for foot operation in the showers. With this type of service outlet it was possible to determine the true water requirements of the rural communities.

Pre-control investigations included a survey of available water sources, a house and population census and four annual parasitological surveys.

To assess the main aim of keeping people out of rivers and streams, water contact studies were undertaken at 15 sites on the main river and its tributaries and quantitative data collected on the age and sex of persons having contact with water, the reason for it, the time of day, the duration and extent of each contact.

RESULTS

After eight years of constant metering the daily requirement has consistently remained at just under 45 litres per person. This suggests a design based on 60 litres per capita per day is adequate. More recently 60 lpcd was used in St. Lucia to design a distribution

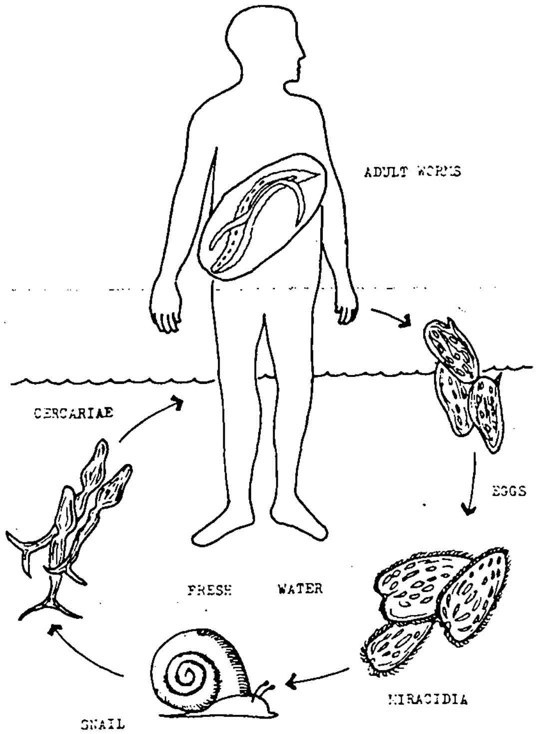

FIG. 1 LIFE CYCLE OF <u>SCHISTOSOMA MANSONI</u>

Fig. 2 Typical household water supply

Fig. 3 Laundry-shower unit with children accompanying the mother to wash and bathe

Fig. 4 Simple swimming pool centrally located in the community

system for two settlements serving a total number of approximately 5000 people and this has proved to be adequate.

Rural water systems in Guatemala have successfully used this design figure, with fordilla type faucets (4).

This figure, which is three to four times less than those now used in many developing areas, could make some water schemes feasible which are now out of consideration due to the high volume requirements.

The domestic water consumption in the water supply communities has increased three-fold from pre-supply usage. The laundry-shower units are used extensively and it may be interesting to note the daily water demand averages 1900 litres for the laundry units and about 750 litres for the shower units. Initially the swimming pool use was below expectations but this seems to be changing with greater use observed in recent years. Local feeling that the standing water is stale water may be partially responsible for the slow acceptance of a locally new form of water play. The daily chlorination of pools has little meaning to people unfamilar with chemical treatment, thus it may seem less attractive to some than flowing water. However, an important fact is that children are no longer bathing in the rivers due in part to the mothers no longer washing and bathing there.

Water contact studies made under similar conditions as pre-controlled studies showed a reduction of 82 per cent in the number of contacts and a reduction of contact time of 96 per cent in the first village supplied with water.

Parasitological results are used to determine the true effects of water supply on the transmission of schistosomiasis. There are several terms used for this evaluation, namely incidence, prevalence, intensity and the potential contamination factor.

Changes in incidence of new infection

The rate of incidence is the number of new infections for a given period (usually one year) expressed as a percentage of the total number in a specific group who were negative on a previous examination. This measurement is more sensitive and responds more rapidly to changes in infection rates than do the other forms of measurement. The change in incidence of new *Schistosoma mansoni* infection in children up to ten years old living in the first community to be supplied with water is shown in Fig. 5. The overall incidence of new infections for this age group fell from 31 per cent prior to water being provided to 12 per cent in 1975 after 5 years of water supplies.

Changes in prevalence

The prevalence of an infection is the number of persons in a specific group found infected expressed as a percentage of the total number examined. Because the infection of *S. mansoni* is retained for many years the changes in prevalence are registered more slowly. The prevalence rate for all age groups in the first community to be supplied with water dropped from 72 per cent to 36 per cent between 1970 and 1975. The peak rates usually occur in the second decade of life (Fig. 6).

The time required for installing the three water systems was just under two years. Figure 7 shows the prevalence for the total population within the area having water supplies for a period varying from three to five years and also the prevalence of the population in the comparison area for the years of 1970 and 1975.

Intensity of infection

The intensity of *S. mansoni* infection is the geometric mean of egg counts expressed in terms of eggs per ml of fecal material obtained from stool examinations. This measurement is relevant for at least two reasons. First, people with light infection may have very little health impairment. Secondly, the number of eggs excreated are related to the degree of contamination of the environment.

The intensity of infection was generally higher in the project area than in the comparison area prior to the water installation. During the years following water installation the egg loads gradually decreased and by 1973 for the first time the intensity was greater in the comparison area than the water supply area.

Changes in potential contamination index

The potential contamination index is a measurement of environmental pollution with *S. mansoni* eggs. The index is the sum of the prevalence multiplied by the intensity of different age groups and the percent of the age group in the population.

Over a five year period the index of potential contamination was reduced in the communities provided with a water supply by 70 per cent (Fig. 8) which means the chances of someone becoming infected by water contact has been greatly reduced.

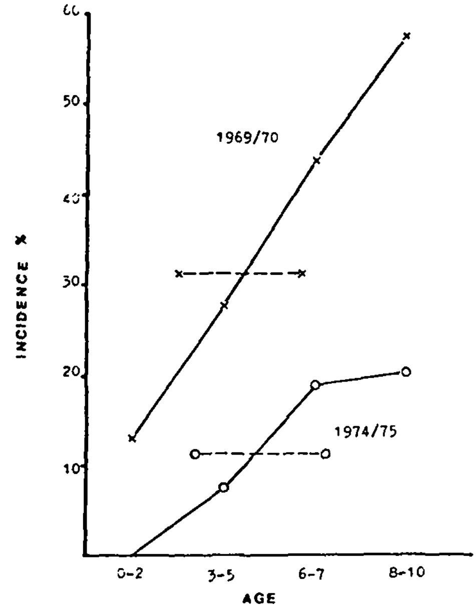

FIG. 5 Incidence of new S. mansoni infections
Before and after 5 years of water supply

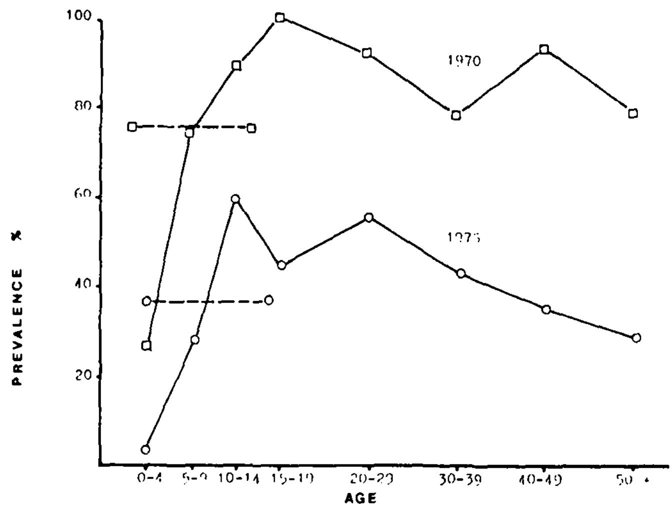

FIG. 6 Prevalence of S. mansoni infections after 5 years water supply

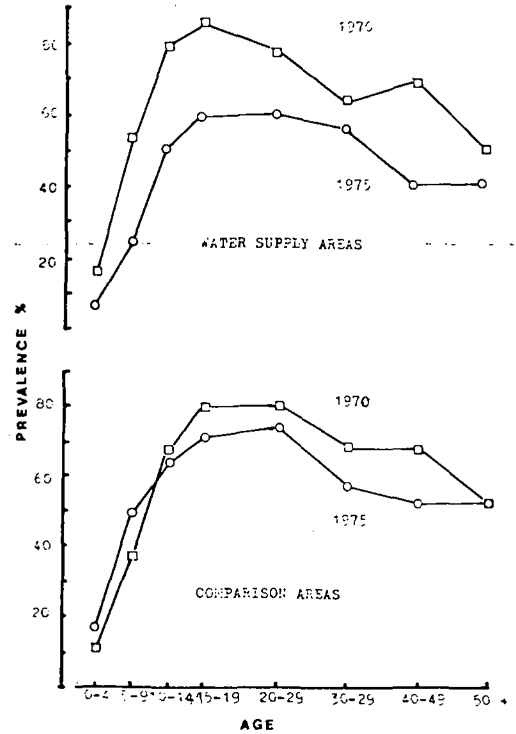

FIG.7 Prevalence of S. mansoni infections in water supply and comparison areas

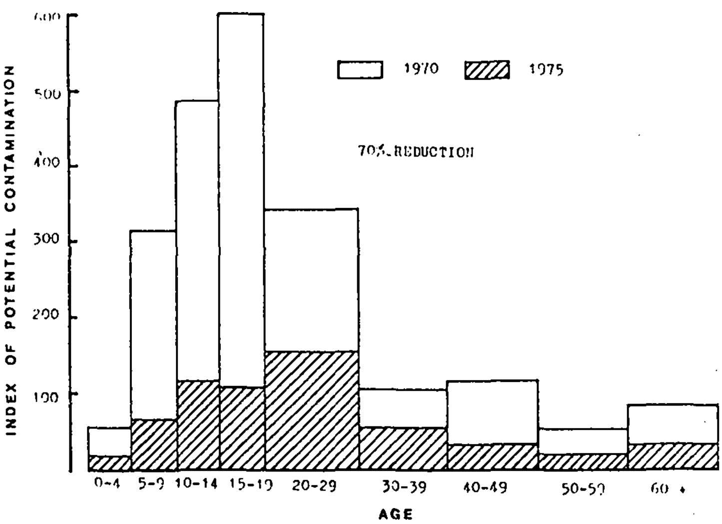

FIG. 8 Index of Potential Contamination in Water Supply Areas

From these data it is clear that the experimental water supplies had a significant beneficial effect on transmission of S. mansoni. The water supply area is within a kilometer of the large comparison area, where many of the children regularly attend school and church, and some of the new infections were likely acquired in the comparison area. Had the project area and the comparison area been separated by greater distance, the changes might have been more dramatic.

Some further observations should be made concerning the comparison area. The public standpipe supply did not contribute to a reduction in transmission even though this source provided essentially all the water for domestic purposes. The river continues to be used for all other water requirements. It is also noteworthy that in 1968, prior to the installation of the standpipe supply, the households near the river and future mainline were found to have a higher prevalence rate of S. mansoni (especially children) than others living further away. Some of the houses near the mainline paid for private connections in the next several years after Government supply was installed. In 1976 the prevalence was significally lower among all age groups living in houses with water connections compared with rates of persons in houses without water, especially among children. Children under fifteen showed the greater differential in prevalence. A significant increase in prevalence was noted in households depending on the public standpipe and the river for their supply. (P. Jordan, personal communication 1977)

DESIGN FACTORS RESULTING IN DISEASE CONTROL

Some discussion of the design factor used in these systems which provided the above results may be important.

Supply source

The supply may come from a variety of available sources ranging from surface water such as ponds, streams and canals to underground water from springs, hand-dug shallow wells and deep tube wells. In all cases the supply should be protected from pollution, otherwise the system may become a transmission vehicle for diseases it should prevent. Extra effort spent on source protection, can yield good dividends and savings on treatment down the line. Careful attention given to the intake location and design can reduce the treatment required.

Limited financial and other resources for construction of major dams, reservoirs or lengthy pipe lines may make these not feasible in a developing country and it may often be more appropriate to develop low volumes, relatively cheap sources of water supply for rural settlements. This approach was used in St. Lucia where a number of small sources were developed using either small diversion dams or infiltration galleries as intake (5).

Storage and sedimentation

Storage and plain sedimentation can provide simple and effective water treatment under favorable conditions. During storage there is a substantial reduction of bacteria and pathogenic organisms which are removed by sedimentation and are also sensitive to changes of temperature and food supply especially in hot climates.

Some studies in the TVA reservoirs showed 80 percent coliform reduction in water after impoundment. Other studies have shown as much as 99 per cent coliform reduction between influent water and effluent water (6).

Storage is required to ensure an uninterrupted supply when peak demand exceeds the capacity of water source. For example, in St. Lucia a storage reservoir of 84 cubic metres provides an adequate supply during peak periods to about 100 households from a source that produces at the rate of approximate 170 litres per minute.

Storage can be valuable in the control of schistosomiasis since the free swimming miracidia must find the intermediate host, the fresh water snail, within a few hours after hatching. Cercariae from the infected snail must find a human or animal host in less than 48 hours in order to survive. Thus two day's storage capacity is sufficient to provide a barrier to transmission provided infected snails do not enter the reservoir. If storage can be substituted for sophisticated treating equipment, the maintenance of a system is greatly simplified and made less costly.

Treatment and water quality

Since the sophisticated treatment of water may not be an absolute requirement for all rural water supplies, the decision on the type of treatment, if any, must be approached on the basis of what choices are appropriate and feasible in each particular system.

In St. Lucia simple types of treatment were used in the interest of experimentation (5). These varied from plain sedimentation to infiltration gallery each combined with storage but not chlorination. These systems have been operational for eight years and no water related epidemics have occurred during this period. Bacteriological analysis of water samples routinely collected, examined by membrane filter technique, showed an average of six Escherichia coli per 100 ml with 28 per cent having zero counts for sedimentation-storage and an average of two E. coli per 100 ml for the infiltration gallery-storage and 64 per cent of the samples with zero counts. Although chemicals are kept available, if needed, no chlorination has been required.

This experience supports proponents who have maintained that international water quality standards, such as recommended by World Health Organization (7), are too stringent for hot climates. Such standards, strictly applied would lead to condemnation of the vast majority of existing water supplies in the developing communities. With limited resources available it would be better to evaluate the prevalent diseases in the area where water supply improvements are planned and design the appropriate system within the available resources. This will usually result in an improved supply even if not a perfect one.

There are circumstances when treatment will be necessary and beside storage already mentioned there are various types of filters which can be utilized to remove suspended matter, ova, cysts, cercariae and much of the bacteria. Horizontal sand filters may be effective in preventing cercariae passage. In St. Lucia laboratory experiments with local river sand (effective size 0.37 mm, uniformity coefficient 13) placed in 1.5 metres long horizontal chambers (cross-section 40 cm x 40 cm), prevented the passage of schistosome cercariae (Unrau and Upatham, unpublished data).

Ordinary slow sand filters and rapid sand filters can provide significant amount of biochemical purification.

The final method of treatment is water disinfection. Water can be disinfected by boiling but this can become very difficult, tedious and even expensive in localities where fuel is scarce or is done on charcoal pots. Chlorination is usually the cheapest method but the chlorine supplies must be reliable for there is little value in spasmodically treating a supply.

For smaller systems manual addition of grandular or powdered hypochlorite to the storage tanks on a daily basis can provide effective results if the storage tank has adequate capacity. Sodium or calcium hypochloride may be easier to obtain in developing countries than chlorine gas but these compounds are unstable and lose their strength during storage or when exposed to air and sunlight.

Small scale household chlorination can be easily and effectively accomplished by using ordinary laundry bleaching solutions which contain from three to five per cent chlorine. One to three drops of solution added to one litre of water will provide a dosage of approximately two to five miligrams per litre (8)

Distribution

The ultimate goal of water distribution should be the delivery of water from a source to the final consumer by the most efficient and economical method. This distribution should be as wide as possible with greatest emphasis on convenience. People tend to use the water which is most convenient for them, be it hydrant, well, river, spring or lake. Quality is not often a part of the consideration since the most convenient source has probably been used for generations prior to a water supply system regardless of its quality.

The key to an effective water delivery system is good distribution, without this the investment is likely to be buried without achieving either its public health or social purpose. The potential benefits in each particular case must influence the decision on the most appropriate and useful improvements. In regions where substantial effort is required to collect water the saving on time and energy may be an important design benefit for water improvements. An extensive study in East Africa (9) showed that water carriers spend a mean time of 46 minutes daily collecting water and in some communities nearly 4.5 hours were needed to collect their water.

Water improvement usually means some improvement in distribution, thus the community standpipe often comes to mind which is a very common type of rural water delivery system. This type of delivery usually satisfies many of the political and social requirements but is less satisfactory with regards to improved health needs.

The public standpipes have many disadvantages in that people will carry insufficient amounts of water to their homes for good hygiene. Furthermore, carried water is frequently and easily contaminated. In St. Lucia water contact studies indicated that standpipes were used for drinking water supplies but river and streams were used for all other water needs such as bathing and clothes washing. The maintenance of a public hydrant is more difficult because of careless use by many people, none of whom considers it his property or responsibility. Long queues at peak hours sometime lead to quarrels among the carriers resulting in waste and damage to the standpipe.

A preferred system is delivery of water to an individual household. The simplest form being a single outlet in or near the house. This eliminates water carrying outside the premise, encourages cleanliness and adequate use for health and hygiene.

Increasing the number and reducing the distance of a standpipe to within 100 metres of all residence might overcome some of the problems mentioned. However, once the essential equipment and materials for an adequate public hydrant supply have been purchased and installed the added capital cost of an individual household supply is but a small fraction of the total expenditures. In St. Lucia the cost of individual service amounted to an average of 10 per cent of the total expenditures but this will vary according to the density and distribution of the houses in each village (5).

Water wastage

Water left to run at hydrants usually causes drainage problems. Waste water can become small pools of stagnant water and mud or create swampy areas, ideally suited for snail habitats which easily become transmission sites for schistosomiasis. The wet swampy areas also are ideal breeding and resting areas for mosquitoes and other biting insects creating a nuisance and a reservoir for disease carrying insect vectors.

The muddy wet ground frequently found near the hydrants or wells adds to the physical unattractiveness of the environment and often become a place where domestic animals gather. Soil transmitted helminths such as hookworm, ascaris, etc. need moist soil for the ova or larve to survive and thus indirectly water wastage may play a role in transmission of some of these diseases.

In addition the wasted water may have been pumped, stored and treated to meet the physical, chemical and bacterial requirements. Where storage and sedimentation is the choice of treatment the storage capacity may be inadequate to provide the designed retention time due to excess waste of water and in fact reservoirs may even run dry. Any and all of these factors add to the cost of water supply.

It is common to see valves left open with water flowing freely, especially when the supply is not metered or paid for on the basis of amounts used. Such wastage is difficult to control especially at communal outlets. Attempts to police the water wastage problem is usually not very effective due to habits, culture or education of the population.

Numerous devices and techniques to reduce waste have been tried including such things as small diameter pipe or small orifice outlets to limit the flow. Spring-loaded valves are also relatively common. Unfortunately customers are often quite adept at devising ways of faulting these devices. One acceptable solution for these wastes can be the adoption of flow limiting devices like the fordilla faucet.

Several favorable reports on the use of fordilla valve (4,10) resulted in this valve being used in all the experimental water supply projects in St. Lucia. These valves have been very successfully used for eight years in several projects, with the water saved soon paying for the additional cost of the faucet.

Additional economic design benefits can be realized by the use of the fordilla valve which permits the use of smaller diameter and less expensive distribution lines because of fewer valves being open simultaneously. It also allows the use of supply sources, such as small streams, which would otherwise be inadequate in quantity to provide a constant supply.

Recent studies comparing the fordilla valve to the ordinary free flowing valve at public hydrants in St. Lucia showed a saving of up to 44 per cent of the supply in densely populated areas and at least 11 per cent in sparsely settled areas could be realized through the use of a flow limiting valve.

COMBINED PROJECTS

It is not expected that household water supplies alone will rapidly lead to a complete cessation of transmission. Therefore another project area was selected for the evaluation of combined control techniques. Two communities, the first containing approximately 600 houses and the second 400 houses, were selected for combined control methods. The community of 600 households was supplied with individual water supply and chemotheraphy was offered to all positive persons. The other community of 400 houses was provided with household water supply and water seal latrines.

Central Water Authority provided the source from a river high in the interior of the island and provided the major main lines and Research & Control Department was responsible for the installation of the household distribution, chemotheraphy and water seal latrines. Since the water installation was completed in late 1977 and latrines in early 1978 the results of this project are not meaningful at this time but these systems will be monitored until 1981.

Additional studies

The provision of adequate safe water does more than reduce transmission of the schistosomiasis parasite - it should reduce the presence of intestinal helminth, bacterial and viral diseases in addition to the normal utility benefits to the community.

To evaluate the effects of sanitation on infant health 227 infants below six months of age were enrolled in a prospective longitudinal study.

A third of the infants live in a valley where most of the water comes from local rivers and few homes have primative pit latrines. Another third of the infants live in a valley which recently received individual household water supply but waste disposal is by primative pits. The last third of the infants live in a valley recently supplied with individual household water and water seal latrines.

The socio-economic and cultural attributes of these three valleys are identical except for recent water supplies and latrines.

Mothers of the infants note the presence or absence of diarrhea daily on a card and monthly measurements of length, weight, arm circumference are made at home visits. Serum specimen are taken every three months for assay of antibody against rotavirus and the enterotoxin of E. coli. Every six months a stool specimen is analyzed for intestinal roundworms and S. mansoni.

Preliminary findings after six months of measurements show the infants in the valley with poor water supplies and sanitation are significantly shorter and lighter than those in the valley with water and latrines. Diarrhea rates in these two valleys are significantly different. Parasitologic and serologic tests results are too preliminary for comment (R.W. Goodgame, personal communication, 1978).

SUMMARY

The experimental water projection in St. Lucia have demonstrated that impressive results can be obtained in the reduction of transmission of schistosmoiasis when adequate, reliable and conveniently delivered water supplies are available. The water supply in the comparison area was unreliable, inadequate and inconvenient during the study period and thus had no effect on the transmission of schistosomiasis.

Not only was there a reduction in the prevalence of infection but also a reduction in the intensity of infection which may be more important over a longer time span.

The project also demonstrated that conveniently delivered water can change old customs and habits, such as washing and bathing in the river. As a result of the reduced water contact, not only is infection prevented but contamination of the water is decreased.

Aside from the direct health benefit associated with safe water supplies, there are many other "quality of life" benefits which places it on a high priority when any communities improvements are considered. Because water supplies are not disease specific authorities may find it more acceptable when interested in the broad spectum of social and health programs.

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SANITATION AND DISEASE IN BANGLADESH URBAN SLUMS AND REFUGEE CAMPS

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Abstract
Faecal pollution of the environment on a massive scale has made excreta-derived disease a normal part of life in Bangladesh. There are probably in excess of 250,000 cases of clinical cholera annually. In children under two years of age, living in refugee camps between 33 and 66% have at least one attack of diarrhoea and the consequences are often extremely serious when combined with poor nutrition. In many parts of the country parasite prevalence is extremely high e.g. > 95% for Ascaris. The obvious remedies to these problems are
1) an adequate means of managing human excreta and ensuring a safe water supply,
2) an insistence on basic personal hygiene through social pressure, and
3) a basic health service including an educational element. The emphasis in this paper, which reflects part of Oxfam's programme in Bangladesh, is on attempts to find suitable sanitation technologies.

INTRODUCTION

In 1970 there was a serious cyclone in East Pakistan which resulted in an estimated 50,000 deaths. This disaster helped to precipitate, a few months later, a bloody civil war which caused eight to ten million refugees to flee over the borders into India. By early 1972 many of these refugees were returning to the renamed nation of Bangladesh. They returned to a country which was bankrupt and one in which the existing poverty is exacerbated by annual flooding of much of the land resulting in crop damage and food shortages or famine. A major effect of these tragedies was to increase the slum dwelling population around the major cities by hundreds of thousands. The ghetto type Bihari community alone is estimated at between 300,000 and 400,000. The mean population density overall, in Bangladesh, is between 1,000 and 1,500 per square mile, and this is obviously many times higher in urban slums. The task of installing and maintaining basic public services such as conventional sanitation and sewerage systems in these circumstances is overwhelming. Inevitably it is in these situations that there exists the highest incidence and prevalence of the majority of those infections which are transmitted from excreta. Therefore there is the greatest need for effective sanitation, a safe water supply and basic hygiene.

SANITATION SYSTEMS IN USE

One of the commonest places for excreting both in rural and urban Bangladesh is the shielded site. This is used by one or a number of families and may take several forms, but essentially it constitutes a bamboo frame covered with either jute hessian, as in Fig.1, or woven bamboo or occasionally corrugated iron sheeting. These structures provide privacy for the act of excreting only and the excreta deposited on the ground is not contained or treated in any way. These points of excretion are often located on the slope of a pond or stream. These sites have an attendant animal population which includes rats, cockroaches chickens and pigs all of which feed on the excreta and enter surrounding homes frequently. Another equally common type of excreta site, because of the great number of water courses, is in the form of a small landing stage constructed directly over water (Fig. 2). Hence soil and water contamination by excreta occurs on a massive scale. A third type is a pit latrine used by individual or several families. The pit usually has a fixed concrete cover and has no access point other than the squat hole. As there is no simple way of desludging the pit no servicing is carried out. Once full therefore the latrine area becomes fouled but as people require a facility they continue to return to the same area to excrete.

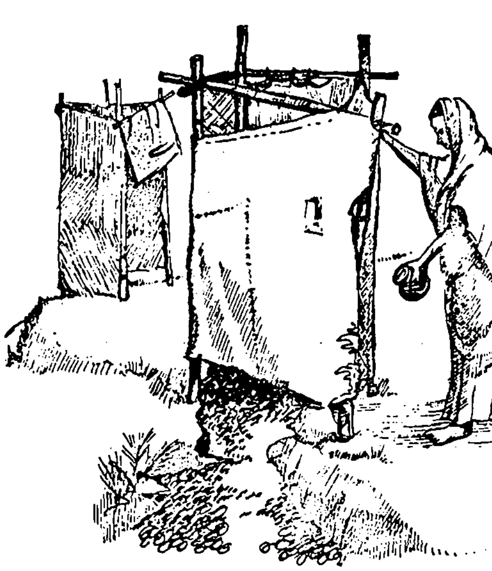

Fig. 1. Shielded site.

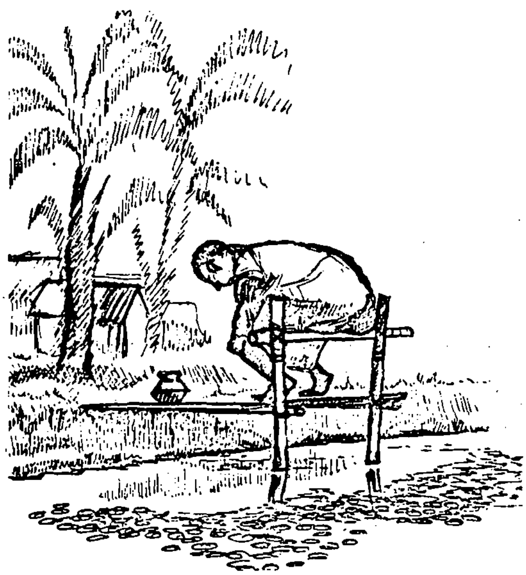

Fig. 2. Open site

Occasionally larger communal latrines of the type shown in Fig. 3 have been constructed for use in slums and refugee camps. In the type illustrated the squat plate area forms the roof of a brick vault in which the back is open for night soil removal. Often the lack of servicing results in the vault overflowing and excreta spills out of the back openings to foul the adjacent ground. Due to social abhorrence at being engaged in this type of work communal latrines are always neglected in terms of building repairs and maintenance and daily servicing.

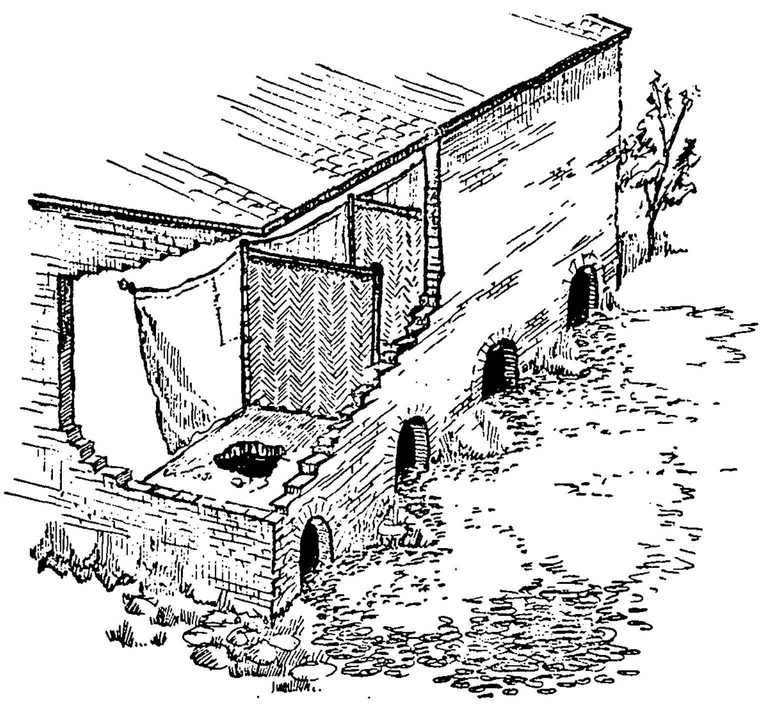

Fig 3. Brick vault communal latrine.

The scale of the problem of dealing with human excreta is highlighted in a recent nationwide survey conducted by the staff of UNICEF in Bangladesh. It is demonstrated that almost half the adult population (49%) and 86% of children use no latrine regularly and excrete promiscuously at no fixed place (Table 1).

TABLE 1. Facilities used for excretion in Bangladesh.

Type	Adults (%)	Children (%)
No fixed place	49	86
Open and shielded sites	46	11.5
Pit or borehole latrine	3	0.3
Waterseal latrine	1-2	1

It may be concluded from the foregoing comments that effective sanitation is practically non existent in Bangladesh. A first attempt was made in 1971, in the Bengali refugee camps in India, by Oxfam, to install communal latrines and excreta containment facilities. Figure 4 shows the installation which served 2000 people daily and which effectively localised excreta. However the plastic lined containment area was still open to the air and allowed flies to breed prolifically and produced unacceptable odours.

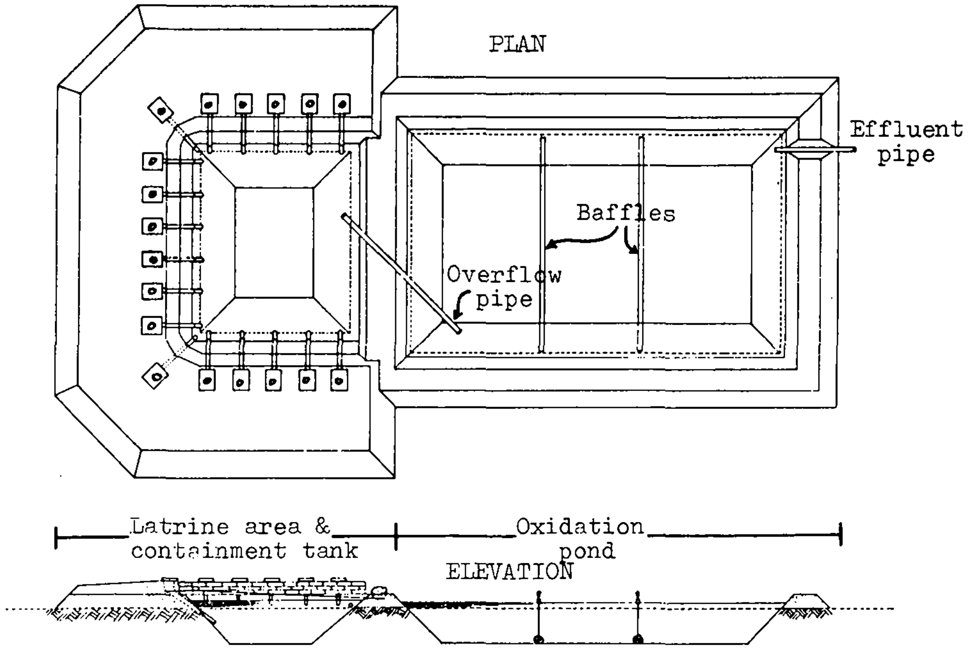

Fig. 4. Oxfam's first communal latrine (Type 1).

As a result of the experience gained in 1971 a three year period of research and development was undertaken to produce a packaged sanitation and sewage treatment unit (Type 2). Over seventy Oxfam type 2 units are now installed in Bangladesh serving a population of 70,000.

CRITERIA WHICH THE TYPE 2 SANITATION UNITS WERE DESIGNED TO SATISFY.

1. The provision of an acceptable place for excretion.
2. Retention of excreta in a protected water-tight location for adequate time to render it harmless.
3. Safe disposal of liquid effluent and of sludge.
4. Light weight and low bulk unit construction to facilitate transportation.
5. Presentation as a package complete with assembly instructions and tools required for installation by a small semi-skilled workforce.
6. Rapid installation should be possible within the shortest possible time of arrival at the intended site. It should be able to be installed in or on the ground, regardless of waterlogged or other adverse soil conditions.
7. The unit should function by gravity flow and be independent of a power source.
8. No chemical dosing procedures should be required.
9. Minimal maintenance should be necessary. This would include keeping the latrine area clean and flushed, and periodic desludging of the containment tanks by employing local labour.
10. It should ultimately be possible to drain, dismantle and relocate the unit.

DESIGN OF THE OXFAM (TYPE 2) SANITATION UNITS

The sanitation unit is assembled from the contents of a wooden crate 2m x 2m x 1m and weighing approximately 500 Kg. Each unit at the time of writing costs £3,200 with an estimated working life of 5-10 years. The first unit was installed almost 4 years ago and is operating satisfactorily. The unit consists of 20 glass fibre squatting plates which are assembled in to parallel rows of 10. Each row is connected to a 20 litre capacity flush tank which in the earliest installations was flushed manually by carrying water to the tank. In later installations tube wells have been drilled adjacent to the tank and flush water pumped direct into the tank. The excreta is flushed direct into the first of two treatment tanks from the 2 pipes below each line of squat plates. The pipework is plastic and of the push-fit type requiring no jointing techniques or special tools. It is ready for immediate assemble.

The two treatment tanks are composed of nylon reinforced butyl rubber with a capacity of 21,000 litres each. Each tank weighs 80Kg when empty and folds down to less than 1m^3. When rolled out flat and filled with water or sewage each tank measures 9m long by 2.8m wide and 0.9m high and has a pillow shape. The tanks are of standard design, each with a 100m inlet and outlet pipe connection, a desludging port at a low point on the tank, and a 50mm vent pipe for gas release at the highest point of the tank.

Each tank may be used singly as a containment unit for short term use. More commonly two tanks have been connected in series to treat sewage by sedimentation and anaerobic digestion as it flows slowly through the unit. The retention depends on the daily input; thus an input of 4,600 litres per day will give a retention time of 8 days for 2 tanks in series, whereas 2,000 litres per day provides a retention time of approximately 18 days. This is a vital factor in relation to the sedimentation and destruction of parasites and pathogens and the prolonged retention time produces a much greater efficiency in this respect than short retention conventional septic tanks.

Since the water used in the unit is less than 5,000 litres per day the effluent problem is minimised and it has been the practice to allow this to flow over a percolating filter constructed of locally obtained brick or stone. The percolating filter medium covers an area 1m x 1m with a minimum depth of 1.5m and it is fed by a V-notch distribution pipe. The effluent from the filter is allowed to drain to ground in a narrow trench within a protected enclosure which includes the tanks, percolating filter and desludge area. Thus the whole treatment area is enclosed by a bamboo fence.

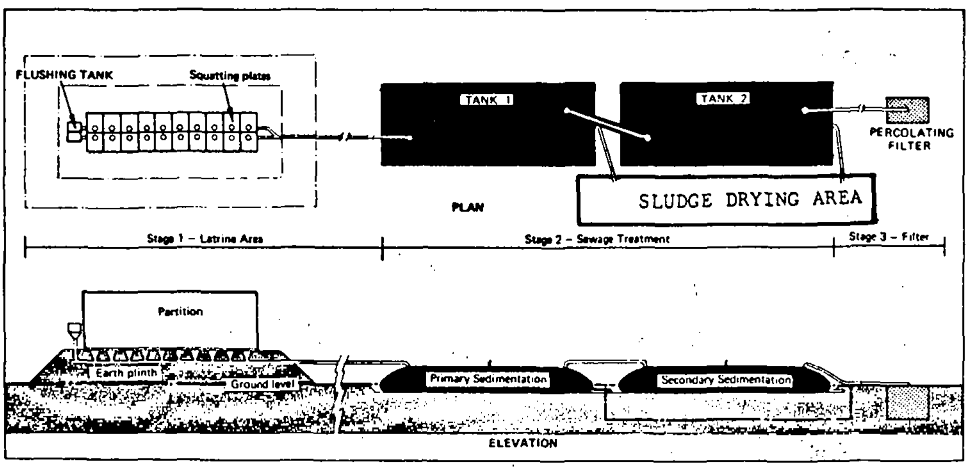

Fig 5. Oxfam sanitation unit (Type 2).

ON-SITE CONSTRUCTION OF TYPE 2 SANITATION UNITS.

In choosing the site for a unit the following factors have to be taken into consideration. The unit must be accessible to all families in the population to be served and therefore the site should be near the centre of the community. However the siting of the unit may be determined by the availability of an area large enough to accommodate latrines, tanks, and sludge drying beds i.e. approximately 440 sq.m. A source of water is essential and this is usually obtained by a hand operated 36mm (1½") diameter tube well. The water supply should be established first so that the latrine plinth can be constructed adjacent to it. Use should be made of any slope to the ground to assist the flow through the unit and to minimise the major element in construction time which is earth moving to produce the latrine plinth. The top of the plinth measures 5.5m x 11m. Advantage is taken of the plinth construction to excavate the sludge drying bed. A 2m difference is required between the top of the plinth and the bottom of the treatment tanks to ensure gravity flow. The treatment tanks are laid out on firm, level ground adjacent to the sludge drying bed. The three main components of the unit i.e. latrine area, tanks, and sludge drying bed can be laid out in several configurations and some of these are indicated in the Oxfam Sanitation Brochure (1).

MAINTENANCE OF OXFAM (TYPE 2) SANITATION UNITS

Due to the traditional lack of maintenance of sanitation facilities a major endeavour in the Oxfam sanitation programme is to ensure a high standard of daily servicing and cleaning. The following arrangements have been made or are recommended.

Daily maintenance.
Three cleaners are required per unit working 8 hour shifts with three spare cleaners per six units to give a six day working week. The cleaners primary functions are as follows:
(a) Flush the unit regularly.
(b) Clean the squatting plates 3 to 4 times per shift.
(c) Guard the unit.
(d) Wash the outside of the tanks daily to remove deposits of bird lime and other debris.
(e) Clean the distribution sheet and outlet holes on the filter daily.
(f) Check that the sewers are clean and unblock if necessary.
(g) Assist people in using the latrine properly.
(h) Refill the tanks after desludging.
(j) Notify supervisor of any damage or loss from the Unit.

Desludging.
Regular monitoring of the level of suspended solids at each stage of treatment has provided the most useful indicator of the efficiency of the sedimentation tanks. We have demonstrated a highly significant correlation between the removal of parasites by sedimentation as well as the removal of microbial pathogens which are largely adsorbed onto solids, and the retention of solids in the tanks. In particular the concentration of suspended solids carried over from Tank 1 to Tank 2 gives a very practical measure of the time at which desludging of Tank 1 is due.

This is clearly demonstrated in Fig 6 which shows in general a sudden and unacceptable rise in suspended solids at about 10-15 weeks after the previous desludge. A desludge cycle of 10-12 weeks has therefore been established with teams of 3-4 workers responsible for 12-15 units.

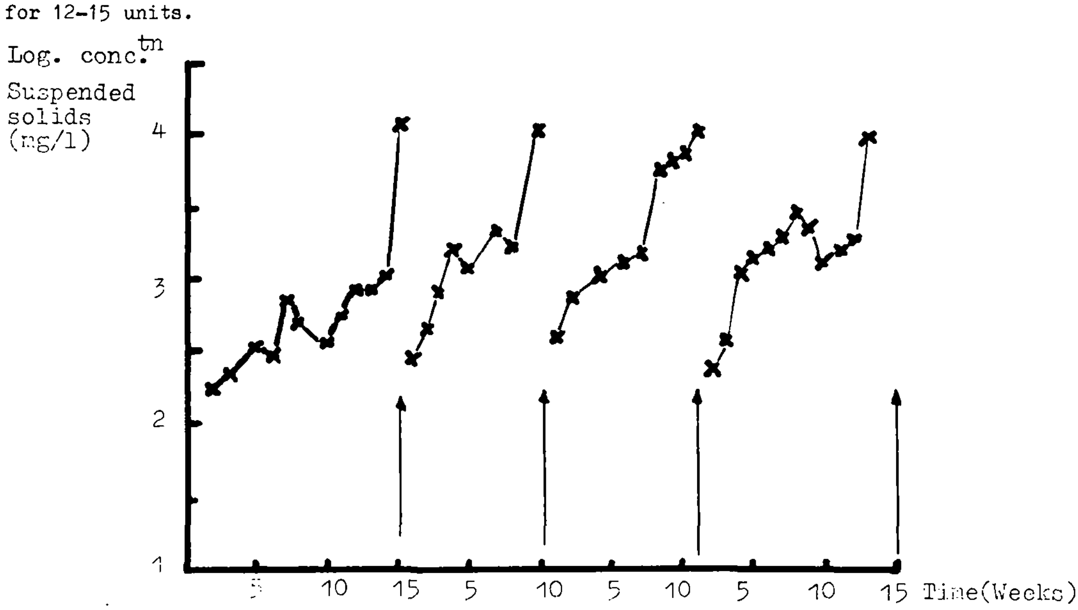

Fig. 6. Suspended solids in the outlet of a sanitation unit Tank 1 effluent. (Vertical arrows indicate the time at which desludging was carried out in the sludge accumulation cycle).

USAGE & ACCEPTABILITY OF OXFAM (TYPE 2) SANITATION UNITS.

Bearing in mind the established patterns of excretion in Bangladesh there was a major element of uncertainty concerning the social acceptibility of a sanitation programme, designed as a communal facility. Therefore at various times over the past 3 years detailed counts have been made of the number of indivduals using a sanitation unit over a 24 hour period. Although originally designed as a 500 use per day facility, data indicate that as many as 1,500 individuals may use a sanitation unit daily, and at every location counted 1,000 people (± 20%) used each unit daily. Figure 7 illustrates the average use of one unit.

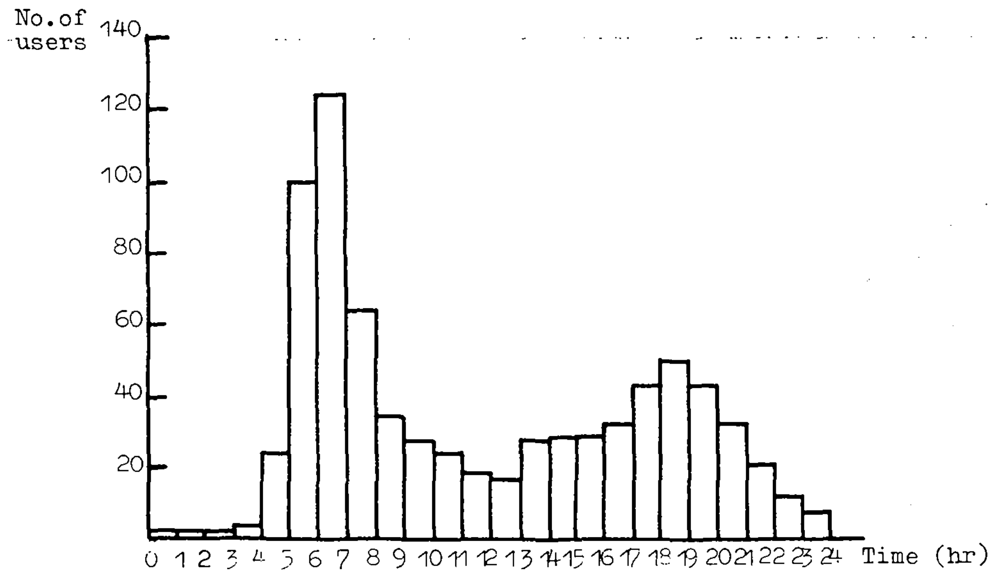

Fig. 7. Daily use of Oxfam sanitation unit (mean of 3 consecutive days).

Thus there can be no question about the acceptability of the facility provided and we would argue strongly that the key to this success is the employment of a latrine attendant charged with the duty of maintaining the cleanliness of the squat plates, along with other duties. However, an important point in relation to usage is the age structure of the community in relation to the age structure of those using the latrines since it is possible that those (the young) age groups most severely afflicted by the excreta-derived diseases are also those which are least likely to use the facility. Figure 8 shows that with the typical age distribution, 48% of the population are under 15 years of age, but only about 32% of the 1-14 year age group use the sanitation facility. If we exclude the 4% of the population aged under 1 year, then there are still 12% of juveniles not using the latrine on a regular basis. We regard this as an important area for improvement, persuasion and even inducement.

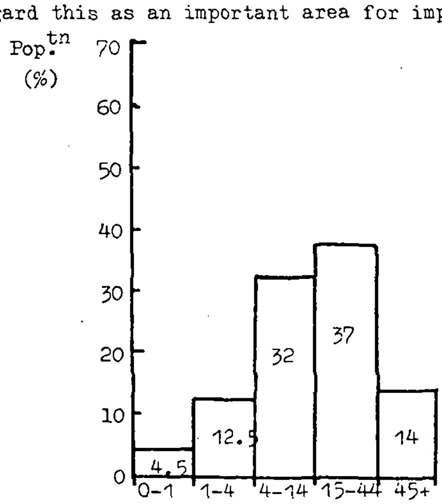

Fig. 8a. Age structure of the population of Bangladesh.

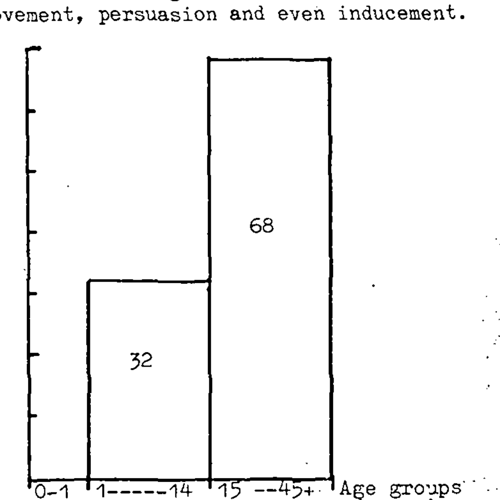

Fig. 8b. Age structure of population using Oxfam sanitation units.

DISEASE ORGANISMS : SURVIVAL & REMOVAL

At various times during the past 4 years the removal of a range of pathogens through the Oxfam sanitation units have been monitored by Howard, Lloyd & Webber (2), Lloyd (3), Lloyd & Daniel (4) and Daniel (5). However, because of the particular importance of cholera in Bangladesh, the initial investigations were carried out to determine the survival times of Vibrio cholerae in anaerobic sewage held under controlled laboratory conditions. From several of the published epidemiological studies we estimate that there are probably in excess of 250,000 cases of cholera annually in Bangladesh, and Mosley et al (6) suggest a similar figure. Even slight improvements in sanitation and water supply can markedly reduce the transmission of V. cholerae as demonstrated by Azurin & Alvero (7). This reduction occurs because the vibrio population survives for relatively short periods in the environment.

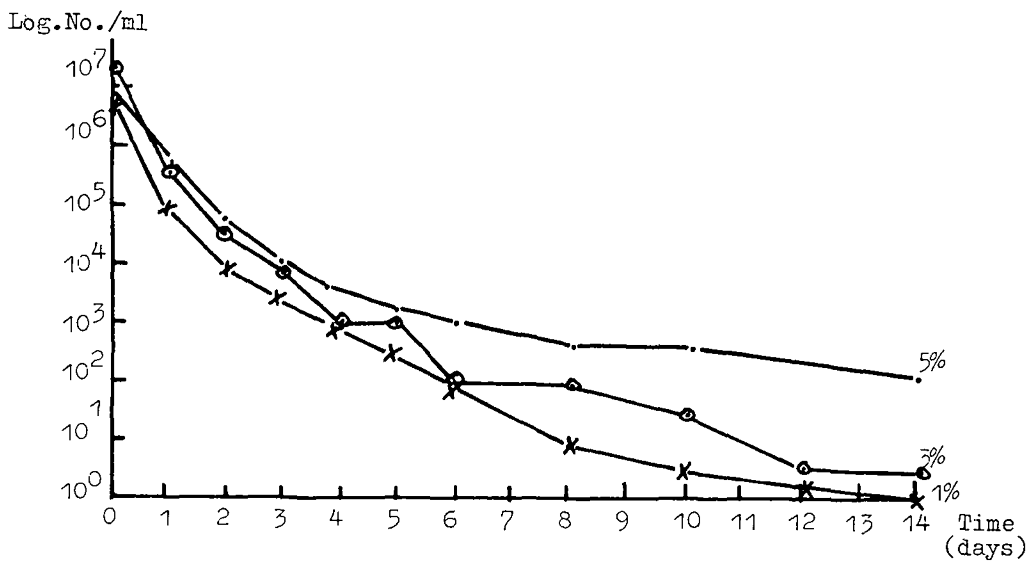

Figure 9. Survival of Vibrio cholerae in anaerobic sewage at 25°C in different solids concentrations (1%, 3% and 5% solids).

Figure 9 demonstrates that there is at least a 3 log (1,000 fold) reduction of cholera vibrios during the first 7 days when held in anaerobic sewage at 25°C. This is irrespective of suspended solids levels in the range 1 to 5%. In duplicate series, for each strength, the vibrios were no longer detectable in 1% solids sewage after 14 days, however survival of low numbers of pathogens was prolonged by the higher concentrations of solids. The environmental risk of transmission should therefore be greatly reduced if sewage containing cholera vibrios is held for at least 8 days, particularly in view of evidence which suggests a high minimal infective dose for cholera. Howard, Lloyd and Webber (2) confirmed that the Oxfam units produced at least a 2 log (100 fold) reduction of cholera vibrios when charged with the Dacca cholera hospital effluent using a retention time of about 8 days. More recently Daniel (5) undertook a one year study of pathogen removal and was unable to detect cholera vibrios in any of the units in refugee camps. Lloyd (3) detected low numbers of cholera vibrios in the raw sewage entering several units, but none in any 100ml sample from the Tank 1, Tank 2 or percolating filter outlets. There is no contradiction in these findings of low cholera vibrio counts as the incidence of clinical cholera, even in heavily endemic areas, is usually less then 2.3/1,000/annum.

It is extremely difficult to obtain reliable data for the incidence of diarrhoeal disease in the refugee camps. No detailed epidemiological studies have been carried out and diarrhoea is considered to be a normal part of the way of life. In some camps the relief agencies keep child health records for the first five years using the Morley 'Road to Health' Cards but gastrointestinal infections are not usually recorded. However in some camps minimum estimations have been made e.g. in 1977 in one camp near Dacca 270 cases of diarrhoea were reported for a population of 700 children. Other estimates double the number of cases in the under two years old age group. Microbiological techniques permit the quantitative recovery of the Salmonella group from sewage and as another representative of the enteropathogenic bacterial group and one which is a common cause of diarrhoea it has been included in the programme of monitoring the sanitation units. Salmonellas are invariably recovered from samples of raw sewage sometimes in numbers exceeding 10,000 per litre, this suggests a Salmonella carrier rate ranging from as little as 0.1% to as much as 10%. The data of Lloyd and Daniel (4) demonstrate encouraging reductions of salmonellas through the sanitation units and although sanitation cannot affect food-borne infections it should significantly reduce water-borne infections.

Counts of Ascaris ova have revealed an average of 2×10^6 per 2 litres of raw sewage. Allowing for the fact that the adult female Ascaris produces about 2×10^5 ova per day which is flushed in approximately 2 litres of sewage, this means theoretically that every person using the sanitation units could carry a load of 10 adult female Ascaris worms given an equal distribtuion through the population. In other words 100% prevalence is possible, but in practice this is not the case, although surveys in several parts of Bangladesh have revealed prevalence levels in excess of 95%. Howard et al (2) have demonstrated that the sanitation units can produce a 3 log (1,000 fold) reduction in Ascaris ova through the sanitation units. However as pointed out earlier the youngest children tend not to use the facility and they contaminate the soil near the houses to produce an important source of infection. Therefore although the major cource of ova is now confined to the sanitation units, sanitation alone cannot markedly reduce the prevalence of ascariasis unless every effort is made to ensure 100% usage of the sanitation facility and this must be combined with a mass campaign of treatment e.g. by the administration of piperazine.

FUTURE PLANS

These experiences in providing sanitation in Bangladesh and India, indicate the direction of future work. In addition to the present commitments of financing and maintaining the seventy existing sanitation units, four further projects are planned. These are summarised as follows.

Consolidating the existing community sanitation programme

The Oxfam (Type 2) Sanitation Units, some of which are in their fourth year of service, have shown that in crowded slum conditions where individual family latrine units are not possible, a clean efficiently operated, communal latrine provides an acceptable alternative and a most valuable service to the community. Therefore these existing units must be made as trouble free and as permanent as possible, and the local community should become fully responsible for the servicing and upkeep of them.

The main technical improvement will be to replace the butyl tanks with a more permanent tank structure and to improve the latrine building and flooring. One of the designs presently being considered to replace the butyl tanks is to use containers made of high quality precast concrete pipes of 1.2m diameter, which are manufactured in close proximity of the present slumsites. Figure 10 shows the proposed layout. A trial unit will be installed using these materials and recommended protective coating measures will be used on the concrete. The main advantages of using this conversion, from butyl to concrete pipe, is that it can be carried out, with no interruption of the latrine service, and with the minimim of on-site construction with its many problems. If the squatter population is forced to move to another location by the local authorities (a not unknown happening) then these concrete tanks could be dismantled and moved to a fresh site.

Parallel to this development, communal aqua privies serving 1,000 people will also be installed.

The Saidpur scheme

In the town of Saidpur, in northern Bangladesh, a survey of the insanitary sonditions has been undertaken by McFraser and Howard (8). This town with a population of 100,000 with a continuing growth of slum areas, has little or no sanitation and presents a most depressing picture of disease and ill-health . The town is typical of many others in West Asia and other parts of the world. The proposed sanitation scheme for Saidpur includes a night soil and refuse collection service from existing houses, and for the homeless, communal latrine blocks serving populations of 2,000 will be constructed. Cartage of the excreta to a composting area, from these latrine blocks will be either by railway or by road tankers. In the first instance a specific neighbourhood of the town containing about 11,000 people will be organised in this way and the overall capital costs of the scheme is estimated at between £5 - £6 per head of population served. Figure 11 gives an impression of the communal latrine blocks planned, and the final scheme might have up to twenty such units functioning in the town.

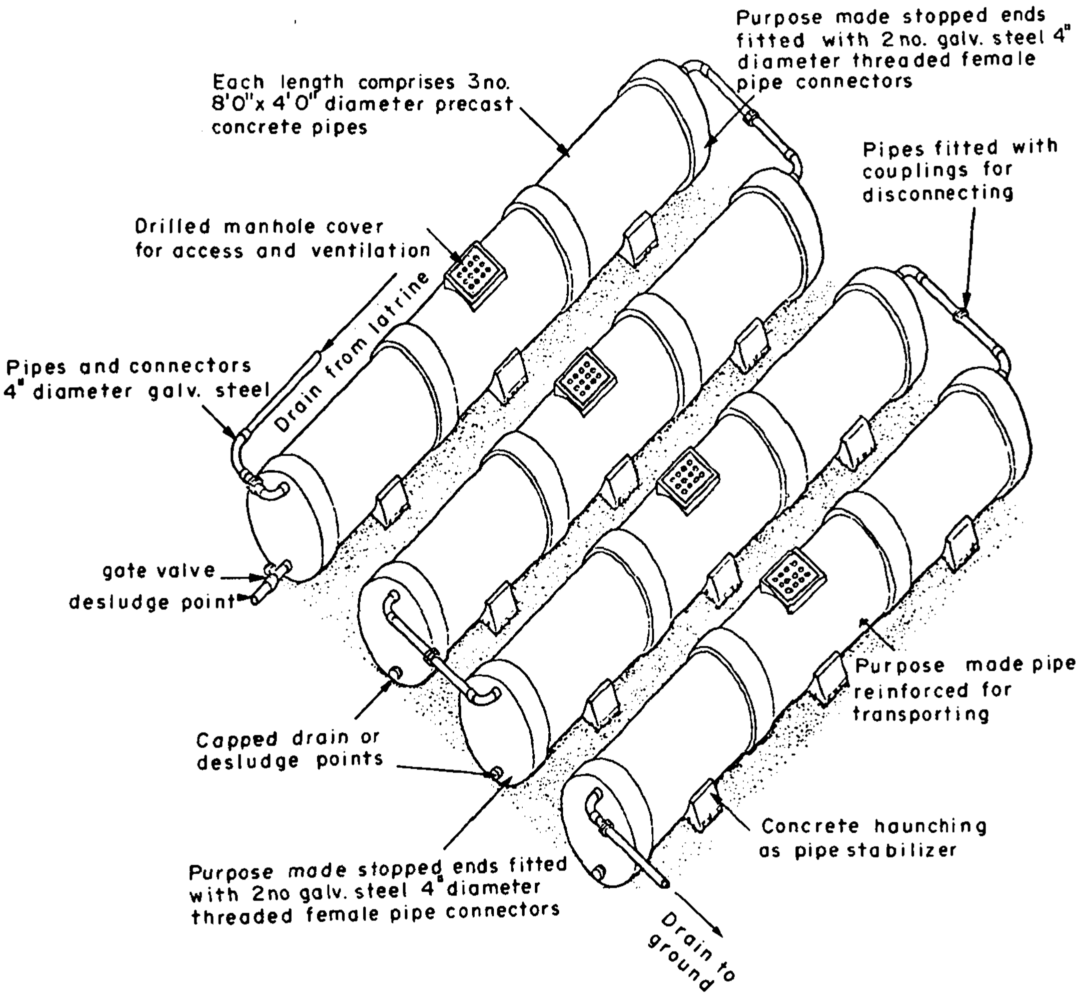

Figure 10. Proposed precast concrete pipes to replace existing butyl tanks in the Type 2 units

Family latrines

Individual family latrines are the preferred facilities if the location and other conditions permit. Text books often recommend for family use boreholes, pits, or aqua privies, but problems of high water tables or annual flood conditions are such that these recommended systems often vomit their contents over the landscape. This suggests the recommendations are faulty and are not relevant to such situations. An important lesson learned from our past operation is that sewage containers, tanks and aqua privies should be constructed at or above ground level. The ease of desludging by gravity from the Oxfam Units which are at ground level have proven over several hundred desludging operations that straightforward gravity desludging is a basic requirement and that if sewage tanks are placed in the ground then there is little likelihood of desludging taking place. The evidence for this statement is overwhelming. This lesson seems to have been learnt by the Vietnamese in their extensive and successful sanitation programmes which entails the building for family use of double 'septic tanks' built above ground for on-the-spot composting of excreta (Fig 12).

"Of all the public health measures designed after long years of research, and put into operation by the Vietnamese, the double septic tank has perhaps been the single most important factor in the prevention of disease and the promotion of health." McMichael (9). This is a design and system which must be given a much wider usage and development and we are currently seeking Vietnamese collaboration in commencing trials of double 'septic tanks' in India and Bangladesh. However we are aware of the problems of introducing an alien technology which may not function for social reasons. The Vietnamese system of treatment is a dry one, whereas the traditional Indian method of anal cleansing is by washing. It is possible therefore that the introduction of water may inhibit the excreta composting processes and hence allow prolonged pathogen and parasite survival. Therefore in addition, above ground aqua privies for families will also be tested.

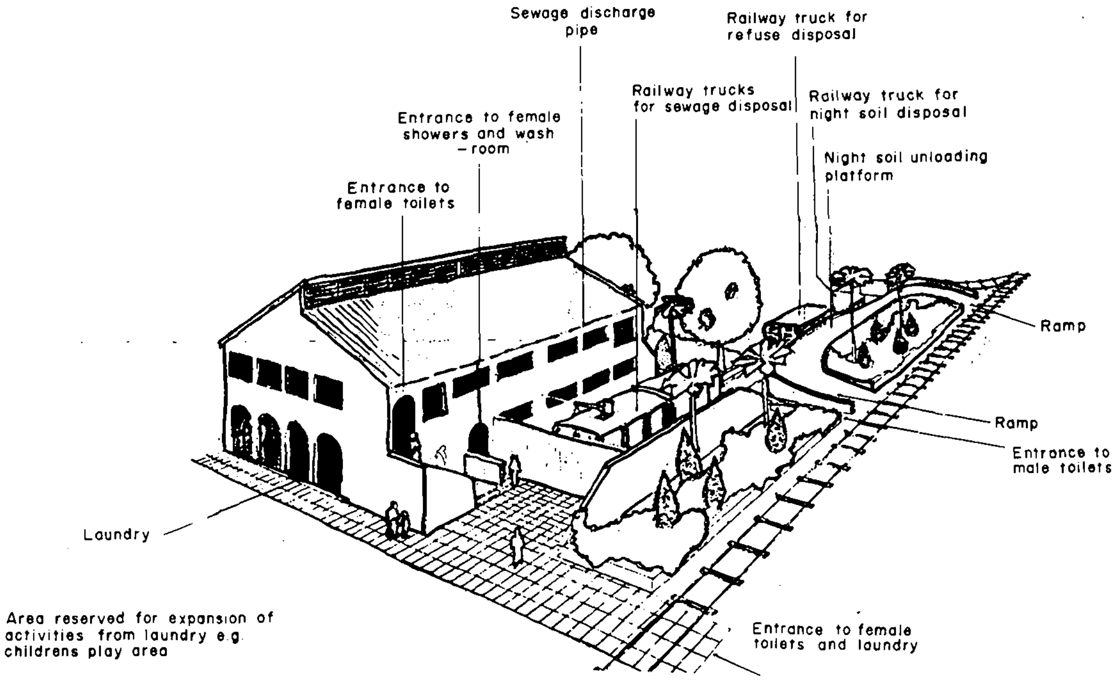

Figure 11. Proposed latrine and laundry block for Saidpur.

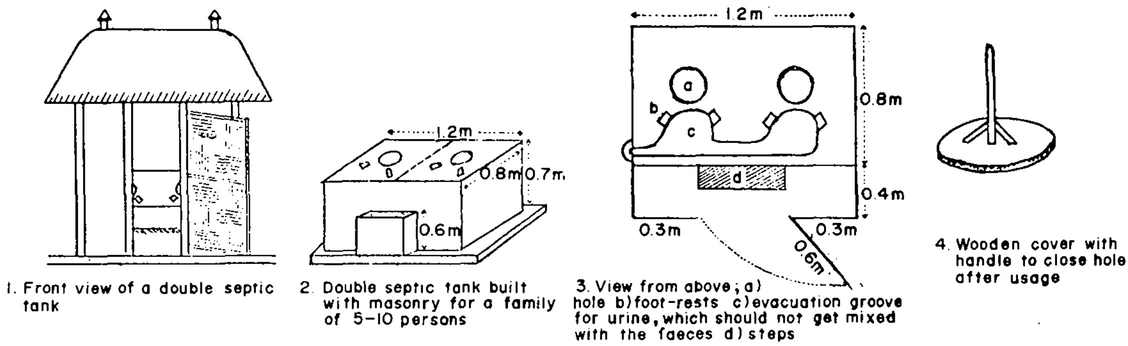

Figure 12. Vietnamese double septic tank (McMichael 9).

Sanitation information exchange project.

The fourth project arises from the conference on "Sanitation in Developing Countries Today" held in Oxford in July, 1977. This project, with an Indian secretariat and advised by a Calcutta-based consultancy intends to establish links with groups and organisations working in sanitation and health problems in West Asia. The objectives will be to assist engineers and planners, bringing them together at a series of meetings and collaborative sanitation trials over a two year period.

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HEALTH FACTORS IN URBAN WASTEWATER MASTER PLANS

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INTRODUCTION

The explosive growth of urban communities in the developing world has been one of the most striking phenonema of the past few decades. This growth has given rise to cities of unprecedented size and population density which lack the standards of infrastructure commonly considered essential in more developed and prosperous countries: perhaps one third of the urban population in the developing countries has no sewerage facilities whatsoever.

It is in the light of such circumstances that national and local authorities commission 'Master Plans' for the provision of facilities to meet the immediate and future needs of urban communities up to a selected time horizon. Master Plans for the supply of water and the disposal of wastewater are now often commissioned jointly or simultaneously, an example being the Canal Zone in Egypt where comprehensive Town Plans for each of the three main cities in the zone have been completed and Master Plans for water supply and wastewater disposal are now being prepared. This paper is concerned principally with the health effects of wastewater projects although in practice it is difficult to distinguish between improvements due to the installation of water supplies and those due to provision of wastewater facilities if both occur at the same time.

The preparation of a wastewater Master Plan will involve the study of engineering, health, and socio-economic factors in order to identify a development programme which will be technically, financially, politically and socially acceptable and capable of being successfully managed and operated by the responsible authority. The Plan will recommend a preferred strategy, list and cost the required new facilities and propose a phased programme of implementation. It will normally cover collection, conveyance, treatment and disposal, taking into account the possibility of the beneficial use of the effluent and separated solids. To achieve this end the study will usually include the preparation of an inventory and an evaluation of the existing facilities; the projection of wastewater flows and quality taking into account population growth, land use, and water consumption; the definition of goals and design criteria; the identification and comparison of feasible alternative strategies; the selection of a preferred strategy and the preparation of the development plan. Within the constraints affecting it, the strategy will seek to provide the maximum benefit to the community at the lowest cost within the shortest time. The choice of strategy will not depend solely on economic considerations. Of the many other factors that should be taken into account, it is usually important that the Plan should:

- provide facilities when they are required and have a stream of capital and operating costs such that a suitable financial plan can be devised;
- ensure that any benefits (either direct or indirect) are maximised;
- meet its objective at a cost that can be afforded by the community;
- make the maximum possible use of local labour and material, keeping foreign costs to a minimum;
- be socially and politically acceptable, not offend any religious susceptibilities or contravene any civil laws;
- be easy to operate and maintain, and minimise the use of energy;
- have no significant adverse effect on the environment, either within or beyond the project boundary;
- make maximum use of existing facilities and, insofar as is practicable, incorporate committed ongoing projects; and
- be flexible enough to accommodate changes in the predicted urban development pattern and be capable of expansion beyond the set planning horizon adopted.

A Master Plan will serve not only to provide the right framework for the development of facilities but will also provide a means for funding agencies to assess the need for and, the practicability of, the schemes proposed. One of the elements of a plan which is considered carefully by funding agencies is the likely impact of the plan on the health of the community.

Many disciplines will be involved in shaping the preferred strategy, including:-

- Politicians who will assess the overall constraints, particularly the resources that can be allocated to the project at each stage of implementation.

- Engineers who will decide which schemes are feasible in relation to the physical environment bearing in mind the state of technological advancement of the community to be served, and

- Economists who will advise on the availability and use of resources, and the comparison of alternatives.

All will be dependant on the advice given by the medical fraternity who will be required to help define, in public health terms, the nature and extent of the existing health problems, the likely impact of alternative strategies, the expected benefits of the preferred strategy and the best way of phasing implementation.

WATER RELATED DISEASES

There is a wide range of human diseases which are transmitted by or are associated with water. These can be divided into two main groups:-

Group 1 - diseases caused by living organisms (e.g. cholera, scabies, schistosomiasis, malaria),

Group 2 - diseases caused by organic or inorganic substances carried in water (e.g. lead poisoning).

The first group of diseases is normally associated with low living standards and poor sanitation and such diseases are typically prevalant in developing countries having tropical climates. A sub-division of the group according to the principal mode of transmission was originally proposed by White et al [1] and a slightly modified version of this classification given by Feacham [2] is reproduced below:-

TABLE 1. Group 1 Diseases

Category	Example
1. Faecal-oral (Waterborne or water-washed)	
(a) low-infective dose	Cholera
(b) high-infective dose	Bacillary dysentary
2. Water-washed	
(a) skin and eye infections	Trachoma, Scabies
(b) other	Louseborne fever
3. Water-based	
(a) penetrating skin	Schistosomiasis
(b) ingested	Guinea Worm
4. Water-based insect vectors	
(a) biting near water	Sleeping sickness
(b) breeding in water	Malaria

The provision of wastewater facilities can affect the transmission of disease in all four categories shown but is probably most significant in the first three.

The second group of diseases may be caused by the ingestion of a wide range of substances carried or dissolved in water. Some examples are given in Table 2.

TABLE 2. Group 2 Diseases

Constituent	Disease
Organic Halogens	Cancer
Poly-nuclear aromatic hydrocarbons	Cancer
Lead	Lead poisoning
Nitrate	Methaemoglobinaemia
Sodium	Hypernatraemia

Group 2 diseases are of little significance in most developing countries at the present time but may become more so when improved sanitation and living conditions have reduced the incidence of Group 1 diseases.

HEALTH ASPECTS OF EXISTING WASTEWATER SYSTEMS

An understanding of the health aspects of an existing situation can only be gained both by study of the physical environment (which causes the spread of disease) and by study of the health record of the population within the Plan area.

In practice, it will generally be difficult to gather accurate information about conditions likely to cause disease or about the extent of disease. Although there are usually very good reasons why undesirable conditions have come about, there is nevertheless a reluctance on the part of those officials most intimately involved to admit that they exist.

For instance, during a recent study officials denied that there was any discharge of effluent into a river from which substantial water supplies were drawn downstream. Subsequent site inspection revealed a very large discharge of mixed treated and untreated sewage. On the same study non-medical members of the team were unable to obtain any reliable statistics concerning the extent of enteric disease. However a pattern of high infant mortality was uncovered by subsequent detailed and tactful probing by a doctor specializing in public health matters who was brought in for these aspects of the study.

The extent to which an existing wastewater collection, treatment and disposal system affects the health of a community can only be a matter of judgement. A physical survey of the area by an experienced health expert can bring to light aspects of the existing situation which constitute the principal hazards to health.

THE IMPACT OF ALTERNATIVE STRATEGIES

Viable alternative strategies can only be determined with a sound knowledge of the existing situation. In addition to the health aspects described above, information must also be gathered in respect of the general environment, often over a very wide area. Such studies may include topography, geology, hydrology, geography, demography, biology, agronomy, oceanography, and meteorology.

The basic questions that have to be answered are:-

(a) What quantities of wastewater will have to be dealt with?

(b) How will the wastewater be conveyed from the points of origin to the point of disposal?

(c) What points of disposal are available?

(d) Will treatment be required prior to disposal and if so what degree of treatment?

(e) If treatment is required, will there be any solids removed?

(f) If solids are removed, where can they be disposed of and what method and degree of treatment are required?

All of these questions are to some extent inter-related and all have a bearing on public health. In particular, quantity has a pronounced effect on all other aspects; what is tolerable on a small scale may not be tolerable on a large scale.

Whilst much has been written about the desirability of providing technologically simple solutions, it is also important that the scheme eventually provided satisfies so far as possible the aspirations of the community. Unless those responsible for operation are persuaded that the scheme is worthwhile, there is little chance that it will be a success.

WASTEWATER SYSTEMS

There are many systems for conveying, treating and disposing of human waste but all fall into one of four basic methods:-

<u>Method 1</u>, Direct defecation on the ground (or to water) where natural aerobic decomposition takes place.
<u>Method 2</u>, Solids and liquids discharged to a reception pit which is eventually filled in and a new pit constructed. Anaerobic decomposition takes place during and after filling.
<u>Method 3</u>, Solids are partially separated from the liquids near the point of origin, collected and conveyed by some form of vehicle, and disposed of at some remote point.
<u>Method 4</u>, Liquids and solids are conveyed together by pipeline from the point of origin to a remote point of disposal, usually via a treatment plant.

Using Method 4, it is possible to convey safely both the liquid and the solid elements of wastewater over long distances and to treat both to any required degree of purity at a place well removed from built-up areas. Nevertheless, all four methods are perfectly satisfactory in public health terms in the correct environment, the major factor governing the desirability to change towards Method 4 being population density. Only Methods 3 and 4 are normally appropriate to an urban situation, and in very densely populated urban areas only Method 4 is satisfactory.

DISPOSAL OF LIQUID WASTEWATERS AND SLUDGES

While nearly all wastewater systems comprise the three interdependant components of conveyance, treatment and disposal, the ultimate aim is satisfactory disposal. Alternative points of disposal must therefore be considered at an early stage in any Master Plan.

The quality of effluent will be governed by the requirement that the discharge at the disposal point shall not have an unacceptably deleterious effect on human health, the environment, agriculture, industry or recreation.

In a practical situation, there is no universal rule to define whether an effect is unacceptably deleterious. In public health terms, in tropical developing countries, the level of acceptability will often be set by reference to economic criteria (which are discussed later) and with due regard to local standards of health. For example, there is no point in spending large sums of money to remove all helminth ovae from an effluent which is being discharged to an area where schistosomiasis is endemic. A standard should be set so that, in the short term, the discharge does not aggravate the existing problem whilst, in the longer term, there is sufficient flexibility to ensure that effluent quality improvements can be made to suit any likely overall schistosomiasis control programme.

Of increasing importance, particularly in arid areas, is the re-use of effluent particularly for agriculture. Although agricultural re-use has been practised for many years, the present move is towards large scale operations sometimes using such techniques as spray irrigation. This technique involves new risks associated with the inhalation of aerosols. Sorber and Guter (3) report that salmonellae can be 1 000 times more infective when inhaled than when ingested. The advantages of spray irrigation to agriculture, particularly where sloping land is to be irrigated, have therefore to be set against the increased health risk of this method of application.

The most common disposal point for sludge is agricultural land where it can represent both a useful soil conditioner and a fertiliser. As with effluent re-use, however, its application must be exercised with caution since, in the raw state, it is a potential health danger to all who come into contact with it directly or indirectly. In all cases where re-use is practised, adequate control and supervision is essential.

Health considerations as they relate to various possible points of disposal are set out in Table 3.

TABLE 3. Health Aspects at Disposal Points

Point of Disposal	Considerations affecting health
1. Watercourse	(a) Use downstream for potable supply, agriculture, recreation or fisheries.
2. Static body of water	(a) Uses as 1 (a)
3. Sea	(a) Use for recreation, fisheries, possible use for potable supply or agriculture after desalination.
4. Surface of land	(a) Agricultural applications: health of agricultural workers, health of crop consumer, health of anyone having access to area.
	(b) Non-agricultural applications: health of worker on distribution system; any person having access to area.
	(c) All surface applications; pollution of underground strata or neighbouring watercourses, etc. by reason of runoff; pollution of air (by aerosol effect).
5. Underground	(a) As 4 (b) where recharge basins are employed.
	(b) Pollution of potable supplies elsewhere in acquifer depending on nature of acquifer.
6. Industry	(a) Health of industrial workers.
	(b) Contamination of product.
7. Fish Ponds	(a) Uses as 1 (a).
	(b) Contamination of product.

TREATMENT OF LIQUID WASTEWATER

It is possible to achieve any required effluent standard to suit the health aspects of a given disposal point by selecting an appropriate treatment process. In most circumstances, the choice will be between one of the processes given in Table 4.

TABLE 4. Effect of Treatment In Pathogens

	Treatment Processes	Removal Efficiency %		Relative Cost (Compared with B)
		Virus and Pathogenic Bacteria	Helminths	
A	Settlement	30 - 40	60	30%
B	'A' plus biological treatment	85 - 95	85 - 95	100%
C	'B' plus chlorination	95 +	85 - 95	120%
D	'B' plus microfiltration	90 +	95 +	130%
E	'B' plus 8 days in maturation ponds	95 +	95 +	120%
F	Waste Stabilization Ponds	95 +	95 +	60%

The above figures are illustrative only; removal efficiency will vary according to the type of virus, bacteria or helminth and cost will vary from place to place depending on many factors. Process F is particularly dependent on land costs, as waste stabilisation ponds require about ten times as much land treatment as treatment by conventional settlement and biological treatment.

In general, viruses are more difficult to remove than bacteria. Chlorination, the most commonly used disinfectant, has been found by Shuval (4) to be ten times more effective as a bacteriacide than as a virucide. The use of chlorine is in any event to be treated with caution because of the risk of regrowth of pathogens, the toxic effect that chlorinated effluents can have on fish and the possible formation of compounds which are injurious to human health if ingested.

Treatment processes can themselves provide a health hazard if not properly maintained; insects breeding within the media of percolating filters or around waste stabilization ponds can be disease vectors.

TREATMENT OF SLUDGES

All wastewater treatment plants produce sludge and this usually has a moisture content of about 95-98%. The drying of sludge substantially reduces its volume and weight and hence eases transportation to the disposal point but has little effect on pathogens. The efficiency and cost of various processes are compared in Table 5.

TABLE 5. Effect of Sludge Treatment on Pathogens.

Treatment Processes		Removal Efficiency: Viruses, Pathogenic Bacteria, and Helminths.	Relative Cost
G	None	Low	Nil
H	Open drying beds	Low	Low
J	'H' plus storage	Medium	Low
K	Mesophilic digestion	Medium	Medium
L	Thermophilic digestion	High	High
M	Mechanical drying	Low	Medium
N	Incineration	Complete	Very High

Note: The cost of open drying beds (Process H) is very dependent on climatic conditions.

Raw sludge contains large numbers of the full spectrum of bacterial, viral, parasitic and amoebic pathogens present in domestic wastewater and, if accessible, it encourages fly breeding.

International experience has shown that, subject to rigorous controls, the use of sludge after digestion or stacking for an adequate period does not present an undue risk to public health. The processes of digestion of wet sludge or, to a lesser extent, the long term storage of air dried primary and secondary sludges largely eliminate offensive odours and substantially reduce the numbers of pathogens; numbers of bacteria may be reduced by two orders while viruses may well be eliminated, particularly if the digestion or storage time is long. The cysts of Entamoeba Histolytica (amoebic dysentry) are normally destroyed by digestion. The eggs of parasitic worms, with the exception of Taenia Saginata (beef tapeworm), however, are highly resistant in general and survival of a proportion of the viable organisms can be expected. In particular, ascaris and ancylostoma are recorded as having survived digestion and air drying for periods of 6 to 2 years. By maintaining the sludge in the thermophilic range at a temperature of 55°C for about 2 hours or at 80°C for 15 minutes almost complete disinfection can be achieved at very considerable costs.

CONVEYANCE

The three conveyance systems which can be adopted in an urban situation are underground conduit, surface channel and road vehicle; a combination of all three may be adopted.

If properly designed, constructed and maintained, underground conduits are substantially free of health hazards for the general public though risks remain for those people who have to enter sewer systems for inspection and maintenance, particularly from toxic gases and asphixiation. Where wastewater and surface water flows are conveyed in a single pipeline, it is customary to provide hydraulic relief by overflowing to nearby surface channels so that such channels can become polluted with wastewater at times of rainfall.

In many parts of the world, wastewater is conveyed in open channels sometimes completely undiluted with surface water. The risk of spreading disease is twofold; by direct human access or by insect or animal vector.

Conveyance by vehicle can range from the use of donkey carts for the transfer of cesspit contents to the nearest ditch, to the use of totally enclosed vacuum filled tanker lorries. With open carts there is danger from accidental spillage and even deliberate tipping of the contents in public places. Even where tankers are used, there are some risks to the operators where contaminated hoses have to be handled and control has to be carefully exercised to ensure that deliveries are made to authorised unloading points.

In most urban situations, buried pipeline systems are appropriate for the densely built up areas whilst in less developed parts vehicles may sometimes be used satisfactorily for collection of separated solids, the liquid faction of the wastewater being discharged underground or to local open channels.

COST BENEFIT AND ECONOMICS

One of the most difficult problems in the planning of wastewater schemes is the assessment of the economic benefits and disbenefits of health aspects of alternative strategies. There are three reasons why this problem is so intractable. Firstly, health statistics, particularly those available in developing countries, are notoriously unreliable and it is common for there to be considerable under-reporting or mis-reporting of enteric disease; secondly, there is no way in which changes in morbidity rates occasioned by the implementation of wastewater development plans can be accurately differentiated from changes in morbidity due to other reasons, and thirdly even if a change in morbidity could be estimated, it is difficult to put a value on this change.

However, these difficulties have not prevented attempts being made to quantify the benefits of wastewater improvements. That there is a direct relationship between morbidity and sanitation is beyond doubt. The Public Utilities Department of the IBRD (5) have reviewed the published information from twenty six relevant studies which, when examined as a whole, provide sufficient evidence of a correlation. The studies also show that the degree of health improvement which can be expected depends on the original health characteristics of the community, cultural habits, educational level, the physical environment, and socio-economic factors.

The economic benefits resulting from a wastewater development can be sub-divided as follows:-

- benefits to individuals in terms of improved health and living conditions (i.e. improvements in people's well being);
- benefits to the community from improved social and economic development, increased productivity and reductions in the cost of health services; also secondary economic benefits such as increased revenue from tourism;
- benefits from reuse of effluent and use of sludge.

The calculation of the economic benefit of reused effluent and of sludge is a straightforward exercise. Similarly, given an estimate of the expected reduction in morbidity, it is relatively easy to assess the saving in costs to the community of curative medicine. However, the other benefits are not easy to quantify. In developing countries there is usually considerable unemployment or underemployment making it difficult to assess the effect on productivity of decreased morbidity; also the secondary economic benefits arising from the implementation of a wastewater scheme can only be a matter of conjecture. Finally, benefits such as improved social and economic development and improved wellbeing of the individual cannot be satisfactorily quantified.

The capital cost of providing a modern sewerage system for a large urban community in a tropical country is typically in the order of £100 per capita and the annual running costs may be about £1 to 2 per capita. Even if optimistic assumptions are made concerning the value of health improvements due to the implementation of a Wastewater Master Plan it is unusual for a net positive benefit to be shown. Furthermore, average incomes in developing countries are so low that it is likely that a large portion of the community will be unable to afford the service. As a general rule it is normally reckoned that for developing countries no more than 5% of total family income should be devoted to charges for water and waste facilities. Thus, if the goal of government is to raise the general level of health of the community it is often necessary for the provision of wastewater facilities to be viewed as a 'public service' which must be subsidised out of public funds. The inter-relationship between the level of service, the health benefits expected and the amount of subsidy the authorities are prepared to provide should be fundamental to the formulation of the basic Wastewater Master Plan Strategy.

CONCLUSIONS

In the foregoing sections it has been shown that there are a large number of ways in which health considerations affect wastewater master planning. In the past the engineer has tended to insist on high standards for water supply and for waste disposal partly as a result of the ancestral wisdom that 'cleanliness is next to godliness' and partly because of the difficulty of evaluating the relative health benefits for different degrees of service. This standpoint is now being challenged by many professionals involved with the provision of sanitary facilities in tropical developing countries. They claim that the best use of limited funds may be to give a less than perfect service to a greater number of people. Clearly the final choice between the two approaches must be with the politicians and administrators, but the advice necessary for them to make the choice must come from the professionals. The right advice will only be given if there is wider co-operation than at present between the medical and engineering professions in formulating solutions to the problem.

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EPIDEMIOLOGICAL STUDIES TO ASSESS THE HEALTH EFFECTS OF RECLAIMED WATER CONSUMPTION BY AN URBAN POPULATION

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Abstract
A need for additional water supplies has been recognized in a number of countries around the world. This need is more urgent in those areas where there is a low mean annual rainfall and where periods of severe drought aggravate the water shortage problem. One such country is SWA/Namibia which largely consists of desert and semi-desert areas. To date SWA/Namibia is the only country practising direct re-use of reclaimed waste water.

The Windhoek water reclamation plant was commissioned in 1968 and processes effluent obtained from a conventional sewage treatment plant. The reclaimed water is mixed with purified water obtained from a conventional plant which treats raw dam water. The mixture is chlorinated before being pumped to the city reservoirs where it is further admixed with borehole water. Not all sections of the city receive water augmented by the reclaimed product, nor is augmentation practiced as a continuous process but only when conventional supplies are inadequate.

In SWA/Namibia reclaimed water was released for consumption after exhaustive studies on both microbiological and chemical quality had shown it to be of a standard equal, and frequently superior, to that of conventional metropolitan water supplies.

During May 1975 the Windhoek City Council carried out a population census and detailed computer-based demographic data were compiled with projections of various statistics into the year 2000. The same basic scheme used to collect the demographic data by the City Council was subsequently used for the epidemiological study.

Our epidemiological studies, which were conducted in an expanded form from 1976, were an 'experiment of opportunity' in that circumstances had necessitated direct water re-use. Major problems were therefore posed by our inability to select an ideal study population. For example, the population served by the water reclamation installation is that of the capital, Windhoek, which has a population which totalled approximately 75 000 in 1975. Its size is therefore too small to yield statistically significant results in some of the less common conditions, especially on the short term.

Apart from the size of the study population other problems presented themselves which could not be easily overcome and may affect data analysis. The following should be mentioned:

1. Windhoek has a considerable non-resident labor force. Although statistics were provided concerning this group it is difficult in individual patients to determine whether illness or death was influenced by factors operating inside or outside Windhoek.

2. During times of political uneasiness hospital attendances tended to drop and the reduction in hospital visits was probably largely caused by the failure of the milder cases to come forward.

The health aspects of reclaimed water consumption which are being studied concern the potential of waterborne infections on the one hand, and of chronic disease due to toxic effects on the other. Most waterborne infections usually manifest themselves in no uncertain manner as explosive outbreaks occurring shortly (within days to weeks, depending on the aetiological agent) after exposure by the population at risk to the contaminated source. The other group of adverse effects on health comprise the often delayed manifestations resulting from exposure to chemical substances which may be either harmful per sé, or are present in harmful quantities.

An attempt is being made to compare gastro-intestinal infections in communities within Windhoek which are similar in as many respects as possible excepting water supply. At the same time some communities serve as their own controls when conventional water supplies are adequate and not augmented by reclaimed water. Seasonal fluctuation is to be calculated in communities receiving a non-augmented water supply all year round. The following infections are subject to study:

1. Diarrhoeal diseases
2. Viral hepatitis
3. Viral infections of the central nervous system

For practical reasons the studies had to be based on patients ill enough to seek medical advice. The relevant laboratory services to the population of Windhoek are centralized and standardized, and used by all the hospitals, private nursing homes and private medical practitioners in the city. This greatly facilitated the study and the laboratory served as its centre with a nurse epidemiologist (N.E.) employed in a full time capacity.

In the case of diarrhoeal diseases these are reported to the laboratory and a sample of stool or a rectal swab is submitted at the same time or collected by the N.E. for bacteriological and virological examination. Standard data are recorded on each patient using printed forms. These data concern the patients age, sex, ethnic group and occupation. In addition the hospital, clinic or medical practitioner visited by the patient is identified, as well as the ward/unit in question and the date of onset of symptoms. The latter group of data were needed to enable the recognition or exclusion of hospital based outbreaks of gastroenteritis. Residential data were collected and coded according to the City Council's census enumeration areas of which there are more than 160 in Windhoek.

All patients presenting with jaundice were reported in the same manner and blood samples were subjected to a variety of liver function tests and examined for the presence of hepatitis B antigen.

Infections of the central nervous system were identified by chemical, microscopic, bacteriological and virological examination of all cerebrospinal fluid samples received in the laboratory.

Monthly returns of total numbers of patients admitted to wards or treated in clinics were obtained.

Mortality studies are based on death certificates of people who died in the various hospitals. Deaths which occurred outside hospitals as a result of accidents or homicide are therefore excluded as well as deaths due to natural causes which occurred at the homes of the deceased. Additional data obtained in the mortality study but not in the morbidity study concerned the tribal origin of the patient. Racial differences in the prevalence of several chronic diseases are well known. There may also be tribal variations in disease distribution in SWA/Namibia and this may be information essential to the correct interpretation of our eventual findings. Autopsy studies will also be done.

The morbidity and the mortality studies were still in progress at the time of writing. The findings and conclusions based on the morbidity data are to be presented during December 1978 at the symposium. The mortality studies are to be continued as it is not expected that any significant conclusions can be drawn at this stage.

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A REVIEW OF RURAL EXCRETA DISPOSAL SYSTEMS

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Abstract

At an international meeting held in Ghana in 1977, 25 excreta disposal systems were reviewed and ranked for possible use in rural areas in developing countries. The three top ranked systems were the RcA latrine, the Dug Well latrine, and the ROEC. The ROEC has since been modified into what has been called the V.I.P. latrine.

INTRODUCTION

Man cannot escape from excreta; for they come from man himself. Their regular excretion by him is a necessary requirement for his health. Yet, improperly disposed of, excreta can create aesthetic nuisance, degrade property and lower its economic value, and, above all, create serious public health hazards and undermine development. For over 50 infections are believed to be transmitted through infected excreta (Ref. 1). It is also believed that faecally-related diseases, together with air-borne diseases and malnutrition, account for the majority of deaths among the poorest people in the developing countries. Moreover, the ill-health resulting from excreta can impose economic costs by impairing the productivity of employed workers and capital goods, by wasting current resources, particularly nutrients, and by impeding the development of natural resources, animal wealth, and tourist potential (Ref. 2). For these reasons it would have been expected that facilities for proper disposal of excreta would form a part of the basic amenities for all human habitats. Yet, in many communities in the developing countries, such facilities are woefully lacking. Instead, the open field is the place commonly used in such communities for defaecation by all but the aged, children under about seven, and the infirm.

There are several possible reasons for this, including the following:

(i) No appreciation of the role of excreta in disease transmission
(ii) Traditional attitudes towards defaecation in the open fields
(iii) Ignorance about appropriate technology for excreta disposal
(iv) High cost of available technology
(v) Lack of national policies and programmes on rural sanitation
(vi) Inadequacy of relevant trained personnel
(vii) Inadequacy of machinery for educating, motivating, and mobilizing communities to ensure their understanding, cooperation, and participation in rural sanitation programmes.

Several inputs are needed for rectifying the situation. One such input is the introduction into local communities of one or more appropriate technologies that are at once effective, safe, and acceptable from the economic and socio-cultural standpoints. The search for such technology has been the object of a project on the Disposal of Human Excreta in Rural Areas. The project is being undertaken by the Environmental Quality Division of the Civil Engineering Department at the University of Science and Technology at Kumasi, Ghana; and it is funded by the International Development Research Centre (IDRC) of Canada. In connection with this project, an international Technical Advisory Group (TAG) meeting was convened in Kumasi from 12th to 15th July 1977 to review and rank different types of latrines that had been short-listed. Participants in the meeting came from Botswana, Canada, Ghana, India, Nigeria, and Tanzania.

This paper deals with this TAG meeting and its outcome.

REVIEWED SYSTEMS

Twenty-five different types of latrines were reviewed at the meeting. Table 1 presents them classified into four major types. Two operational parameters were used in the classification; these were the system's dependence or otherwise on water for its operation, and the location of the excreta disposal site relative to the defaecation site.

Thus each system must be either an off-site disposal system or an on-site disposal system; it must also be either water-dependent or water-independent. This leads to the following four types of latrine systems which appear in Table 1:

Type 1: Off-site water-independent systems
Type 2: Off-site water-dependent systems
Type 3: On-site water-independent systems
Type 4: On-site water-dependent systems

TABLE 1. Latrine types considered in review

	Water-Independent systems	Water-Dependent systems
	Type 1	Type 2
Off-site systems	1. Bucket latrine 2. Vacuum truck cartage system	1. Water closet plus conventional sewerage 2. Vacuum truck cartage system
	Type 3	Type 4
On-site systems	1. Conventional pit latrine 2. Vented pit latrine 3. Off-set dry pit latrine 4. Borehole latrine 5. Vietnamese double vault latrine 6. Gopuri latrine 7. Multrum 8. Utafiti latrine 9. Single compartment utafiti 10. Single vault latrine 11. Off-set single vault 12. Off-set compost vault 13. Off-set compost pit	1. Aqua privy 2. Botswana type B 3. Septic tank latrine 4. Chinese 2-partition 3-tank system 5. Dug well latrine 6. Khatghar latrine 7. Watergate latrine 8. RcA latrine 9. Septic tank system

All the systems have been described in the Report on the TAG meeting (Ref. 3).

REVIEW PROCEDURE

The review procedure involved the following steps:

1. Selection of attributes deemed desirable in a rural latrine
2. Assignment of relative numerical weights to each attribute
3. Application of a rating scale to obtain an unweighted score which reflected the extent to which each system possessed each of the listed attributes.
4. Determination of the weighted scores
5. Summation of the weighted attribute scores for each system and ranking of the systems accordingly, with the highest rank going to the system obtaining the highest aggregate weighted score.

Selection and weighting of attributes

Twenty-six attributes were used in the review. Each of them was placed in one out of six major classes of attributes, namely, cost, health, technology, aesthetics, safety, and ecology. These six major attributes were ranked and given numerical weights. For rural conditions, "cost" was considered paramount. Consequently, it was given the highest weight of 40. In contrast, ecology received the lowest weight of 4. Table 2 presents the ranks and the relative numerical weights of each of the six major attributes.

Next, based on the ranks within classes, the relative weight for each class was distributed among its members. Thus the relative weight of 40 assigned to the class of "cost" was distributed equally between the two members of the class; however, in the class of "health" the relative weight of 32 was distributed among the four class members as follows:

Hygienic................ 12
Fly-free................ 12
Rodent-free............. 4
Mosquito-free........... 4

TABLE 2. Ranks and class weights of major attributes

Attribute class	Rank	Relative weight
Cost	1	40
Health	2	32
Technology	3	24
Aesthetics	4	16
Safety	5	8
Ecology	6	4

In this way each attribute was assigned a numerical weight. The resulting distribution of relative weights for each attribute is as presented in Table 3.

TABLE 3. Selected attributes

Class designation	Attribute No	Attribute Description	Definition (where necessary)	Relative weight: Class member	Relative weight: Class total
COST	1	Low construction cost		20	40
	2	Low operating & maintenace cost		20	
HEALTH	3	Fly-free	Flies have no access to faeces or if they do they cannot escape from latrine.	12	32
	4	Hygienic	System has low potential for disease transmission	12	
	5	Mosquito-free		4	
	6	Rodent-free		4	
SAFETY	7	Safe to user	User is unlikely to fall into latrine	8	8
AESTHETICS	8	Easy to keep clean		4	16
	9	Odourless		8	
	10	Can be located in private house		4	
ECOLOGY	11	Ecologically compatible	Has no adverse effect on plant and animal life	2	4
	12	Re-usable end-product		2	
TECHNOLOGY	13	Permanent squatting plate	Position of squatting plate does not need to be changed	1	24
	14	Permanent system	Complete latrine system is permanent in the sense that capacity is not Progressively exhausted necessitating transfer to new site	2	
	15	Permanent superstructure	Position of superstructure is permanent	1	
	16	Construction materials readily available	(This is not restricted to locally produced materials)	2	
	17	Construction skill readily acquired	Implies simple technology	2	
	18	Special construction equipment unnecessary		1	
	19	Low space needs	Plan area requirement for system is low	1	
	20	Easy to operate by user	Easy to keep system functioning properly	2	
	21	Easy to maintain	Defects are readily repaired	1	
	22	Desludging is infrequent	This refers to removal of sludge or excreta from system	3	
	23	Insensitive to ablution materials	Anal cleansing materials do not affect or foul system performance.	1	
	24	Low water needs		2	
	25	Operates without water		2	
	26	Operates without power	Operates without mechanical or electric power	3	

Rating and scoring procedure

To reflect numerically the extent to which each system possessed a particular attribute, the following 5-point rating scale was used:

Extent of possession of attribute	Corresponding score
Never present	1
Seldom present............	2
Occasionally present.......	3
Frequently present.........	4
Always present............	5

This rating scale was used to get the unweighted scores obtained by each latrine system for each of the attributes.

The weighted score was obtained by multiplying the unweighted score by the relative weight of the attribute. Thus, considering the bucket latrine as an example, its unweighted score for the attribute "low initial cost" was five; but "low initial cost" has a relative weight of 20. Consequently the weighted score obtained by the bucket latrine system for the attribute of "low initial cost" was 5x20 or 100. Using this procedure, weighted scores for all the attributes were determined for all the 25 latrine systems. From the summation of these scores for each system the aggregate scores and ranks were obtained.

RESULTS

The results of the ranking exercise are summarised in Table 4 which shows the aggregate weighted scores and ranks of each system. The best ranked system was the RcA latrine. This is an on-site water-dependent off-set pit water seal latrine designed for hand flushing. It was developed in India in 1958 through a Research-cum-Action (RcA) Project established in 1956 by the Union Ministry of Health in India in association with the Ford Foundation. Depicted in Fig. 1, the RcA latrine is made up of a squatting plate, a pan, a trap designed to maintain a water seal of 2cm, a disposal pit, and a short pipe (about 2m) which runs from the trap to the pit. Two or three pits are sometimes provided in parallel so that when the first pit becomes full, the flushings can be diverted from it to the second or third pit. Only about 1.5 litres of water are required for flushing it. It is odourless and fly-free. It is inexpensive, simple to construct, and easy to maintain.

The second ranked system, the Dug Well latrine is basically the same as the RcA except that its pit is located directly below the pan and trap.

The third-ranked system was the Reid's Odourless Earth Closet (ROEC) developed and patented in South Africa in 1944. It is an on-site water-independent off-set pit latrine. It consists of a pedestal seat or squatting plate and a vented pit located behind the toilet room. The pedestal seat or squatting plate is connected to the pit by means of a curved converging chute. Fig. 1 also shows one type of ROEC recently tested in Tanzania. It is odourless and fly-free. It can also be installed either for domestic or for communal use.

It is noteworthy that the Vietnamese Double Vault latrine (also known as the Vietnamese Double Septic Tank) was ranked sixth; the conventional pit latrine was ranked 15th; and the aqua privy was ranked 22nd.

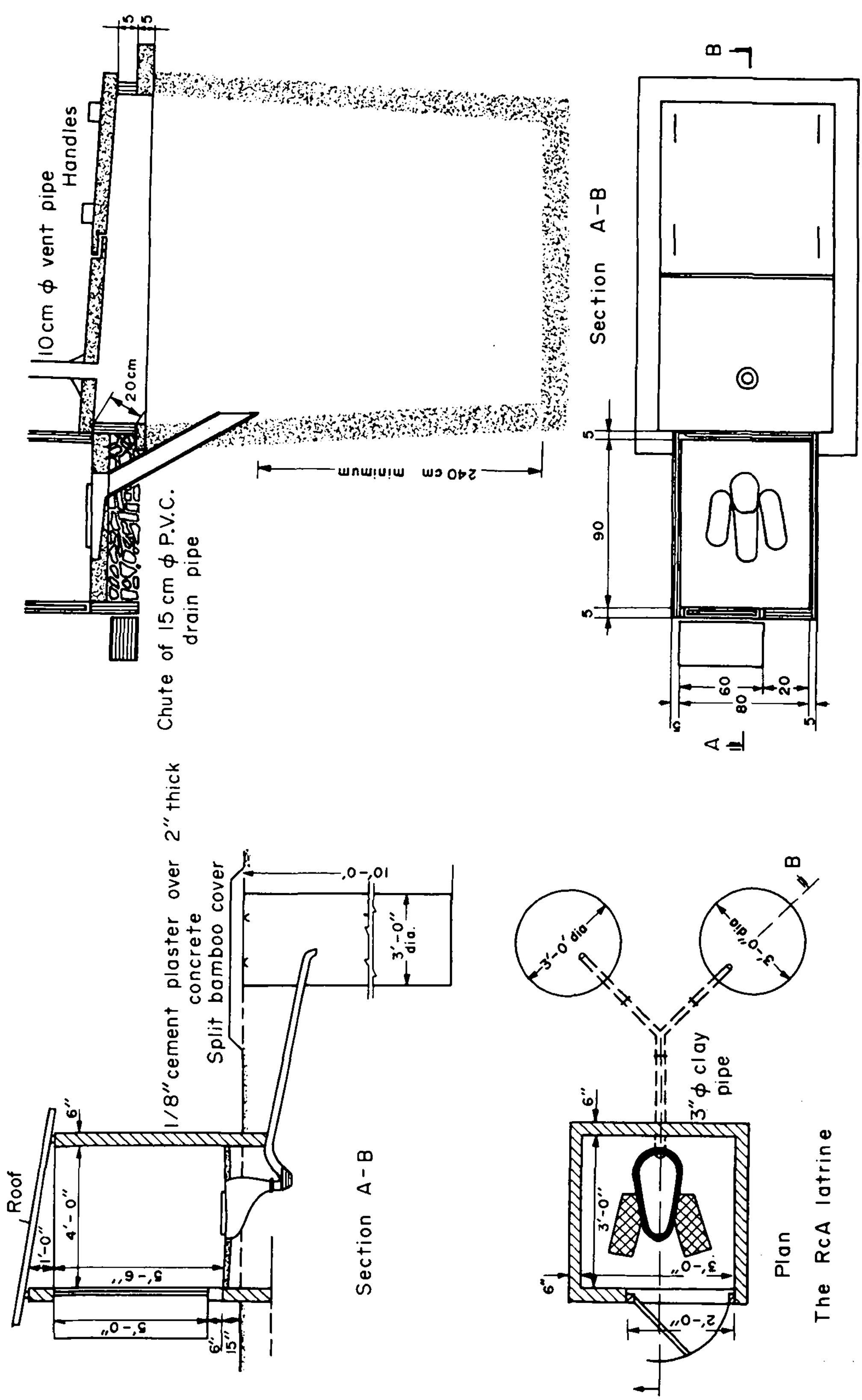
DISCUSSION

From Table 3 it can be seen that attributes which the TAG meeting considered most important for rural latrines were as given below.

	Attribute	Weight
1.	Low initial cost	20
2.	Low operation and maintenance cost	20
3.	Hygienic	12
4.	Fly-free	12
5.	Odourless	8
6.	Physically safe to use	8

These six attributes were given a total weight of 80 compared with a total weight of 124 for all the attributes. The highest ranked system, the RcA, possesses all six attributes. The ROEC does not necessarily have a low initial cost, but it possesses the remaining five attributes.

Significantly, the TAG meeting gave a low weight to permanence of a rural latrine. The reason for this was not explicitly given. But it would appear that the cost of a rural latrine system may be a function of its expected life.



The Reids odourless earth closet (ROEC)

The RcA latrine

Fig. 1.

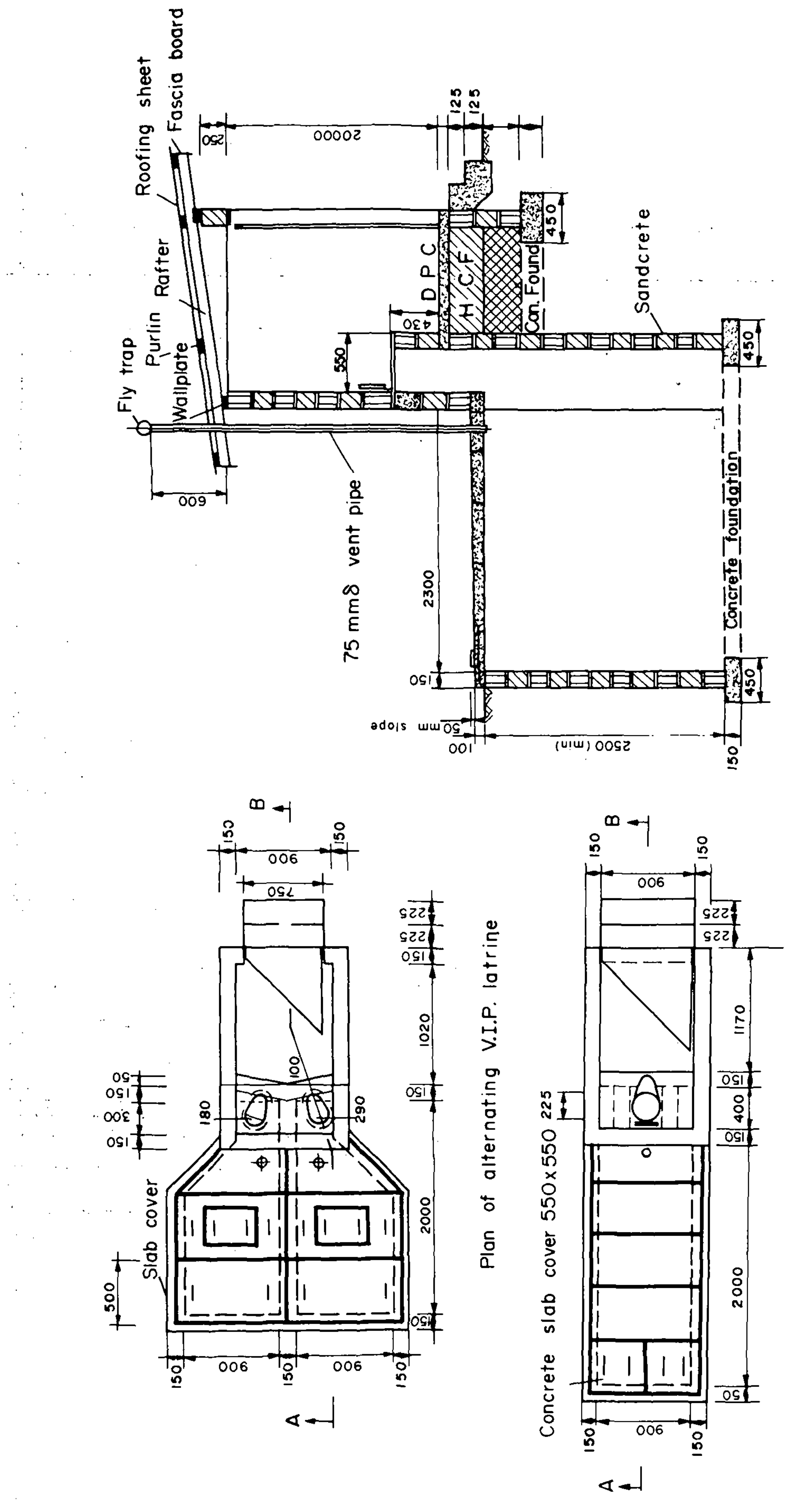

Roofing sheet
Fascia board
Rafter
Purlin
Wallplate
Fly trap
75 mmδ vent pipe
D P C
H C F
Con. Found
Sandcrete
Concrete foundation
50mm slope
Slab cover
Plan of alternating V.I.P. latrine
Concrete slab cover 550x550

Fig. 2.

TABLE 4. Weithted scores and ranks of reviewed latrine systems.

Attributes / Latrine types			Cost		Health				Technology: Operation & Maintenance							Technology: Construction							Aesthetic			Safety	Ecology		Total scores	Ranks
Relative weighting			40		32				14							10							16			8	4			
			20	20	12	12	4	4	3	3	2	2	2	1	1	2	2	2	1	1	1	1	8	4	4	8	2	2		
Specific attributes			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26		
			Low initial cost	Low operation and maintenance cost	Hygienic	Fly - free	Rodent - free	Mosquito - free	Operates without mech/elect power	Dislugging is infrequent	Easy to operate	Low water need	Operates without water	Easy to maintain	Insensitive to ablution material	Readily available construction mat.	Readily acquired construction skill	Permanent system	Permanent squatting plate	Permanent superstructure	Low space required	Special construction equipment unnecessary	Odourless	Easy to keep clean	Can be located in private house	Physically safe to users	Ecologically compatible	Usable end products		
A	1	BUCKET LATRINE	100	20	12	24	16	16	12	3	6	10	10	2	5	8	10	10	5	5	5	5	8	8	12	40	4	4	360	24
B	2	VACUUM TRUCK CARRIAGE SYSTEM	80	40	48	36	12	16	3	6	6	6	2	2	2	6	8	10	5	5	4	5	24	16	16	40	4	8	410	20
B	3	WATER CARRIAGE SYSTEM	20	60	60	60	4	12	6	15	8	2	2	3	1	2	6	10	5	5	5	5	40	20	20	40	6	4	421	18
C	4	CONVENTIONAL PIT LATRINE	100	100	36	14	8	8	15	15	10	10	10	5	5	8	10	2	1	1	3	5	16	12	4	32	8	2	438	15
C	5	VENTED PIT LATRINE	80	100	48	36	8	8	15	15	10	10	10	5	5	4	10	2	1	1	3	5	32	12	4	32	8	2	468	11
C	6	OFF-SET DRY PIT LATRINE	80	100	48	36	8	16	15	12	10	10	10	4	5	6	10	8	4	4	3	5	32	12	8	40	8	4	498	3
C	7	BOREHOLE LATRINE	80	100	36	24	8	8	15	15	10	10	10	5	5	8	10	2	1	1	3	1	16	12	4	32	8	2	426	16
C	8	VIETNAMESE DOUBLE VAULT LATRINE	60	100	36	48	20	20	15	9	8	10	10	4	4	6	10	10	5	5	3	5	24	12	4	40	10	10	486	6
C	9	GOPURI LATRINE	60	100	36	36	12	16	15	9	6	10	10	4	4	4	10	10	1	5	3	5	25	12	4	40	10	10	456	12
C	10	MULTRUM	60	100	36	36	12	16	15	12	6	10	10	4	4	4	10	10	5	5	4	5	24	16	8	40	10	10	472	10
C	11	UTAFITI LATRINE	60	100	48	36	12	16	16	12	6	10	10	4	4	4	10	10	5	5	4	5	24	12	8	40	10	10	480	7
C	12	SINGLE COMPARTMENT UTAFITI LATRINE	60	100	48	36	12	16	15	9	6	10	10	4	4	4	10	10	5	5	4	5	24	12	8	40	10	10	477	8
C	13	SINGLE VAULT LATRINE	60	80	36	24	8	8	18	9	6	10	10	4	5	4	10	10	5	5	4	5	16	12	4	32	4	4	392	21
C	14	OFF-SET SINGLE VAULT LATRINE	60	80	48	36	16	8	15	9	10	10	10	4	5	2	10	10	5	5	4	5	32	12	8	40	4	4	452	13
C	15	OFF-SET COMPOST VAULT LATRINE	60	100	48	36	16	16	15	9	6	10	10	4	4	2	10	10	5	5	4	5	32	12	8	40	10	10	487	5
C	16	OFF-SET COMPOST PIT LATRINE	80	100	48	36	8	16	15	9	6	10	10	4	4	4	10	8	4	4	4	5	32	12	8	40	10	10	497	4
D	17	AQUA PRIVY	60	80	24	24	20	8	9	9	6	8	2	3	4	2	8	10	5	5	3	5	16	8	12	40	6	2	379	22
D	18	BOTSWANA TYPE B TOILET	40	80	48	36	20	8	9	9	8	8	2	3	4	2	8	10	5	5	3	5	32	16	12	40	6	2	421	18
D	19	SEPTIC TANK LATRINE	40	100	60	48	20	8	15	9	8	8	2	3	3	2	8	10	5	5	3	5	40	16	8	40	6	4	476	9
D	20	CHINESE-2 PARTITION -3 TANK TOILET	60	80	36	36	16	12	15	6	8	8	2	4	3	4	8	10	5	5	2	5	24	12	8	40	10	10	329	25
D	21	DUG-WELL LATRINE	80	100	60	48	16	20	15	12	8	8	2	4	3	2	10	2	1	1	4	5	40	16	4	40	8	8	517	2
D	22	KHATGHAR LATRINE	60	80	48	36	12	12	9	9	8	8	2	3	5	2	10	10	5	5	3	5	24	12	4	40	6	4	422	17
D	23	WATERGATE LATRINE	20	80	48	36	12	12	15	9	6	8	2	3	5	2	8	8	4	4	3	5	24	12	4	40	6	2	378	23
D	24	R&A LATRINE	80	100	60	48	16	20	15	12	8	8	2	4	2	2	10	10	5	5	3	5	40	16	16	40	8	8	543	1
D	25	SEPTIC TANK SYSTEM	20	80	60	60	16	8	9	12	8	2	2	3	1	2	6	10	5	5	1	5	40	20	20	40	8	4	447	14

The results show that the three top ranked systems are all modifications of the conventional pit latrine which was itself ranked 15th. The modifications which have been made render them, inter alia, both fly-free and odourless. In the case of the RcA and the ROEC, the use of off-set pits also makes them physically safer to use than a conventional pit latrine whose pit is located directly below the defaecation unit.

The results show further that the first 18 systems all have on-site disposal facilities. Although the location of the disposal site relative to the defaecation place was not explicitly used as an attribute, it appears that for rural conditions the relative location of the disposal site is an important attribute. It is to be expected that off-site systems would tend to be more expensive to run than on-site systems. Furthermore, they are more likely to expose scavengers to excreta-related infections. Therefore, on-site disposal should be included in the list of important attributes for rural latrines.

It may be noted that six out of the first ten systems are compost or mouldering latrines. Although the proper use of such systems requires more education than systems like the ROEC, nevertheless they are likely to grow in popularity because of their role in the recycling of wastes.

It may be noted that in ranking the systems, only one use was considered, namely, excreta disposal. No additional weight was given to those systemswhich could be used for additional purposes like the disposal of refuse or sullage, or for the production of useful end-products like fuel, fertilizer, or soil conditioners. These additional uses may have to be taken into account where appropriate.

RECOMMENDATIONS

Based on the results of the review the following recommendations were made for the rural sanitation programme in Ghana:

(i) Where water is always available, the RcA may be promoted
(ii) Where water is scarce, the ROEC may be promoted.
(iii) The following three types of compost latrines may be tested in the field:
- .Off-set compost pit latrine
- .Vietnamese double vault latrine
- .Utafiti latrine, which is a Tanzanian modification of the Multrum.

UPSHOT OF REVIEW: THE V.I.P. LATRINE

Experience in Botswana has shown that the inclined chute of the ROEC is subject to fouling by excreta. This fouling tends to undermine the hygienic properties of the ROEC. The design of the ROEC has therefore been modified to eliminate such fouling. In the revised design there is no chute; instead, the near end of the pit has been extended just below the superstructure so that faeces from the pedestal seat or squatting plate can drop directly into the pit. This modification of the ROEC has been called the Vented Indirect Pit latrine or the V.I.P. latrine, for short. It is expected to cost about the same as the ROEC.

A second modification of the ROEC is the Alternating V.I.P. latrine. In this modification, the pedestal seat or squatting plate in each toilet room or compartment has two openings. Each opening leads to one of two adjacent indirect pits. Thus behind the toilet room are two adjacent pits, each with a corresponding toilet seat opening within the same toilet room.

In operation only one pit is used at a time. When the first pit becomes full, the second pit is brought into use. When the second pit becomes full, the decomposed contents of the first pit are removed for possible use in agriculture; and the emptied pit is returned into use. This way the two adjacent pits can be used alternately for a long time. To ensure that there is no survival of pathogens in the decomposed material removed from a pit, each pit should be able to last for at least two years. In practice, it is recommended that each pit is designed to last between three to five years.

The Alternating V.I.P. latrine will be more expensive than the ROEC or the V.I.P. latrine; but it has two advantages over them; it can be considered a permanent latrine; it also yields an end-product that can be used as a soil conditioner to improve agriculture. Fig. 2 shows plans for the V.I.P. and the Alternating V.I.P. latrines; it also shows a cross-section of the latter. The cross-section of the V.I.P. is similar.

In the communal version the number of pits is one more than the number of toilet cubicles. If the pits are numbered sequentially from one end they can be divided into two sets, namely, odd-numbered pits and even-numbered pits. In operation either the odd-numbered or the even-numbered pits are used at any given time. When a member of one set of pits becomes full, all members are taken out of use, and the other set is brought into use. Hence these two sets of pits are used alternately.

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ALTERNATIVE SANITATION IN BOTSWANA

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INTRODUCTION

In April 1976 work commenced in Gaborone on a study of low cost latrine options, climaxing several months negotiations between the Government of Botswana, and International Development Research Centre of Canada. To date three Interim Reports have been issued, documenting library and field research undertaken by the Project Working Group, making specific recommendations for a program of field trials, and presenting conclusions and a fresh set of recommendations on the basis of data derived from a 4-5 month monitoring period. At this point in time (June 1978) an extensive Pilot Study covering three towns is in its feedback phase, and long before the date set for this Conference, a Final Report will have been drafted, making specific proposals for implementation and follow through.

In the main text of this contribution, following the introduction, the writer hopes to, well within the limits set by the Conference organisers:

(1) summarize the approach adopted to the task by the Working Group;

(2) present its impressions of the relevance of the undertaking - as perceived from contact with politicians, public officials and the target population - and

(3) describe activities with which the Project has become associated as a result of the widening of interest in this field in Botswana.

Pursued through the efforts of only one full time and two part time professional staff comprising the writer M. D. Blackmore - Project Leader, an Engineer/Planner; R. A. Boydell - Project Engineer; E. N. Mbere - Project Sociologist (full time), the Botswana Study is now in its closing stages, and by the time of the Conference, will, as a Unit within the Ministry of Local Government and Lands, have ceased to exist, at least in its present form. However, it is the unanimous feeling of all those who have shared in the Project's interest and in its routine, that concern for environmental sanitation, if it is to become institutionalized, requires the creation of a successor in title, a full time Unit in the Ministry of Local Government which can function as clearing house for fresh data on available technology, a source of advice to Local, Town and District Councils, and participating consultant in implementation schemes. So much anticipates the recommendations of the Final Report.

To conclude this introduction, the writer takes pleasure in presenting the representative of the Botswana Government, Mr B. P. B. Bagwasi, Under Secretary for Urban Affairs in the Ministry of Local Government and Lands, who in the absence of all three members of the Working Group - now no longer in Botswana Government Service - and as ex officio Chairman of the Project Steering Committee, will deliver the following contribution to this Conference.

1. INCEPTION

The Projects terms of reference called for the identification of one or more latrine systems which satisfied criteria of cost - P150 at 1975 base, simplicity of use and maintenance, hygiene and low water consumption for use in the country's low cost urban neighbourhoods including squatter upgrading areas, and site and service developments.

To prepare the ground, a number of investigations were pursued by the Project Working Group which required extensive travel throughout Botswana, and lengthy periods of absence abroad, largely in Zambia, Tanzania and India. Assessments of sociological and health implications of discerned practices were formed from sample surveys in the four towns, Gaborone (capital), Lobatse, Selibe-Phikwe and Francistown, and a number of technologies evaluated - according to a ranking system, described in the First Interim Report - whose introduction might satisfy the prejudices of the former and the reasonable demands of the latter.

Specific recommendations framed at that stage went considerably beyond the brief and related to sanitary shortcomings in the urban fabric generally. Probably wisely, the more so since the country's very low population predicates the relatively easy eradication of basic problems, only those recommendations for latrine field trials were proceeded with. These were in respect of basically three system types.

(1) An aqua privy, widely known today as the Botswana Type B.

(2) Pits - a modified, non experimental, straight drop, and an offset, the ROEC.

(3) Various types of composter/mouldering latrine.

2. PRELIMINARY TRIALS

The Type B
Popular dissatisfaction with an earlier precast fibre glass aqua privy (the Apec) reinforced impressions gained from other sanitarians that this technology was generally inimical to the African outlook. However a credible explanation for the rejection of the Apec emerged from an analysis of its design construction and use, and Working Group inclinations were solidly in favour of a further experiment with this principle. And so the Type B was evolved.

Conceived around the necessity for any household to bring onto the plot, however far the source, a certain minimum volume of water for primarily domestic purposes, the Type B simultaneously overcame the problem of sullage disposal, and the need for aqua chamber topping up through a reuse facility. Based on the Vaal Potteries Spiraflow Aqua Pan, the Type B incorporated one of two alternative washing fitments - an internal hand basin/external wash through - plumbed into the flushing rim of the pan, whose hydraulic design characteristics encouraged a spiral scouring movement of water when flushed from the fitment, around the ceramic wall and chute, before discharging to the chamber.

The Straight Pit
Conventional pits abound in all parts of Botswana, and typically suffer from major structural faults - leading to collapse of slab and superstructure into pit - and an inevitable tendency for use to continue beyond the stage which sanitary wisdom indicates is desirable. The Working Groups basic attitude to pits was a realistic one. Notwithstanding future project achievements, the system would continue to play an important and major role in the country generally if not in the towns specifically. Accordingly a design for what was a partially offset pit was produced whose detailing was constrained only by the need to overcome structural failure, and small numbers of demonstration prototypes built in all four towns. At the same time it was emphasized by the Working Group that this was not strictly a part of the "urban" project, and there was no intention to proceed with the system beyond the first stage, since the stand had been taken and generally endorsed, that urban latrines should be permanent and therefore easily emptied.

The Offset Pit - the ROEC
This system had attracted the Groups interest during the surveys carried out in Botswana since it had obvious advantages over the straight drop pit which were not being realised in use. Rather surprisingly for a latrine, all of whose users were convinced champions of its merits, its adoption was largely confined to the village of Molepolole - two hours drive west of the capital - where early examples could be inspected dating back some 2 decades. Adopted by the Working Group as a compromise latrine on the pit principle, the ROEC satisfied the criterion of permanence through ease of emptying - via removable concrete planks - and offered users unfamiliar with it, the basic simplicity of the ordinary pit.

The Composters
At the time the Botswana Project commenced there prevailed what could well be described as the "composting imperative" over the activities of newcomers to sanitary experiment in the continent. The Working Group accordingly succumbed to the tempting glamour of the continuous composter's promise of rapid landscape renewal, to the extent of three variants of the "Multrum" in all towns. Regrettably! ....

Simultaneously, a conventional design for a Double Vault composting latrine was produced, two in each town built, and an alternative to the ROEC or ordinary pit thereby established. Justified more lately in terms of its much less onerous excavation needs as compared with the ROEC, the D/V has merit in those areas, common in Botswana's site and service developments, where extensive rock occurs at shallow depths; but expressions of enthusiasm for its virtues as an instrument of conservation are now rather muted within the Working Group. Even technocrats can be embarrassed!

Superstructures
Although Project interest necessarily centre around "systems" and therefore what went on

underground, studies carried out in Botswana indicated the existence of preferences with respect to the superstructure which could influence a plotholders response to the latrine as a whole. Mindful of this possibility the Working Group followed their sociologist's advice and reflected known preferences for generously sized superstructures, some with some without, screen walls. Except insofaras this move anticipated adverse response to an otherwise good system - important to the Working Group for obvious reasons - it had little significance in fact for post-project schemes of implementation, latrine provision in site and service schemes universally being exclusive of the superstructure which is left to plotholders' individual preference.

3. OPERATIONAL EFFECTIVENESS

As might have been expected, but none the less embarrassingly so because of its exclusion from further trials, the straight drop pit proved the least troublesome during observation, and not surprisingly therefore, one of the best looked after. A welcome absence of smell and fly nuisance could of course be attributed to this factor, but engineering preference in the Working Group is to accept the mesh capped vent pipe - common to all project latrine types - as the real explanation!

In fact, the degree of user care given the offset pit, the ROEC, closely parallelled that in the case of the straight drop, but intermittent nuisance of a low order was observed during the hottest - and wettest - weather. Absence of stack effect was in fact monitored in Lobatse on a number of occasions, not all of them coincident with the presence of smell nuisance, and bitumen painting of the ground cover slabs appeared to have little effect on the extent to which ventilation from this source arose.

Also producing very little nuisance, but with marked and inexplicable differences as between different prototypes, the Type Bs similarly enjoyed an appreciable measure of acceptance and care, performing gratifyingly well with respect to solids digestion, and effluent absorption even during the wettest part of the year. Obvious at a very early stage was the much greater preference for the external washing fitment, the internal hand basins in no case serving a locally perceived need for the level of toilet hygiene associated with high water consumption societies. However, disagreement existed at the relevant time as to internal or external fitment, some political preference being known to favour the former. In as much as the prototypes confirmed the consensus of Working Group feelings in this matter, and eliminated doubt as to the correct approach for the Pilot Study, this aspect of experimentation was entirely justified.

The spirit of enthusiasm for leading doubting plotholders across the threshold between bare sandsoil gardens and richly carpeted lush springy green swards, quickly evaporated amongst the Working Group. And with it any future for the Multrum and the two variants on its experimented with at the prototype stage. Very little optimism was felt after the first month of monitoring, that Botswana could be sufficiently motivated by the virtues of a few kilograms or so of humus every 6 months to perform the necessary task of removal, and so keep the installation operational. But, at least, the "imperative" was satisfied.

The much different emptying requirement of the Double Vault's cycle though, made possible a switch in projected responsibility from plotholder to Local Authority, and perhaps with more than a hint of salvaging bruised dignity involved, led the Working Group to endorse the system as suitable for further trials. However, very little optimism is felt that this latrine will yield the quality of dry granular humus associated with it in the Far East because of firstly the paucity of degradeable material available for composting with faecal matter in the Botswana urban site and service context, and secondly because of the seasonal flooding of the underground chambers - expensive to eliminate - and the subsequent impossibility of early dewatering of the pile. The only honest description of the contents of those chambers already closed off - at the time of the switch - is soggy and septic! (This was in February, the middle of the rainy season).

4. SITING IMPLICATIONS

Unambiguous acknowledgement that it would not be reasonable to proceed on the basis that emptying of dry latrines would be carried out conscientiously by plotholders was made during prototype trials. The emptying imperative - for locational permanence - however remained, the Local Authority Sanitation Department being the next obvious choice. Facilitating the operation accordingly became a Project concern. Type Bs of course presented no difficulty except in relation to available vacuum tanker capability. The dry systems however introduced new problems to which the Working Group envisaged "mechanical" rather than "manual" solutions, and pursued with South African plant manufacturers, but so far with no progress to show.

Nonetheless two principles have been established to guide plot development. Firstly, access to the latrine from the road should be facilitated by siting it in an otherwise unbuilt on corridor along the plot boundary. Secondly orientation should be such that emptying covers, ie the "backs" of the Type B, ROEC and Double Vault, should face the road from which access would be gained for servicing purposes.

5. ELIMINATION AND REFINEMENTS

For reasons already indicated prototype trials eliminated the continuous composters from further consideration. In its Third Interim Report the Working Group presented an analysis of performance which pointed unambiguously to more extensive trials in the Pilot Study proceeding with the Type B, ROEC and the still favoured Double Vault. During the actual construction phase late alterations were made reducing size of superstructure for Type Bs in Gaborone, ROECs in Lobatse, and slab thicknesses generally in Francistown. Simultaneously repositioning of the external washing troughs to the Type Bs was decided on, leaving unimpeded access to the chamber cover for servicing operations.

In repositioning the timber framed superstructures to Double Vaults in Gaborone and Lobatse, the writer experienced difficulty in aligning post horns with socket holes in the slab, an arrangement devised for both positioning and stabilising purposes. Accordingly all Double Vault superstructures now built for the Pilot Project incorporate slotted holes in both bottom rails, allowing for flexible positioning over rag bolts grouted into the slab.

6. THE PILOT STUDY

Experimentation in the Botswana Project has passed through an early prototype phase - in which some 52 units overall were built in the 4 towns - and is now in the major Pilot Study monitoring phase, 30 of each of the 3 selected systems having been built, 10 each in the site and service areas of Gaborone, Lobatse and Francistown. At the time data gathering is terminated and the draft of the Final Report prepared, major problems will remain unsolved - unavoidably. However, the situation regarding technologies per se has already crystallized and the firm expectation is that the type B aqua privy will be presented as a sole "wet" option and the ROEC the first choice "dry" system, with the Double Vault recommended as back up for situations in which excavation proves difficult and costly. Little optimism though is held out for achieving a usable compost at the emptying stage in the cycle - which appears on the chamber volume and rate of use to be 2-yearly, more or less as designed.

7. PUBLIC RELATIONS

The Project was conceived as a cooperative effort involving interested Ministeries (Local Government and Lands, Health, Mineral Resources and Water Affairs) and Town Councils. Accordingly, although the Working Group is an all civil service one, strenuous efforts have been made to involve at all stages the Health and Housing Departments of the Town Councils, and elected representatives. Meetings of the Steering Committee bring all interested bodies together, and "teach ins" held in all towns prior to the launching of the prototype study saw the active involvement of plotholders, Council Officials, and Councillors.

A different approach but with a similar intention was adopted for the Pilot Study, for which, in all three towns, tours of the relevant plots were mounted for Councillors and Officials, and the opportunity created for not only inspection, but more improtantly exchange of views with cooperating plotholders. Response can be described as appreciative - and appreciable - and an early return on this investment is expected in the form of a self help contribution from participants in the Pilot Study, with pressure from local official sources assured. In fact the contribution expected - and programmed into the planning of this phase of the Project - is very little in terms of material input, comprising the painting of the superstructure door and frame and provision of an appropriate brush for Type B and ROEC. Regrettably, perhaps shamefully, Project personnel were not successful themselves in stimulating this level of self help.

Gratifyingly, political interest in Central Government is much in evidence, the Minister for Local Government and Lands having taken the lead in informing himself through direct personal contact, of the feelings towards systems under trial. At the time of writing and in advance of the release of the Final Report he has in fact preempted its recommendation by edict suspending activities in towns, involving systems known not to be favoured by the Working Group.

8. PROJECT RELATED ACTIVITIES

Project roles in a major Ministry campaign and in the sanitary upgrading of a particularly troublesome squatter settlement - Peleng Village - in Lobatse are being discharged, the need for its input extending far beyond the projected life of the Working Group Unit.

Firstly, and also on an interministerial platform, a National Radio learning campaign has reached an advanced stage of planning, its theme being sanitation across a broad spectrum, and its target population villagers from the Districts remote from urban facilities. Awaiting the arrival of a media coordinator to initiate the implementation of the campaign, the early material to be broadcast focuses on latrine provision, for which the Working Group has provided the technical consultancy. Operating on the lines of an earlier Broadcasting campaign for the improved management of tribal grazing land, the planned approach will be to identify a number of "link" personnel in the Districts for whom basic training courses in the necessary skills will be established in the Capital. With logistical support in the form of a materials and transport unit, these people will become the first tier in a descending chain of extension workers which will make individual contact with the householders reached by the campaign. Extending over probably three years, implementation is now likely to commence in early 1979 with the mounting of a brief Pilot Project within a limited catchment, for proving purposes, and to finalize approach.

Early in April 1978 a Ministry of Overseas Development mission to Zambia was conducted by the writer, on an extensive tour of the Marais/Vincent sewered aqua privy schemes of the early sixties. Comprising John Pickford of WEDC (Loughborough University of Technology) assisted by Bob Boydell - Project Engineer until November 1977 - and Ron Carrol of the Overseas Division BRE, the purpose of the visit was to explore the feasibility of adopting this principle in the sanitary upgrading of Peleng Village in Lobatse, a hillside settlement which for reasons of geology would be difficult to serve with Project hardware in an unadapted form.

A prior briefing by Professor Marais and Mr L. G. Vincent both now in Cape Town, provided the writer with a source of first hand background material which proved invaluable in the conducting of the study, and for which, particularly in view of the very short notice at which the visit was made, his own, and the Mission's, very grateful thanks are reaffirmed.

In general, the impression acquired from extensive, and on John Pickford's part "intimate" "heroic" would perhaps better describe) familarization with widely separated installations, was that they were on the point of collapse because of lack of servicing. Sewer blockages in Matero Township Lusaka were evidently common occurrences, and upper sludge mats on effluent in manholes uncovered along one blocked line during inspection, pointed to quiescent conditions having become established over a considerable period of time. In all cases solids build up in chambers had long passed the critical stage, and where chutes were not actually below the sludge level, they were sufficiently close to ensure rapid progress of fresh influent to sewer. Manual (again with acknowledgements to John Pickford) sampling and examination of solids contents indicated a very high proportion of grit and similar detritus, for which the explanation was deemed to be the squat plate type of inlet universally adopted by Marais and Vincent.

However, with qualifications which senior governmental sources feel Botswana can satisfy, the verdict of the Mission was broadly, that the scheme could be recommended to MOD for the Peleng application. Since the core unit of the Type B is a pedestal, rather than plate, elimination of grit from the chamber would not prove problematical, and the rate of accumulation of sludge proper, as deduced from Type Bs in use over a period in excess of 1 year, suggests a servicing interval of at least 7 years, and an additional burden on Town Council of not insuperable dimension.

9. EXTERNAL RELATIONSHIPS

A small country with rather a lot happening and about to happen in fields of concern to all delegates, summarizes Botswana in the context of conference interest. Involvement by outside bodies has been, and continues to be sought, both to maintain impetus which has been built up within the country following the closure of the Low Cost Sanitation Project, and to maximize the regional/international spin-off from its activities. In addition the financial implications for implementation, of recommendations made and about to be made, are closely monitored by, amongst other donor agencies, the World Bank.

At this time some success has been met in enlisting the consultancy services of the Overseas Division Building Research Establishment (UK) in two specific problems which will survive the Low Cost Sanitation Unit in the Ministry of Local Government and Lands. These are firstly the pressing problem of dry latrine emptying procedures and secondly construction standards and organisation, the most immediate need being to satisfy much lower cost targets than proposed in the Project's terms of reference. Insofaras the Peleng proposals are concerned, general consensus has been reached that since MOD is the funding body both for this item of urban aid and for BRE Overseas Division, the prolongued monitoring requirements of this major experiment similarly be met through the organisational resources of the latter body, but - and this emphasizes the need for a successor body, unit or individual within the Ministry of Local Government and Lands, following the termination of the Project and departure of the Working Group - working in cooperation with locally based assistance.

10. CONCLUSIONS

Apologies are made for presenting a contribution which lacks the sort of detail e.g. maps, working drawings, survey data, relating to experimental work carried out in Botswana, which Engineers particularly, might regard as an essential ingredient. However, a considerable volume of formal documentation exists, comprising Reports and Drawings, to which, for those delegates who have an unsatisfied interest in the Botswana Project, access is possible through IDRC, Ministry of Local Government and Lands, P/Bag 006, Gaborone, John Pickford's WEDC Documentation Unit and BRE. To the extent of his availability, and in a non official capacity, the writer would also be pleased to elaborate on any matters arising from this Paper, as would, undoubtedly others who have served on the Working Group, Bob Boydell, Nomtuse Mbere, and whose activities have contributed in great measure, to the production of this descriptive, but very limited contribution.

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NEW PROSPECTS FOR URBAN EXCRETA DISPOSAL IN DEVELOPING COUNTRIES

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Abstract
This paper reviews existing conditions of water supply and excreta disposal (See note b) in developing countries, the historical development leading to present excreta disposal practices, the costs of using these practices in developing countries, suggests an alternate approach and recommends actions for its implementation.

INTRODUCTION

Water supply and excreta disposal is essential for human health. Sadly, a majority of people in developing countries lack access to these services. Fortunately, there is a growing awareness of the need to overcome past neglect, as evidenced by the various resolutions at the UN Water Conference in Mar del Plata in 1977, the declaration of the 1980s as the Drinking Water and Sanitation Decade by the UN General Assembly and activities directed towards increasing service levels by UN and other agencies and national governments.

THE NEED FOR EXCRETA DISPOSAL

The need to dispose of waste, in particular human excreta, is as self-evident to members of primitive societies as it is to those of the most sophisticated culture, though the reasons for this perception differ. As a minimum, people attempt to maintain their immediate surroundings in a reasonable state of cleanliness and free of human excreta. But as development takes place and living conditions improve, peoples' attitude towards excreta disposal and the demands made on waste disposal systems in general change. As a consequence, disposal methods change to satisfy changing requirements. The history of excreta disposal in industrialized countries provides many examples of this change in demands (Ref. 1, 2).

There are at least three major reasons for excreta disposal and each requires or at least permits different solutions. They are:

Health

A wide range of communicable diseases is transmitted from the excreta of an infected person to a healthy person. The manner in which the disease is transmitted varies. It can be direct, for example, if food or utensils have been in contact with infected excreta; it can be through the contamination of water by excreta or even by penetration of the disease through the skin. Because human excreta is the vehicle, directly or indirectly, for the transmission of these diseases, removing the excreta from human contact will reduce, possibly eliminate, the disease.

It is clear that excreta disposal alone is not sufficient to create an adequate health environment. The provision of a sufficient amount of safe water can reduce the incidents of some of the diseases, but cannot eliminate them as long as access to disease carrying excreta is not prevented. It is unfortunate that large investments have been made for the provision of water supply in developing countries without the simultaneous provision of adequate means of excreta disposal. In addition to the physical facilities, water and

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: For the purpose of the discussions in this paper, excreta includes urine.

sanitation projects should make provisions for health education and promotion of personal hygiene without which proper use of the facilities and thus their benefits cannot be fully realized.

Aesthetics and convenience

As the standard of living improves and society begins to satisfy not only the basic needs of its members but is able to provide less essential benefits such as improvements in housing, recreation and so forth, aesthetics of excreta disposal becomes a more important consideration. People expect a disposal practice which is not only protective of their health environment but odorless, comfortable, and convenient to use. This desire has resulted in a steady stream of improvements from the pit latrine to the present flush toilet with all the necessary supportive systems and investments the latter requires. It is clear that the improved health benefits of a flush toilet, if any, above those provided by a well constructed, well maintained pit privy, are in no way proportional of the extra cost of a sewer system required to accommodate flush toilets. Thus the extra cost is attributable primarily to greater convenience. It is clear, also, that a pit privy would not be a feasible solution for high density urban areas but it is by no means certain that waterborne sewerage is necessarily the only or optimum solution to excreta disposal for every urban area. It is an aesthetically satisfactory and pleasing high cost solution which has become the choice where affordable to prospective users.

Environment

When excreta disposal consisted of latrines and similar facilities (onsite disposal methods), environmental impacts were restricted to the immediate disposal area. With the introduction of waterborne sewerage and its use of large amounts of water to flush excreta to nearby water courses, environmental degradation began and eventually became intolerable leading to the introduction of sewage treatment to reduce detrimental downstream impacts of waste disposal. Governments, having accepted the waterborne system, today have little choice but to keep making ever increasing investments in treatment facilities in order to protect the environment from the growing waste flows. In fact, while the high standard of living in industrialized countries is associated with the use of a number of water using appliances which require a sewer system, there is increasing evidence that both sewage and drinking water treatment processes are deficient in eliminating some serious health hazards created by present day waste disposal methods. Ironically the ever more sophisticated treatment which must be provided to drinking water and sewage in order to protect the environment and the water consumer is a direct result of the continuous expansion of waterborne waste disposal. (See note a.)

HISTORICAL DEVELOPMENT OF EXCRETA DISPOSAL METHODS

In Deuteronomy 23:13, 14 (Ref. 3) the Lord instructed the Israelites to keep their camps clean, as follows: "You must have a latrine outside the camp, and go out to this; and you must have a mattock among your equipment and with this mattock, when you go outside to ease yourself, you must dig a hole and cover your excrement." Since Deuteronomy contains some of the oldest writings of the Bible, it can be assumed that appropriate waste disposal was of concern wherever people congregated, even in antiquity (it is interesting to note, incidentally, that there is no reference in the Bible to the need for clean water).

The pit latrine is probably the users' earliest attempt to increase the convenience of defecation by providing privacy not available in the field and eliminating the need to travel distances to the disposal site. If properly designed and maintained, the latrine is still a perfectly acceptable and safe method of human waste disposal. The majority of the people in rural urban fringe and squatter areas of developing countries today use it in one form or another. Where use of the latrine is appropriate, it presents the most cost-effective solution for the safe disposal of human waste.

As the population in the cities increased and land became more and more densely populated, there was less and less room for backyard latrines. They gave way to bucket latrines and, on occasion, to public latrines, with excreta being collected and discharged into nearby water courses. In addition, the development of municipal water systems required the disposal of increasing amounts of water which was usually discharged to open drainage ditches or the

Note a: For example, presently mandated removal of chlorinated hydrocarbons is a direct consequence of water-carriage waste systems based on an inexpensive water supply. These systems carry chlorinated effluents containing organic wastes to streams which are almost completely removed by downstream water plants. Unfortunately, low but measurable concentrations of chlorinated hydrocarbons such as chloroform remain. These must be removed at considerable expense to make the water safe for drinking.

street. Obviously, as water consumption increased and more wastes were generated very unsanitary conditions resulted, leading eventually to the water closet and the discharge of their contents to underground drains and nearby water courses. As population increased further and water consumption rose, treatment of the discharged waste had to be instituted in order to reduce the massive pollution of receiving waters, ultimately leading to the presently employed separate sanitary and storm sewer systems. Today storm water treatment is being considered in some cities because even the rain water picks up enough pollution from roofs, streets and other paved surfaces to present a substantial source of contamination.

It is clear that the present stage of sanitation technology has been reached by a process of devising solutions to problems created by a previous solution which in turn was implemented to eliminate yet another previous problem. This cause and response relationship can be extended all the way back to the change from dry to waterborne disposal. Unfortunately, neither then, or anytime since was a comprehensive examination made to determine whether waterborne waste disposal is the best solution, most likely because its consequences were not adequately foreseen. Instead, every time a new waste disposal problem arose, usually as a result of a previous waste disposal technology, a new method was developed to solve it. Each time the new technology represented the least-cost solution in the financial/engineering sense. Given the massive sewerage investments which now exist in the industrialized countries, any other solution is probably not feasible nor acceptable unless a definite correlation between cancer and other illnesses and our waste disposal and water treatment practices can be established, a development which is not entirely beyond the realm of possibilities.

On the other hand, developing countries have serious waste disposal problems and in a majority of cases, have not yet made a final commitment on how to manage their wastes. They do not have the time it took industrialized countries to progress from the latrine to the present system unless they wish to slow down their development, clearly an unacceptable proposition. Neither do they have the funds to do in one step what industrialized countries had decades, even centuries to accomplish and invest in a system which, mostly for convenience sake, uses daily 30 to 40 gallons of potable water to flush a few pounds of excreta down the drain and to the nearest water course. In short, there exists today not only the opportunity but the obligation to take another look at excreta disposal practices, an opportunity which is of vital importance to the people in developing countries. For if less expensive methods to solve excreta disposal problems cannot be found, many people will be condemned to live out their lives in unsatisfactory sanitary conditions.

WATER SUPPLY AND EXCRETA DISPOSAL SERVICE LEVELS

Existing service levels

To understand the magnitude of the problem, it is only necessary to look at some of the data presented by WHO at the U.N. Water Conference which took place in Mar del Plata in the Spring of 1977 (Ref. 4). The data were based on three surveys carried out in 1962, 1970 and 1975 and are little more than estimates. In general, water supply figures are somewhat more reliable than those on waste disposal, and urban figures are better than rural. Even so, the figures can really only be used with caution to indicate general trends. For example, definitions of "urban" and "rural" differ from one country to another, what constitutes "adequate service" is subject to various interpretations and so on.

Using the countries' definition to distinguish urban and rural areas, it appears that there has been an increase in the proportion of urban population with access to water supply, through either house connections or public standposts, from 59 percent in 1962 to 67 percent in 1970 and 77 percent (450 million) in 1975. For the rural areas, it appears that the proportion of people with reasonable access to water supplies (i.e., where members of a household do not have to spend a large part of the day fetching water) also increased, from 14 percent in 1970 to 22 percent (310 million) in 1975. (See note a.) However, between 1970 and 1975 there was little or no change in the proportion, from 25 to 27 percent (148 million), of urban population served by a public sewerage system, and only a marginal increase, from 42 to 50 percent (295 million), in the proportion using a household system (such as pit, privy, septic tank or buckets).

It must be recalled that during the period 1962-1975 urban populations grew at a faster rate than ever before in history, partly because of a relatively high natural rate of increase of population (births minus deaths) but mainly because of massive migration into these areas from the villages. (See note b.) Thus, information on the percentage of people served

Note a: Figures for 1962 are not available.
Note b: Some of the "urban increase" was also definitional - i.e., communities moving from rural to urban status as they passed the dividing line in terms of population size.

understates the real efforts made in supplying water to ever greater numbers of people. For example, between 1970 and 1975 the total number of urban people served increased by 42 percent, from 216 million to 450 million, even though the total number of people waiting to be served dropped only from 156 million to 134 million.

In the rural areas the population increase was slower, but despite an increase of over 70 percent in the relatively small number of people with water service, from 180 million to 310 million, little or no impact was made on the backlog of service, with over 1.4 billion rural dwellers still without safe or convenient supplies in 1975 - roughly the same number as in 1970. Rural excreta disposal service levels show a similar pattern, with only 14 percent (195-million) considered to have adequate excreta disposal and 1.5 billion without adequate disposal.

Proposed future service levels

At the Mar del Plata Water Conference, the delegates passed a resolution endorsing the goal to provide water supply and sanitation services to all people by 1990, requesting the U.N. General Assembly to declare the 1980s the INTERNATIONAL DRINKING WATER AND SANITATION DECADE and recommending to governments various actions in preparation of the Decade.

If these targets are to be achieved, based on predicted population growth and including presently unserved population, the total additional population to receive services amounts to 580 million and 1.7 billion for urban and rural water supply and 590 million and 1.8 billion for urban and rural excreta disposal respectively.

Quality of service

Before discussing investment needs it is important to review the quality aspect of water supply to show how little the quantitative figures may actually mean. For example, in one country in Southeast Asia urban service levels are reported to have increased from 60 percent in 1970 to 80 percent in 1975; the numbers of people served by house connections or public standposts increased from 66 million to 107 million and the backlog of unserved population was cut from 44 million to 27 million. On the face of it, this appears to be an outstanding achievement. Yet in reality, a declining quality of service has more than offset the increases in service levels. Customers who had, on average, ten hours of service in 1970 now have only three hours. The safety of the water, as a result, is in greater doubt than ever. Moreover, those customers who can afford it are being obliged to spend large amounts on storage facilities, while customers in the poorer areas are having to wait longer to ensure that they get the supplies they need. Under such circumstances, maintenance of the distribution system is extremely difficult, while there is no guarantee with intermittent supply that even chlorination will ensure water safe for human consumption.

In short, therefore, it is quite likely that less than 500 million of the 2.4 billion people living in the developing countries now have reasonable access to adequate supplies of safe water. Moreover, with continuing population growth, pressure on facilities may actually reduce this number unless adequate investment is made in additional water resources.

On the basis of the only available figures on excreta disposal facilities (for the years 1970 and 1975), it appears that there has been very little increase in the proportion of people served, or, in other words, that these facilities have just about kept pace with the growth of population. At the same time, the proportion of low-cost, household facilities such as pit privies, septic tanks or bucket systems has increased so that the relative importance of public sewerage systems has proportionately declined, probably as a result of the limited funds available for investments in sewerage.

It is more difficult to define adequate excreta disposal facilities than adequate water supply. A pit privy near a shallow well may contaminate the water source and thereby be inadequate, whereas the same privy further away may be perfectly hygienic. Reusing excreta as fertilizer may be adequate for the disposer but not necessarily for the producer or consumer of agriculture products, unless further hygienic measures are taken. In general, it is probably true to state that "formal" excreta disposal facilities become more and more necessary as the density of population increases. Thus what may be adequate today could well be inadequate tomorrow. Moreover, new investment in waste disposal facilities will not necessarily increase the overall proportion of population served in cases where it is necessary to change the type of facility.

Investment needs

From the information given above on trends in the level and quality of service in recent years, it is quite clear that investment in the sector has been sadly deficient. On the basis of World Bank and WHO estimates and various "rules of thumb", per capita investment for urban water supply (involving a mix of house connections and public standposts) amounts to $50 - 150 in today's prices and the comparable figure for simple piped systems in rural areas would be about $30 - 50 and $5 - 10 for communities served by a single handpump equipped well. For waterborne sewerage, per capita investment in urban areas runs at

$100 - 400 with instances of per capita costs in excess of $1,000, although for other excreta disposal facilities, particularly in rural areas, this figure may be cut to less than $30. Estimated investment figures are rough, and subject to considerable variation depending on existing levels and quality of service, the degree of treatment to be provided, technical constraints and many other factors. Nevertheless, a possible range of $50 to 100 billion for water supply and $100 to 300 billion for excreta disposal indicates clearly the magnitude of the problem in financial terms.

The most important lesson to be learned from these figures, is the need to find less expensive means for excreta disposal, for it is clearly beyond the capability of governments and agencies in developed and developing countries to fund the investments required if sewerage is the disposal method of choice. The challenge and opportunity for health workers and sanitary engineers is to find methods of excreta disposal which are effective and affordable to users in developing countries.

APPROPRIATE TECHNOLOGY

Clearly, there is a great need to develop and adopt technologies which will bring adequate excreta disposal services within the financial capacity of the consumer in developing countries. These technologies must not only consider cost but the social and cultural aspects of waste disposal. There are often strong social and religious taboos or preferences about one or another method of waste disposal and personal hygiene which might preclude certain solutions. At the very least, education to familiarize decision-makers and consumers of the value and the methods of excreta disposal is necessary. Sanitation technologies must reflect to the maximum extent possible the natural preferences of the intended beneficiaries, in order to have the desired health impacts. For example, where water is a religious requirement for anal cleansing there is obviously no sense in providing dry pit latrines. In some areas, the feeling of being outdoors is desired; in most, privacy is of utmost importance. The construction of the privy or toilet enclosure will have to reflect these preferences.

With funds unlikely to be available to build sewers for everyone, a look at alternatives in an effort to improve the acceptability and the performance of some traditional but frequently abandoned technologies is relevant. In an attempt to make its lending in the water supply and waste disposal sector more effective, the World Bank is beginning to implement a recently completed major research project into appropriate excreta disposal technologies and related health benefits (Ref. 5). Results of the study are now being disseminated through the publication of reports and manuals. In addition, World Bank staff is organizing seminars and workshops for health workers and engineers.

Briefly stated, the study showed that many of the traditional methods of excreta disposal can be improved sufficiently to make them viable alternatives to sewerage in all but very densely settled urban areas. The study team fortunately was able to take advantage of much work and field testing presently going on in the low-cost sanitation field and added to this effort through the review of sanitation practices in many countries. The principal contribution by the Bank as a multidisciplinary development finance institution has been the economic and financial evaluation of alternative solutions identified by its consultants in many countries with a wide variety of socio-cultural, economic and climatic conditions.

As work on the research project progressed, it became clear that the solution to excreta disposal problems depended as much on socio-cultural factors and the users' perception of benefits as on technical aspects. This is hardly a unique relevation but is especially important in as sensitive an area as excreta disposal. To be acceptable, a solution must not only solve the problem at minimum cost but permit an increase in service standards to a level perceived as ultimately desirable in keeping with the users ability to afford improvements. In short, a successful solution for the long term has to be dynamic.

STAGED SANITATION SYSTEM

Present practice

Waterborne sewerage and the flush toilet represent today's state-of-the-art in excreta disposal. The system provides maximum convenience to its user and permits the use of the many water using appliances associated with a high standard of living. It is no surprise, therefore, that the common objective of sanitation projects is to provide flush toilets and sewer systems and that potential users consider waterborne excreta disposal the most desirable, in fact, the only acceptable method. Unfortunately, the effect has often been that sewer systems in developing countries have been constructed for the wealthy while little attention has been paid to the sanitation needs of the poor. It is quite customary to find governments and international agencies alike preparing sewerage master plans for a period of 25 to 50 years, divide the plan into several phases for implementation and, occasionally construct the first phase. Rarely, if ever, do such master plans even mention the needs of those inhabitants not covered by the first phase, rarer still are the cases which provide facilities for those living in areas not to be served by the sewer system.

Asking people to forego the convenience of a sewer system, even far in the future, is clearly not realistic. Not providing for a reasonable degree of sanitation is also unacceptable if peoples' health needs are to be served and improvements in living conditions achieved. A solution must be found which eliminates this either/or proposition. Fortunately such a solution already exists.

System components

An examination on how waterborne sewerage came about reveals two basic facts. First, excreta disposal went through many stages before the present system was established. Second, existing systems were improved and new solutions invented whenever the old solution was no longer satisfactory. Whether or not waterborne sewerage is in fact the only or best solution for human waste disposal problems, even in industrialized countries, is for the purposes of this discussion irrelevant. What is important to remember is that sewerage was not a grand design implemented in one giant step but the end result of progressively more and more sophisticated solutions. It should therefore be possible to correct not only the shortcomings of more primitive waste disposal practices abandoned by industrialized countries, but to integrate them in a staged sanitation system which can be progressively improved to parallel growing needs and economic capacity of the user to pay for needed improvements.

Such a staged sanitation system should reflect not only the capacity of user to pay for the facilities, but also his cultural environment and technical competence. If sanitation facilities are to be used, user preferences and customs of personal hygiene must be considered. In fact, staged sanitation might be more successful than the installation of sewerage which is alien even to many who wish to have such a system simply because it is the solution of "advanced" societies. Staging would give users a chance to progress gradually to whatever level of convenience they desire, and at their own speed. Further, no commitment to reach a given stage at a given time is necessary.

In addition to more closely reflecting the users cultural preferences, the staged system can also be chosen to more nearly approximate his technical abilities. Construction of some sanitation facilities can easily be mastered by a home owner. Operation and maintenance of onsite facilities is also very simple and off-site facilities, when they are needed, can be designed for operators with minimal technical expertise. The components of the sanitation scheme would be various on-site and off-site facilities in the combination most suitable to achieve the desired service level (for detailed description of components, see Ref. 5).

Sample scheme

To demonstrate the feasibility of using a staged sanitation system approach, three possible schemes are described, costs are calculated for one of them and compared to sewerage. Each scheme could be started at any stage or terminated at any stage, depending on the desires of the users. For simplicity it is assumed that each stage would remain in service for ten years, after which either the next stage would be added or the existing facility would be replaced or repaired. The schemes described could be varied substantially without adding greatly to the cost. For example, to a standard pit privy with a pour flush, a vault could be added if housing density increases or soil becomes clogged. Similarly, a composting toilet which already has a water tight vault, could be converted into an aquaprivy or pour flush privy with vault with some minor modifications. The three schemes are:

The waterless latrine scheme. The initial installation would consist of a vault latrine with the vault extending outside the latrine housing to permit easy emptying. Emptying would be required every five years. This stage would last until the community water supply was upgraded from communal standpipes or wells to yard hydrants. With increased water availability the dry latrine would be converted to a pour flush latrine by adding a squat plate or bowl with inverted siphon or aquaprivy waterseal. A baffle and overflow pipe would also be added to the vault to carry the overflow liquid to a soakage pit or drain field. Annual collection of accumulated sludge would be required along with a facility to compost or digest it. The third stage would begin when the water supply service is upgraded to house connections and a large quantity of sullage water has to be disposed. At this point a small diameter sewer system would be constructed to accept the overflow from the vaults (replacing the drain fields). This solution would permit the use of cistern flush toilets. Annual collection of sludge would still be required.

The pour flush latrine scheme. The initial installation would be a pour flush latrine with a vault which is emptied by vacuum truck at one month intervals. The collected nightsoil would be composted, digested, or treated in stabilization ponds. As the water supply was upgraded, this scheme could follow the same second and third stages as Scheme I.

The cistern flush scheme. This scheme is essentially for those few users in an urban poor area who already have water connections in their houses. It begins at the second stage of Schemes I and II but with a flush toilet rather than a hand flushed bowl or squat plate. The eventual installation of small bore sewers would depend on water usage and population density.

All of those schemes require the same offsite facilities in stage three, ponds for the treatment of effluent and digestors for sludge treatment. Figure 1 shows a diagramatic presentation of the various components and their possible combinations into schemes.

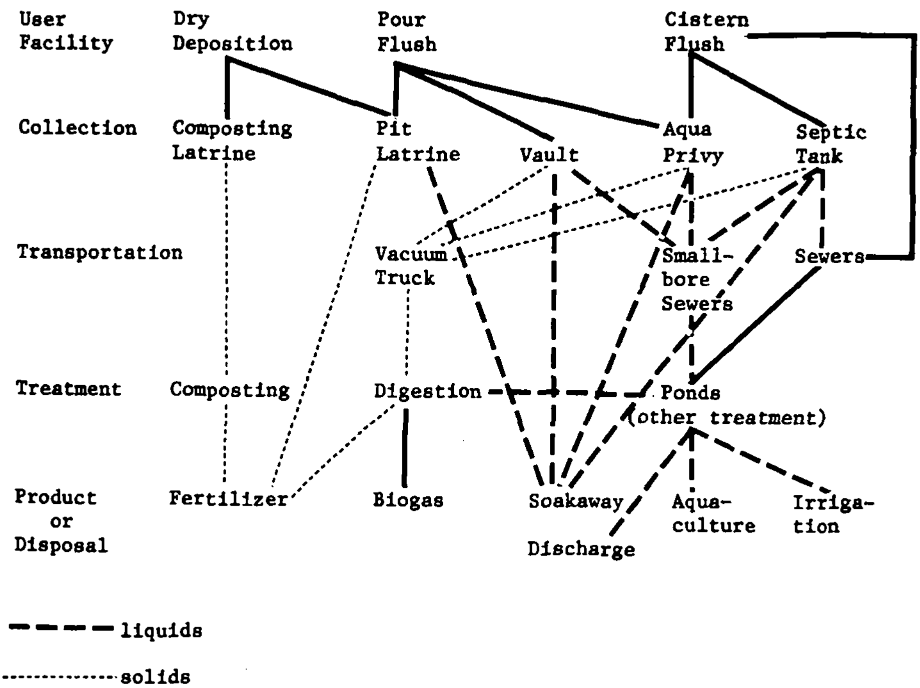

Fig. 1.

The timing, indeed the need for the last stage of these schemes depends mostly on the disposal of sullage water. From the limited information available (Ref. 5), it appears that sullage water has pathogenic bacteria concentrations about four magnitudes lower than excreta, calculated on a per capita basis. Thus, while high water consumption may require sewerage for sullage water disposal, discharge to storm-sewers or well maintained open drains would generally be acceptable and ground infiltration should be possible without undue health hazards.

Comparative economic costs, on a household basis, have been prepared for Scheme I and three variations including the alternative of proceeding immediately with the construction of a sewerage system. The costs are derived from those of existing vault latrines, aquaprivies, sewered aquaprivies and sewerage. They include all construction and maintenance costs of onsite, collection, and treatment facilities. They are economic rather than financial costs in that they include costs borne by all parties (not just the utility), and the value of inputs such as water and capital has been set at reasonable opportunity costs rather than at typical market prices. (See note a.) In addition, the per household cost of sewerage is calculated on the (discounted) population served over time rather than on the design population to reflect its gradual utilization.

Scheme I is costed on the basis of a vault latrine installed in year 1, upgraded to an aquaprivy with drain field in year 11, and then connected to small bore sewers in year 21. Sludge removal and composting occurs annually after year 11. Sewage treatment after year 21 is accomplished through trickling filter plants. The annual cost per household of this three stage system over 30 years is $72.4. (See note b.)

Note a: Water is valued at $\$0.35/m^3$ and the opportunity cost of capital is taken to be 10%.
Note b: This figure includes the "salvage value" of the sewerage system which is assumed to have a 40-year life.

The second alternative is a two-stage scheme which moves directly from a vault latrine (installed in year 1) to small bore sewers in year 11. The annual cost per household over 30 years is $133.5, or about 85% more than the three stage alternative.

The third alternative is simply to install a small bore sewerage system from year 1. This would cost $160.9 per household per year over 30 years.

The final alternative, calculated in the same way and with data from the same city as the sewered aquaprivy for purposes of comparison, is the immediate construction of a full sewerage system. The system was designed to serve about 190,000 people in an area of 3,500 hectares. A five-year construction period is assumed. The facility is assumed to be two-thirds utilized upon completion and fully utilized 10 years after completion. Based on these assumptions, and including the cost of flushing water and all regular operating and maintenance costs, the annual cost per household over 30 years is $318.0. It is four times as high as the cost of the three stage scheme and nearly double that of the one stage sewered aquaprivy alternative.

All calculations utilized conservative assumptions in the sense of choosing a relatively inexpensive sewerage system as the basis for sewerage costs (See note a) and relatively expensive vault latrines and aquaprivies as the basis for on-site costs. (See note b.) However, they were prepared for illustrative purposes only and should not be taken to represent costs which would be duplicated in an engineering simulation of the various alternatives on a particular site.

A RATIONAL SELECTION OF SANITATION PROJECTS

The selection process

Given the range of alternative waste disposal technologies available, the problem becomes one of selection. Evidently the method of selection which will yield the "right" solution is not an obvious one, however, since very few (if any) alternatives other than conventional sewerage have been "selected" over the past 20 years. The number of sewerage master plans gathering dust on shelves in cities in developing countries with desperate waste disposal problems indicate that sewerage is not always appropriate. Even in a few of those cities where sewerage systems have been built, the number of house connections lags far behind projected demand, and as a result both technical and financial problems abound. Apparently, important parameters were left out of the analysis which showed sewerage to be the least-cost solution. Four principal factors, singly or in combination, appear to account for the bias in conventional feasibility studies toward sewerage.

Lack of information

Probably the most widespread cause that alternatives other than sewerage are not included in the investigation is that officials are not aware that alternatives exist, thus do not ask for their inclusion in sewerage studies. Terms of reference for engineering studies usually specify that a sewerage system shall be designed for the city in question. The bias exists in the minds of planning officials and aid agencies, perhaps understandably since they are not expected to have a wide technical knowledge of the field. Due in part to the current fashion of searching for "appropriate technology" (See note c) in the fields of agriculture and industry in LDCs, this bias is rapidly disappearing in the international aid community. Sewerage feasibility studies recently commissioned for two of the largest cities in Southeast Asia have included in the terms of reference the development of sanitation programs for those portions of the population who cannot afford to pay the full cost of sewerage.

Deficient economic/financial analysis

A second factor which has led to the selection of wrong alternatives is that many least-cost analyses are based on financial rather than economic criteria. Thus engineers select the alternative which will be the cheapest (in present value terms) for the utility, given prevailing interest rates and foreign exchange provisions, and often ignoring those costs borne by others, including the householder. An economic comparison would include all costs necessary

Note a: The sewerage system was built in the 1950s and cost $6.7 million in 1978 prices if the local inflation index is used for the price adjustment. However, this adjusted figure implies a capital cost per capita (design population) of about $35 which is extremely low by international standards.
Note b: The vault latrines and aquaprivies on which these figures are based have been criticized for being overdesigned. For example, the construction cost of the vault latrines is over $300 and includes a very solid block superstructure.
Note c: The publication of E.F. Schumaker's book, Small is Beautiful, in 1973 was, perhaps, most responsible for promoting this idea and giving it widespread visibility.

for the system's proper functioning, and would value all inputs at their opportunity cost to the economy rather than their financial cost to the utility. Thus, for example, the fact that sewerage systems require 20-40 liters of flushing water per person per day would be reflected by including the long-run cost of producing that water (including capacity expansion costs, properly discounted) in the cost of the sewerage system. The fact that sewerage systems are generally subject to economies of scale and therefore are not fully utilized until five to ten years after completion would be reflected by calculating the per capita cost of sewerage not on the basis of the design population but on the basis of the present value of the population actually served over time. Just as costs incurred in future years are less expensive than those incurred today, so benefits received in future years are less valuable.

The reasons that sewerage benefits from financial rather than economic costing are that it is relatively capital intensive (and financial interest rates are generally below the opportunity cost of capital), it is relatively import intensive (and foreign exchange is often officially undervalued), it has a very high cost to the householder in terms of the plumbing and internal facilities needed, it has relatively high water requirement (and water is almost always priced below its long-run production cost), and it possesses larger economies of scale than most non-conventional waste disposal systems.

Disregard for socio-cultural aspects

A third problem is the failure to incorporate social factors into the design and selection process. When working in a familiar and homogenous social environment where the engineer is part of the social fabric, this is done almost automatically. However, in developing countries it is necessary to make a real effort to discover the users' current practices and preferences in order to satisfy them at the least cost. Habits and ideas regarding human waste disposal are highly variable across cultures and are not easily discerned by the casual visitor. There are many examples where cultural misunderstandings have led to the non-use or misuse of new technologies, not only for waste disposal but also for agricultural innovations, birth control campaigns, etc. The social dimension of technology design should not be regarded as an appendage to the technical and economic analyses, but as an integral part. In short, the solution should be designed from the ground up rather than imported.

Engineering fees

A final factor which creates a bias toward sewerage is the method of tying consultant fees to the cost of the system designed, for example, through percentage of construction cost payments. It probably takes much more engineering effort and ingenuity to design non-conventional solutions than to use the company's computer programs to optimize sewerage options. Yet, because non-conventional alternatives are much cheaper than sewerage, the engineer would get paid less. This is clearly an inequitable situation and one that is fortunately being changed as more and more countries are turning to fixed fee contracts.

Fixed fees will also permit the employment of professionals in other disciplines by the engineer. Alternate sanitation system design requires a multidisciplinary team in which sociologists, anthropologists, public health specialists and others play an important role.

RECOMMENDATIONS

Education

The single most important activity required for a more rational decision making process and subsequent achievement of appropriate solutions for the human excreta disposal problem is the dissemination of information on alternative waste disposal methods and the education of decision makers and designers on how to prepare and implement such projects. Only if the decision makers responsible for providing waste disposal services are alert to the possibility of using methods other than waterborne sewerage, understand the advantages and disadvantages of the various solutions and know the financial and economic costs of the various potential alternatives, can they make a rational decision matching consumer preferences and ability to pay.

Project preparation and implementation

Governments and development agencies must insist that designing engineers prepare master plans for sanitation rather than sewerage. Master plans should provide intermediate solutions for those areas which are not to be sewered so that all inhabitants of the area obtain excreta disposal services. A master plan should foresee the gradual improvements of services to whatever level the community desires as ability to pay for a higher level of service increases.

The preparation of such sanitation master plans and projects requires both a greater sensitivity by the designer to the needs of the community and a much more direct participation by the community in the design process. It is essential that service level options, their associated cost and operational requirements be explained to the prospective users so they can select the system which most adequately serves their needs.

Designers have to be paid for undertaking these tasks, rather than by a percentage of construction cost which will be less for sanitation systems than for sewerage. Further, the fee will also have to provide for the participation in the design process of sociologists, health specialists, etc., without whose input sanitation projects are unlikely to be successful.

Research

Work must continue on those aspects of waste disposal not yet fully understood and evaluated, for example, the impact of sullage water disposal on the environment. Another area requiring attention is the development of appliances which provide the amenity of water use but with a substantially reduced water consumption. Success in this area would at the very least permit the use of such appliances in areas of low-density development without the need to construct waterborne sewerage. Another area requiring additional work is the reuse of excreta, respectively the products of excreta treatment systems. Reuse could reduce the cost of providing disposal services.

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   II. Research Procedures and Case Studies
   III. Behavioral Factors in Technology Choice
   IV. Sanitation Program Planning: A Field Manual
   V. Health Aspects of Excreta and Sullage Management (prepared by the Ross Institute of Tropical Hygiene, London, England)
   VI. Sanitation Technology Options (prepared by International Development Research Center, Ottawa, Canada)

What are you proposing for the 60-70% not served in phase 1 of your project

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APPRAISAL OF FOUR ALTERNATIVE EXCRETA REMOVAL SYSTEMS FOR URBAN AREAS IN DEVELOPING COUNTRIES

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Abstract

Four low cost sanitation systems (sewerage, sewered aqua privies, vaults and community blocks) are discussed for implementation in an urban tropical setting. Emphasis is placed on a technical, financial and economic evaluation and comparison of these four schemes. The approach outlined in this paper provides an improved basis for the decision-maker regarding choice between systems and types of technology and regarding the factual cost to society of the project i.e. in relation to an alternative project altogether.

1. INTRODUCTION

One essential component of a Health Improvement Programme is a good excreta removal system. The achievements of a curative health programme are deemed to be minor or of short lasting effect, if the sources of reinfection are not controlled. In an urban setting the sanitation system and good hygiene practices supplement each other and form the most important elements in the prevention of many serious diseases.

The difficulties in implementing a good sanitation system for the urban poor arises from the circumstance that such systems in the conventional mode of construction are very expensive compared to the average earnings of the potential users. From a technical and financial point of view conventional sanitation designs such as sewerage do not lend themselves to a staged development and upgrading to a better level of service at a later point in time. Furthermore, these require a high standard of water supply and sophisticated maintenance to function satisfactorily.

This paper outlines an analysis of four excreta removal systems from a technical, financial and economic point of view in order to discuss how different engineering approaches and different levels of customer service reflect on the financial requirements as well as the economic cost and social benefits to society.

2. SYSTEM DESCRIPTION AND BASIC CONDITIONS

Four excreta removal schemes are introduced below in order to prepare for the subsequent evaluation and discussion of urban sanitation. Fig. 1 demonstrates basic principles of the respective systems.

Description of the four sanitation systems

FSW Full sewerage and water supply. Plumbing is provided to each dwelling, because the sewers would not function without adequate flow, e.g. 50 - 100 litre/day. Water taps, flush toilet, and sinks in kitchen and bathroom are provided. Similarly, internal and external piping and a plot manhole is included. The sewage (black and grey) is conveyed in main and trunk sewers to treatment and ultimate disposal.

AP Aqua privies with piped liquid disposal. A community stand-pipe water supply is sufficient for the AP-system, but plot water supply is fully compatible, and such may be installed at a later stage in a phased development scheme. In the AP-system the family toilet is placed separately on top of a tank (cf. fig. 1) which serves four neighbouring plots. A drain for bath and a kitchen sink is provided. The sullage is led to the tank and improves the function of the (self-topping) aqua privy. Sewers may be installed with less slope and smaller diameters than for FSW; consequently, the construction requires less excavation. Settleables and floatables have to be removed from the tank (e.g. biannually) by vacuum truck and taken to the treatment plant.

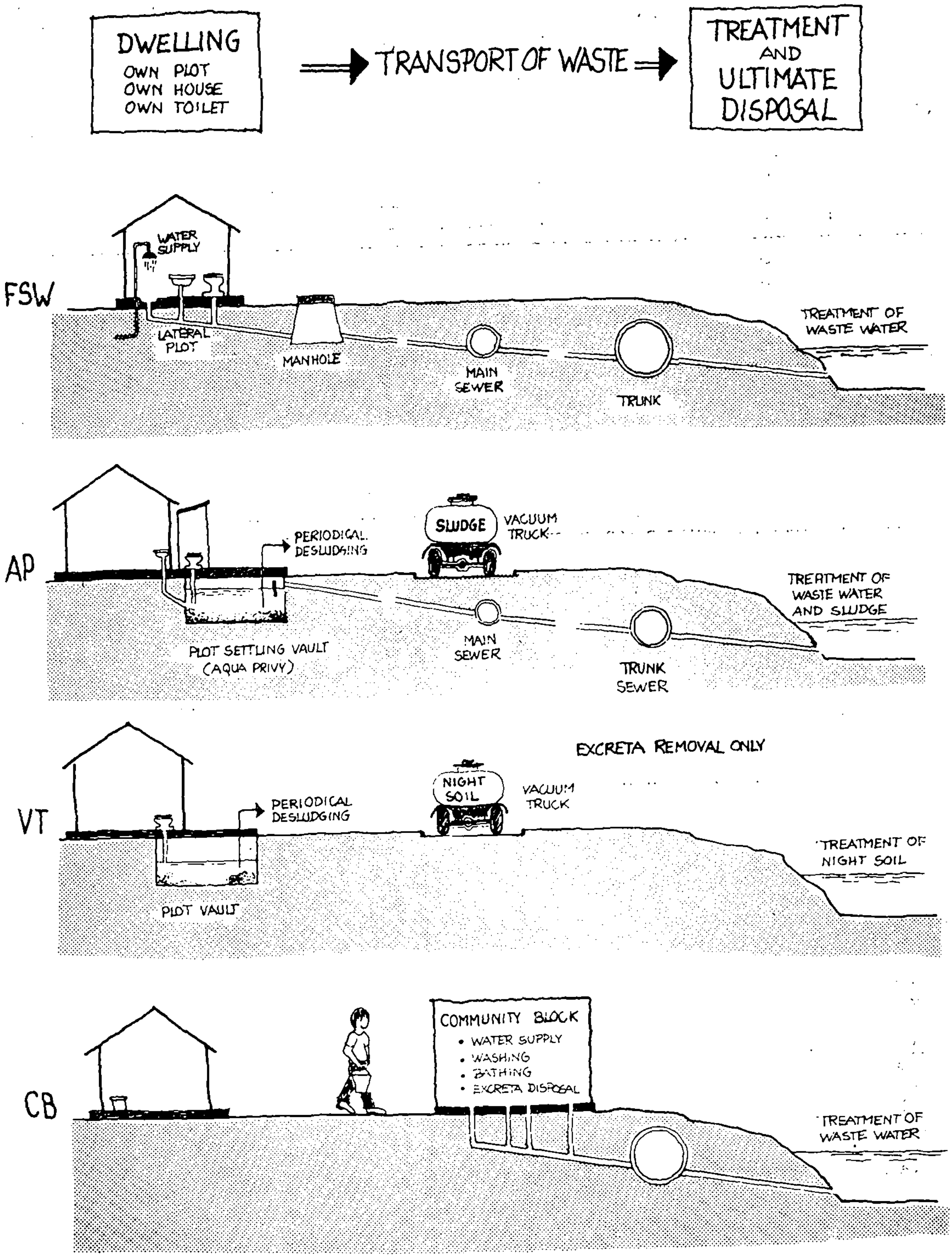

FIG. 1. Four sanitation concepts visualized

VT House vault and vacuum truck. In this scheme only excreta are removed from the plot. Little water - if any - should be added during use of the toilet, which is a stool with a chute leading directly into the subterranean vault. A vacuum truck empties the vault, say twice per month. Families have individual stools but the vault could be shared by two neighbouring houses when these are situated close to each other and near the street (to facilitate easy emptying). This system would typically be combined with a community stand-pipe water supply.

CB House pail and community block. In this system each dwelling is provided with a pail (bucket) of good sturdy design. Excreta disposal takes place at the community block, which is connected to a trunk sewer. The frequency of excreta disposal would be individual of course, but short intervals are recommended to avoid odour and other nuisance. The distance between any dwelling and the nearest community block should not exceed 150 m. Efficient pail rinsing at the community block is required. Other services such as water supply, washing and shower facilities and a few public toilets (e.g. for market customers and visitors) are offered in the community block. The CB-system therefore is a sewered waste removal system, and it may be augmented into a FSW-system later on in a staged development scheme. Privacy during use of the toilet is provided to the same extent as in any of the other systems considered.

The four proposed sanitation schemes are different in their technical function and level of service to the user. A provisional ranking in terms of user convenience would indicate the order already used, i.e. FSW-AP-VT-CB; however, depending on actual design and performance CB could possibly be ranked at least as high as VT.

In terms of health it is difficult to claim preference for one system to another. A more detailed evaluation has been attempted in Hansen, Therkelsen (1) based on relevant disease agents and infection cycles often reported in the literature. That approach provided little evidence of any real differences in health improvement effects between any of these four sanitation systems. It seems that the introduction of an excreta removal scheme as opposed to indiscriminate disposal would definitely improve health, cf. the Cholera study, WHO (2). For the moment it is acknowledged that health impacts of improved sanitation is poorly documented but highly warranted. The present evaluation will therefore be based on the following hypotheses:

1) Neglect of sanitation would definitely imply poorer health and higher risk of the contraction of infectious diseases, particularly in urban, densely populated areas.

2) Any of the four systems proposed herein would qualify as a health improving installation compared to indiscriminate disposal.

3) None of the four systems is preferential in terms of health, if properly used and operated and assuming that basic personal hygiene is observed.

A comparison of the four systems in terms of financial and economic costs will be presented in the following.

It should be noted that stormwater and solid waste removal systems are excluded from the subsequent comparative analysis.

Study area characteristics

The comparison of the four systems will be based on a hypothetical introduction of either one of these into the same urban development area. Fig. 2 shows the area and the proposed plot layout. Data regarding population densities, no. of people/plot, and no. of wage earners per plot are also indicated.

The background information can be summarized as follows:

Climate - Tropical and humid
Soil - Impermeable laterite (clayish), high groundwater table
Area - Approx. 286 ha (virgin development), an average slope of $3^{o}/oo$ is assumed
Plots - 200 m^2 each, i.e. 40 per hectar.

Cost data and present value comparisons

To demonstrate how basic cost data have been derived for the system comparison, table 1 is included as a model. For each system (e.g. VT) and population density (e.g. 200 cap/ha) a distinction has been made between plot installation (PI), collection (C), and treatment (T); and in addition between initial investment, reinvestment every 5 or 10 years, respectively, and annual operation and maintenance (O&M) (cf. table 1, lower part). Details regarding this derivation may be found in Hansen, Therkelsen, Hansen (1, 3).

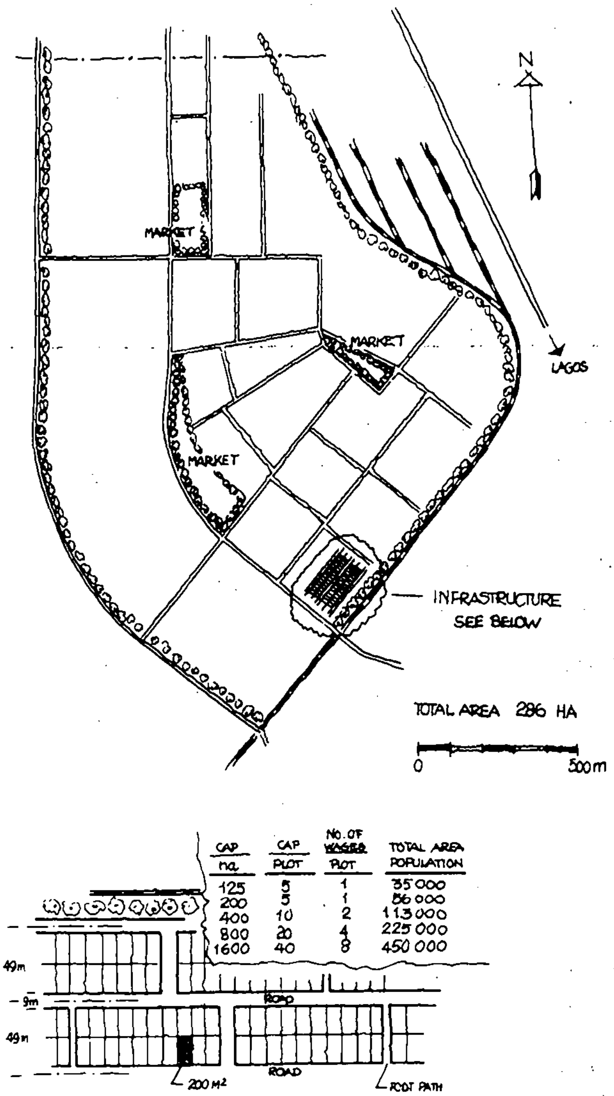

FIG. 2. Study area, plot layout, and population densities

The distinction between types of resources employed as indicated by the abbreviations LAB, LOC, and FOR in the entry column of table 1 is particularly important for the economic analysis in section 4. By applying the % factors (shown to the right) for PI, C, and T-values (found at the bottom of table 1) the detailed resource distribution can be established. Also the applied wages are important to the economic analysis, and they are for the purpose of this paper assumed as follows:

Type of employment	US $/y (1975)
Unskilled labour	600
Driver	1000
Local engineer	4000

Present value (PV) computations are applied to compare projects financially and economically with appropriate interest rates. The following equation will apply to demonstrate the PV-concept:

$$PV = \sum_{t=0}^{t=N} (R_t - E_t)\ (1 + i)^{-t} \qquad (1)$$

where

R_t = sum of all revenues in year t
E_t = sum of all expenditures in year t
N = number of years of project life
i = interest rate (i = 0, 0.05, 0.10 and 0.15 is applied to cover a range of preferences).

TABLE 1. Example of basic cost data and resource consumption for one particular system/density combination

Sanitation System: VT — Population density: 200 cap/ha

Resource item	1000 $ Investment Initial	Repeat 5y	Repeat 10y	O & M Annual	% PI	C	T
LAB unskilled labour	407		132	76	40		21
LOC Skilled labour	222		24		18		17
LOC Engineering local	60				8		
LOC Supplies local	92				11		2
FOR Engineering foreign	15				2		
FOR Supplies imports	891	450	117	16	18	100	56
FOR Fuel imported	43		12	30	3		4
Total (check)	1730	450	285	122	100	100	100
PT, Plot installation 1000 $	745	0	0	0			
C, Collection 1000$	465	450	15	92			
T, Treatment 1000$	520	0	270	30			

PVs can be established for any system and population density using the interest rate as a parameter. Table 2 gives results of such calculations for interest rates 0, 5, 10 and 15% and with a distinction between the resource categories LAB, LOC, and FOR. The numbers shown in table 2 are discussed below in the financial and the economic analysis.

TABLE 2. Example of PV-calculations for four sanitation systems at 200 cap/ha, 60 years life-time, and interest rates as indicated. All figures in 1000 US $ at 1975 price level

Interest:	0				0.05				0.10				0.15			
System:	FSW	AP	VT	CB	FSW	AP	VT	CB	FSW	AP	VT	CB	FSW	AP	VT	CB
LAB	4602	3048	5626	3652	2233	1559	2037	1302	1709	1108	1247	783	1517	1108	957	593
LOC	3304	1221	494	492	2897	1150	409	421	2807	1128	389	404	2775	1128	382	399
FOR	10724	3306	9302	3123	5292	1970	3524	1439	4101	1556	2221	1058	3663	1556	1743	918
TOTAL	18630	7574	15422	7268	10422	4679	5971	3162	8617	3791	3856	2245	7954	3791	3081	1910

While PV-numbers are useful to the project comparison the measure as such provides little information on the actual project cost, e.g. to be claimed from the users of the system. In order to obtain that information the following equation may be used:

$$A = PV \frac{i}{1-(1+i)^{-N}} \qquad (2)$$

where

A = annual user charge
PV = present value, cf. eq. (1)
i = interest rate pro anno
N = life-time of project (planning horizon).

Sanitation project benefits are difficult - if at all possible - to quantify. Therefore, the PV-values from eq. (1) will appear as negative numbers because only expenses are included. The least negative PV thus indicates the more favourable choice (where projects are otherwise considered equal, e.g. in terms of health). Consequently, the user charge (A) as calculated through eq. (2) will indicate the minimum annual payment per user just to balance costs incurred over time. Such user charge indication may adequately support the overall evaluation of different projects and be of particular use for comparison with the level of income i.e. the revenue basis in the community (cf. fig. 5 and the subsequent discussion).

It should be noted that the cost of superstructures are excluded from the cost estimates. These consequently include wastewater and/or excreta disposal installations.

The "life-time" of investments in the four systems may vary, and to a large extent such differences are taken into account by the distinctions indicated in table 1. However, in order to demonstrate the effect of different life-times of initial investments (particularly between piped and non-piped systems) both a 30 and a 60 year life-time will be evaluated. The effect of different "scrap"-values may thereby be illustrated.

For several reasons the employment of labour is a key item. Table 2 includes PV of the total labour component (LAB) of all projects at different interest rates and for 200 cap/ha. With respect to permanent employment only the part of LAB that relates to operation and maintenance should be included (table 3). It is noted that the labour intensity of the different sanitation systems among other things depends on the population density (see table 3). For low-medium densities the VT-system provides for more permanent employment while at high densities the CB-system is the more labour intensive.

TABLE-3. Present values of employment wage sums, taking into account only O&M; US $ 1000 at 1975 price level

Density	System	0%	5%	10%	15%
	FSW	1411	723	443	309
	AP	810	415	255	178
200	VT*	2279	1168	716	499
	CB	1440	738	452	315
	FWS	1741	892	547	381
	AP	1319	676	415	289
400	VT*	2701	1384	848	591
	CB	2519	1291	792	552
	FSW	2461	1261	773	538
	AP	2250	1153	707	492
800	VT	3630	1860	1141	795
	CB*	4709	2413	1480	1038
	FSW	3390	1737	1065	742
	AP	3898	1998	1225	853
1600	VT	4709	2413	1480	1031
	CB*	6930	3551	2178	1517

Note * Indicates which system gives more direct employment at population density given

3. FINANCIAL ANALYSIS

Financial analysis is defined here as the presentation and evaluation of costs in market prices, i.e. prices to be paid for the individual resources necessary to implement a project. Economic analysis is a wider concept. It is defined and applied below in section 4.

The cost of implementing the four sanitation systems for the study area was computed for a number of presumed population densities. It is noted that for the FSW-system water is supplied to the plot and that plumbing with a minimum of 3 taps is installed in the houses. This extra requirement has been debited to the sanitation scheme in the form of additional O&M for the plot installation. The three other schemes do not pose such requirement.

The total costs of the four schemes are indicated in the diagrams on fig. 3 below. It is clearly indicated which proportion of the total cost is allocated to the three elements of the systems i.e. plot installation, collection system and waste treatment facilities. It appears that the relative cost of these elements varies greatly for the four systems, and in addition this does not change proportionately to the population density. For the benefit of the discussion in sections 4 and 5 of this paper it is important to observe that a considerable proportion of the cost is spent on operation and maintenance by nature; this involves long-term employment of local labour which typically is preferable to short-term employment during construction and indeed preferable to an alternative purchase of foreign materials.
Fig. 4 indicates the variation in total present value of the four alternative systems for the range 0-15% of the interst rates and planning horizons of 30 and 60 years. The community block system (CB) is the least expensive for all interest rates, while conventional sewerage (FSW) is the most expensive. The ranking of the vacuum truck (VT) system versus the sewered aqua privy scheme (AP) appears to reverse depending on the applied interest rate and the population density. Another interesting result is that the total present value of any of the projects is not markedly increased by applying a 60 rather than a 30 year planning horizon provided the interest is in excess of say 6%.

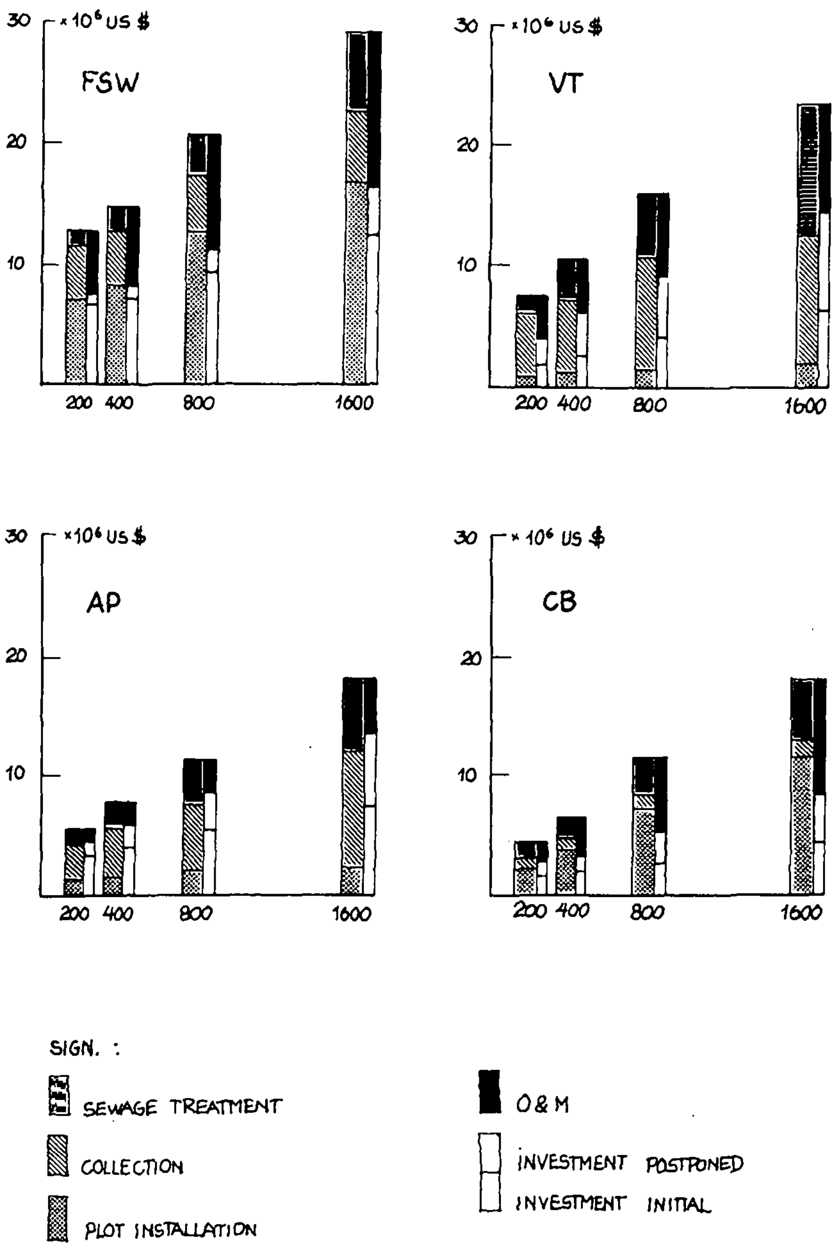

FIG. 3. Major cost elements for the four systems.
Present values at 0% interest and 30 year project life
(then scrap-value = 0)

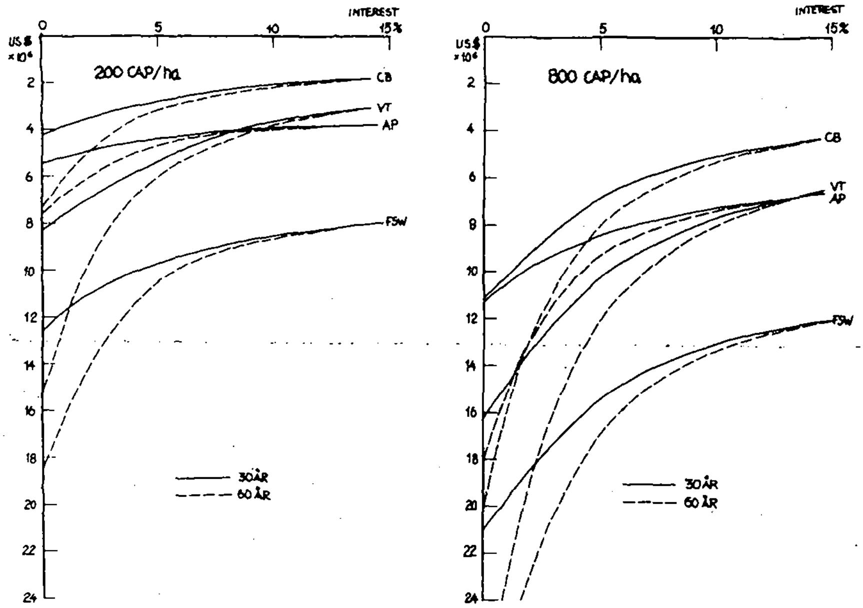

FIG. 4. Present values for different population densities, systems, project life-times, and interest rates

The user charge shown in fig. 5 depends strongly on the density of the population in the area and in addition on the interst rate at which capital is available though to a somewhat smaller degree. In this context the user charge refers to the required charge per income earner who is presumed to support an additional four people. The least expensive system, Community Block, is only marginally favourable for the very high population density. However, the system involves a very large proportion of maintenance and in turn it provides a marked long-term employment of local labour.

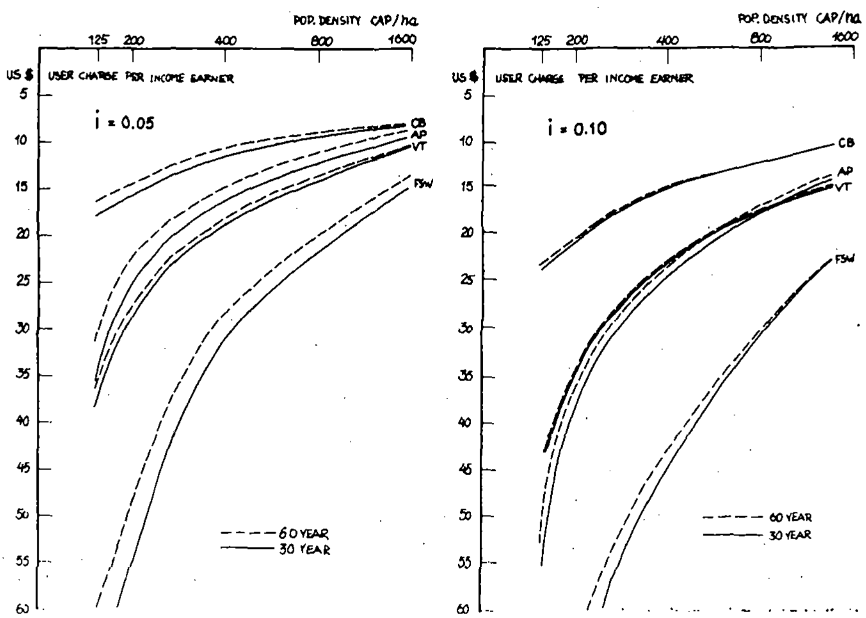

FIG. 5. User charge per income earner (cf. fig. 2) for different population densities, systems, project life-time, and interest rates

4. ECONOMIC EVALUATION

General principles and definitions

The financial analysis produces a cost ranking of alternative projects. In addition it indicates the user charges which are required to cover project expenses, if these are to be borne by the user, and provided that the market prices applied are estimated correctly. However, the national or regional welfare is not addressed by such financial analysis.

An attempt to evaluate welfare would involve accounts of benefits and costs as these are influenced directly and indirectly by the proposed project, e.g. in terms of increased total consumption, more even income distribution, more employment per se, or other goals that may be set for the whole society. Using prices on benefit and cost items which adequately reflect such goals an indication of "total societal profitability" may be obtained. Although such procedure involves theoretical as well as practical problems an attempt to do so may considerably improve the overall insight and thus the basis for decision-making. "Economic evaluation" is thus the term to be used in this paper to indicate what goes beyond the simple financial evaluation to provide a more comprehensive evaluation of effects of the proposed project to society as a whole.

Benefits may be rather obvious and easy to identify and monitor when considering for inst. an irrigation project. The benefits from sanitation projects, however, are not easily identified nor quantified. The health impacts may be significant (though this in itself is a major issue of controversy), but how should such benefits be valued? At the present stage it seems wise to evaluate projects in terms of costs and subsequently for any acceptable least costly solution to discuss separately the individual benefits to the society as quantitatively as possible. This procedure is observed herein.

Costs are defined as (maximum) benefits foregone, and are also named opportunity costs. The meaning is basically that cost figures should reflect the "true values" of commodities, which are not necessarily identical to market prices; e.g. wages for unskilled labour may have to be reduced in an economic evaluation to account for an actual unemployment situation; or imports have to be priced higher owing to an artificially high rating of the local currency. For further reference, see UNICO (4).

It is useful to distinguish between direct and indirect opportunity cost. Total consumption for the society as a whole is used initially to measure the effects from the introduction of alternative sanitation schemes. Other society goals are introduced in the evaluation at a later stage.

Direct opportunity costs

Direct (opportunity) costs (DOC) of a specific resource is defined as the reduction in production (per unit of the resource and measured in units of consumption) that follows from "drawing away" this resource from its alternative use.

It is by no means a simple matter to estimate the direct opportunity costs for each resource. A number of simplifying assumptions have been made and it is assumed that only unskilled labour and imported materials warrant a correction in the market price. Thus, it is implied that all other specific resources can be adequately valued at their actual market prices. The corrections necessary to derive direct opportunity costs (often referred to as shadow prices) are introduced as follows:

Market cost	Direct opportunity cost
LAB	$(1+\lambda)$ LAB
FOR	$(1+\phi)$ FOR

If the direct opportunity costs of resources could be said to reflect the total project impact on consumption in the rest of the economy, no further corrections would be necessary. There is, however, an impact on future consumption which necessitates present value calculations using an appropriate social rate of discount. Since this is essentially a "political parameter", reflecting society's consumption rate of interest two alternative rates, $i = 0.05$ and $i = 0.10$ have been used. Calculations of direct opportunity costs (DOC) for the four systems are shown in table 4, where MC is total cost in market prices. Fig. 6 supplements table 4 for different population densities and life-times of projects.

It appears (table 4) that total direct opportunity costs are higher than total costs in market prices. Opportunity costs of unskilled labour are lower than market costs, but this is more than outweighed by higher costs of imported materials. The ranking of the four systems, however, is unchanged. For both rates of discount the "least-cost" system is CB followed by AP, VT and FSW.

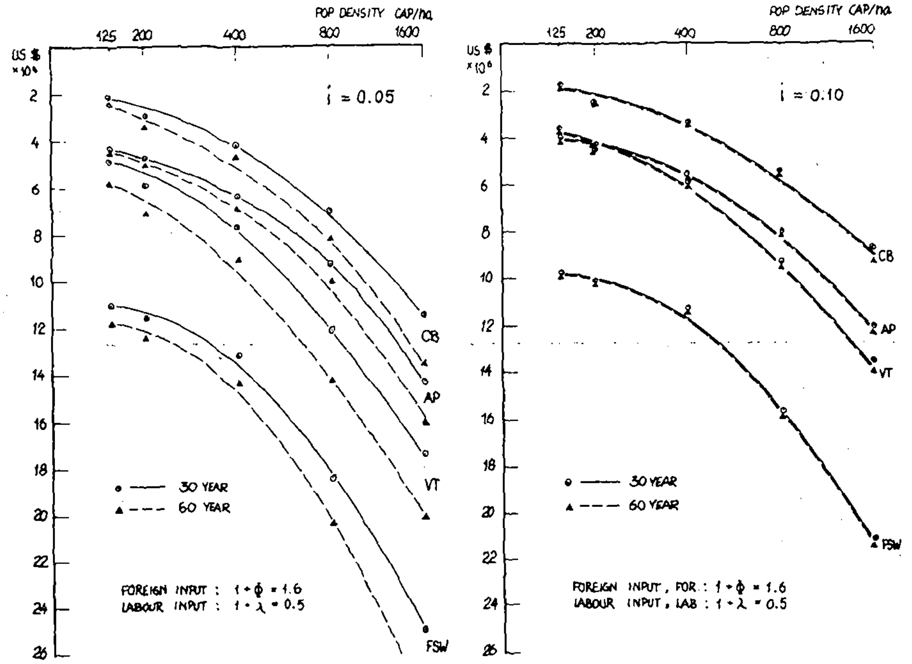

FIG. 6. Direct opportunity costs, DOC, for different population densities

TABLE 4. Present values of direct opportunity costs, DOC; US $ 1000 at 1975 price level; cap/ha = 200 and project life-time = 60 y

Interest	0.05				0.10			
System	FSW	AP	VT	CB	FSW	AP	VT	CB
MC	10422	4679	5971	3162	8617	3791	3856	2245
λLAB	-1117	-780	-1019	-651	-855	-554	-624	-392
ϕFOR	3175	1182	2114	863	2461	934	1333	635
DOC*	12480	5081	7066	3374	10223	4171	4565	2488

Notes * $DOC = (1+\lambda)\ LAB + LOC + (1+\phi) FOR$

$= LAB + LOC + FOR + \lambda LAB + \phi FOR$

$= MC + \lambda LAB + \phi FOR$

where $\lambda = -0.5$ and $\phi = 0.6$

Indirect opportunity costs

The direct opportunity costs do not catch the full impact on consumption of a given project's use of resources. Although direct opportunity costs reflect period by period the corresponding decline in production (and hence real income) in the rest of the economy measured in consumption units, this decline may take the form of a decline in the production of either consumer goods or investment goods. If investment is considered to be too low already (as is often assumed) this possible impact of a project on the composition of total production must be taken into account.

For details on the method of estimating indirect opportunity costs, reference is made to UNIDO (4). The general idea is to divide the economy into different sectors and for each sector estimate the division of any *change* in income between consumption and investment (e.g. the marginal propensity to invest). Then, if the decline in total income in the rest of the economy (equal to total direct opportunity costs) is divided between these sectors it is possible to estimate the investment component of total direct opportunity costs.

Since these "investment resources" have alternative uses yielding consumption in the future, the present value of such future consumption is an indirect opportunity cost, which has to be added to total direct opportunity costs; cf. notes for table 5, equation for PIN, and UNIDO (4) for derivation of the PIN equation.

Fig. 7 indicates an assumed division of the economy into three broad sectors: Sector L (unskilled labour), sector T (the rest of the private sector "tax-payers" assuming that unskilled labourers pay no taxes), and sector G (the public sector or the Government). It is assumed that these three sectors divide any *income change* between consumption and investment according to the following marginal propensities to invest:

$s^L = 0$, $s^T = 0.2$, and $s^G = 1.0$ (cf. their definitions and use in tables 5 and 6).

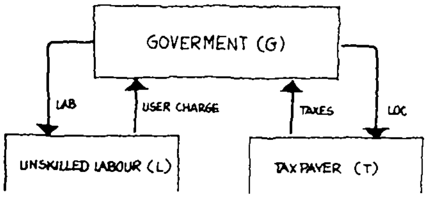

FIG. 7. Cash flows related to project implementation

If a project is established and uses unskilled labour, the direct opportunity cost may be written (1+λ) LAB, which by definition represents a decline in income in sector L. The project would also use local materials and skilled labour for which the opportunity cost is assumed equal to the market value (LOC) and it is borne by sector T. Finally, the government pays for the imported materials (foreign exchange) for which the direct opportunity cost (1+ϕ) FOR represents a decline in government income.

In order to have a project financed and implemented certain cash flows are established between the three sectors L, T, and G, cf. fig. 7. Based on this particular model it is possible to express explicitly for each sector the modification of direct opportunity costs by the said cash flows:

$$DOC^L = (1+\lambda)LAB - LAB + \text{user charges}$$

$$DOC^T = LOC + \text{taxes} - LOC$$

$$DOC^G = (1+\phi)FOR - \text{taxes} - \text{user charges} + LAB + LOC$$

where $DOC^{L,\ T \text{ or } G}$ indicate sector income decline,

and $DOC^L + DOC^T + DOC^G = DOC$ (cf. table 4).

By combination of these sector income changes with the above propensities to invest it is possible to establish total opportunity costs (TOC) i.e. direct plus indirect opportunity costs. This has been done in tables 5 and 6 for different assumptions with respect to user charges imposed on beneficiaries (L-sector) and taxation of the T-sector (cross subsidy). The sector income decline (negative or positive) is also indicated.

TABLE 5. Present value of total opportunity costs, TOC; US $ 1000 at 1975 price level; cap/ha = 200 and 60 y project life-time; *no user charge to beneficiaries*

Interest	0.05				0.10			
System	FSW	AP	VT	CB	FSW	AP	VT	CB
DOC (cf. table 4)	12480	5081	7066	3374	10223	4171	4565	2488
$DOC^L = \lambda LAB$	-1117	-780	-1019	-651	-855	-554	-624	-392
$DOC^T = MC$	10422	4679	5971	3162	8617	3791	3856	2245
$DOC^G = \phi FOR$	3175	1182	2114	863	2461	934	1333	635
TOC*	91365	36851	56686	25799	17210	6997	8079	4298

Notes * $TOC = DOC + (PIN-1)(DOC^L s^L + DOC^T s^T + DOC^G s^G)$

where PIN ="price on investment" $= \frac{(1-s)q}{i-sq}$

q = 0.05; marginal rate of return on investment
s = 0.2 ; society's marginal propensity to invest
$s^L = 0$; labour sector's marginal prop. to invest
$s^T = 0.2$; tax payer's marginal prop. to invest
$s^G = 1$; governments marginal prop. to invest

TABLE 6. Present value of total opportunity costs, TOC; as for table 5 except: *user charge equal to market price borne by beneficiaries*

Interest	0.05				0.10			
System	FSW	AP	VT	CB	FSW	AP	VT	CB
DOC (cf. table 4)	12480	5081	7066	3374	10223	4171	4565	2488
$DOC^L = \lambda LAB + MC$	9305	3899	4952	2511	7762	3237	3232	1853
$DOC^T = 0$								
$DOC^G = \phi FOR$	3175	1182	2114	863	2461	934	1333	635
TOC*	60105	22811	38776	16319	14333	5731	6791	3548

Notes * See notes for table 5.

Table 5 refers to a situation without user charges, thus implying a subsidy from sector T to L. It is demonstrated that the effect of indirect opportunity cost (comparison between DOC and TOC) may be significant; e.g. a factor of 7 for FSW and similarly for any other system at 5% social rate of discount; whereas the factor is less than 2 at a 10% discount rate.

Table 6 refers to a situation where the L-sector pays the user charges (market prices). Hence the TOC is reduced considerably compared to the previous situation. In this case, the different systems do not follow the same pattern when comparing TOC and DOC at a discount rate of 5%, and particularly not at 10%.

In any case the ranking of the systems in terms of cost appears to be identical, irrespective of the methods of economic evaluation.

Sensitivity to altered basic assumptions

The results presented above are based on rather specific assumptions. The question is how sensitive the results are to altered assumptions. Without pretending a complete analysis a few observations can be made.

Firstly, it seems that the ranking is rather insensitive to the parameters λ and ϕ (cf. shadow prices for unskilled labour and imported materials). Since CB uses less FOR and less LAB than any of the other systems, it will have the lowest direct opportunity costs for any relevant set of values of λ and ϕ. The indirect opportunity costs do depend on ϕ but again CB uses less FOR than any other system, and will hence be "penalized" less than the others, irrespective of the value of ϕ and of PIN.

Secondly, the indirect costs are highly sensitive to alternative assumptions with respect to the price on investment and to the financing (user charge or general tax), but again the ranking of the systems does not change.

Thirdly, the ranking appears insensitive to the social rate of discount. But the tables above give figures only for two rates. In fact VT does become cheaper than AP in market prices at a rate of interest slightly above 10% (fig. 4). At high rates of interest the ranking according to economic costs might also change.

Forthly, the project life-time seems to be of minor importance, which is shown for market prices in figs. 4 and 5, and for direct opportunity costs in fig. 6. The total opportunity costs would expectedly change little, and the project ranking remain unaffected. Similar comments could be made for population densities based on analogies from fig. 6.

5. RESULTS AND DISCUSSION

System ranking based on cost

The four evaluated systems have been ranked according to the financial and economic criteria presented above. Only costs have been included in this procedure, because the benefits from improved sanitation have not yet been quantified. To justify the ranking it has been assumed that in terms of health improvement effects, the four systems are comparable if used as prescribed.

It has been found that financially as well as economically the FSW system appears to be considerably more expensive than any of the other systems. The CB, which is also a sewered system, comes out as the least expensive system, while the VT and AP systems are intermediate in terms of costs (figs. 3 and 4).

Though the cost evaluation is highly sensitive to different basic assumptions (cf. section 2) it is believed that the said pattern would apply generally at least for virgin land development or major urban upgrading schemes.

Affordability at market prices
Fig. 5 indicates that the portion of the wage which is to be paid to cover costs in market prices does vary for the respective systems, population densities and rates of discount, although to a smaller extent when project life-times exceed 30 years. This indication may be summarized as follows:

Percentage (%) of wage (600 US $/y) per unskilled labourer at 200-800 cap/ha

Rate of discount		0.05		0.10	
Population density, cap/ha		200	800	200	800
System:	FSW	8.3	3.7	12	5.0
	AP	3.8	2.0	6.3	3.0
	VT	4.7	2.3	6.3	3.0
	CB	2.5	1.7	3.7	2.2

The total range of variation is 1.7-12% of the income for a family/group. Such range implies that a sanitation system is within reach of the low-income groups, even when the market price has to be paid. The prices do vary considerably depending on type of sanitation system and population density. The CB system appears as the "least cost" solution which can be afforded at market prices for most families within the 1-4% income bracket.

The "market price", however, is not necessarily the correct price to collect as revenue after implementation of the project (cf. tables 4 and 5 regarding total opportunity cost). Other aspects of total society impact of improved sanitation have to be taken into account before such decision is made.

Appropriate technology
With regard to appropriateness the following three issues are of major relevance:

a) Techniques and educational background for their introduction
b) Labour or capital intensive systems
c) Employment per se
d) Income distribution.

a) Techniques and education. All four proposed systems require materials and technical skills for their establishment, operation and maintenance. In either case people must be trained to adopt new daily routines, which are necessary for the systems to operate satisfactorily. This applies to the sanitation labourer as well as to the plot inhabitant, but it does not make the proposed systems different from any other comprehensive scheme for urban sanitation. All the four systems are deemed technically appropriate.

b) Labour or capital intensive. A technology is often considered to be more appropriate if it is "labour-intensive", i.e. it provides more employment for unskilled labour, which is normally the less scarce resource in developing economics. Labour intensity is traditionally defined as permanent employment, either per unit of output (= benefit) or per unit of initial investment. Following this distinction and referring simultaneously to fig. 3 and table 3 the following rankings appear:

Population density, cap/ha	Labour wage per unit benefit x)	Labour wage per unit initial investment
200	VT-CB-FSW-AP	VT-CB-AP-FSW
400	VT-CB-FSW-AP	CB-VT-AP-FSW
800-1600	CB-VT-FSW-AP	CB-VT-AP-FSW

Note x) The assumption is that benefits though not directly quantified are equal, at least in terms of health. Unfortunately, the different levels of service offered to the user makes this assumption somewhat questionable.

Obviously VT and CB are competitive with respect to labour intensity. Having in mind that the initial investment for VT is particularly low because of postponed investments (cf. fig. 3) it is fair to characterize CB as the most labour intensive alternative, particularly at higher population densities.

The "least cost" solution (i.e. CB) therefore tends also to be the most labour intensive, subject to the specific assumptions regarding the 286 hectar scheme. It should be noted that the relevance of the cost data is of importance to the more general application of this result. A different pricing of project items may well change the cost ranking.

c) Employment per se. If more employment is considered a good thing because it means increased production, then it is really total production - or rather total consumption which is the final objective. In this case the employment objective is not a separate, additional objective, and the economic evaluation as presented above takes full account of the employment aspects of project, or technology, choice.

Employment can also be considered important because it increases the income of the poorest. They are the 'openly' unemployed in the wage sectors and/or the 'disguised' unemployed in the non-wage sectors of the economy. If this is the rationale behind an employment objective, it might be better to talk in terms of the distributional objectives discussed below.

However, employment might be considered a good thing *per se* that is, irrespective of whether more employment means more total consumption and/or a better distribution of income. If so, employment is a 'merit want' and as such it constitutes a separate objective to be considered in addition to the total consumption objective and distributional objectives.

Unemployment may, of course, be of such an urgent nature that the government is willing to sacrifice other obejctives in order to create 'quick employment'. If so, the candidates could be FSW, having the highest initial employment effect per unit of output, or AP having the highest initial employment effect per unit of initial investment. Since these two technologies are 'capital-intensive' according to the second of the practical definitions suggested above, this seems paradoxical. All there is to it, however, is that one should be extremely careful in using concepts such as 'labour-intensity' and employment objectives.

d) Income distribution. The "least cost" sanitation project identified through the economic evaluation of section 4 might be called 'appropriate' according to the total consumption objective, but of course, there might be other or additional economic objectives.

The employment objective has already been considered, but clearly objectives with respect to the distribution of income (or consumption) between groups and regions are also important in the low-income developing countries today. In the UNIDO-approach which is used in the economic evaluation above, distributional objectives are taken into account by attributing different 'weights' to consumption of different groups and regions. In order to do that, it is necessary to identify the project's impact on income (or consumption) of those groups and regions which are considered important 'target groups' from the point of view of distributional objectives. No attempt has so far been made to do this for the four systems, but a few comments could be made.

In the economic analysis of section 4 three major groups were identified. One might say that distributional objectives imply that a higher 'weight' should be attributed to consumption by 'unskilled workers' than to consumption of the general 'taxpayer'. This would in fact mean a reduction of labour costs relative to what they are according to the economic evaluation. This would in turn 'favour' the technology which - for a given social rate of discount - has the relatively highest 'content of unskilled labour'.

This might in general change the ranking of the four systems, and it raises the question as to whether there is a conflict between the total consumption objective on the one hand and distributional objectives on the other. However, on the basis of the work done so far, this important question cannot be persued further.

There is another point with respect to distributional objectives which warrant a comment. As mentioned earlier, even the "least cost" technology might have negative net-benefits. Since benefits are based on the 'willingness to pay' by consumers this implies that the estimate of benefits are based on the actual income distribution. But if society has an income distribution objective implying, say, a more equal distribution than the actual distribution, one cannot say that benefits estimated on the basis of the actual distribution represent benefits to 'society as a whole'. This might well have important practical implications. If one sticks to the economic evaluation as outlined above, projects - such as sanitary projects - aiming at benefiting the poor might have difficulties in 'competing' with projects providing for the rich.

The two points made in this section suggest that the problems with the introduction of distributional objectives into project evaluation have not yet been fully solved.

Staged development

The four sanitation systems have distinct characteristics with respect to their suitability for:

a) Stages upgrading to a higher service level
b) Stages extension of service area
c) Flexibility to altered development.

Item a): From a technical point of view the CB-system can be upgraded to a higher service level such as conventional sewerage as the need and desire arise, and when the owners of houses decide to have water supply installed. The fact that sewers have to be constructed in areas with existing roads, drains, etc. complicates the delayed implementation, however. The AP-system will function satisfactorily, if water taps are installed in the houses, but the toilets cannot be converted from the aqua privy type to the flush type, since the sewer system is not designed to convey 'raw' sewage. The vault system is not well suited for upgrading because only a piped system would feasibly remove the grey water, and arbitrarily placed vaults could not practically be sewered.

Item b): Because a sanitary drainage scheme by nature utilizes gravity for its function the implementation and later extension of the pipe system is severely restricted by the natural topography. Consequently, it is not well suited to serve separate 'pockets' of development as the demand arises. The VT-system in particular, but also to some extent the CB-system, is much more suitable in this respect.

Item c): It is often experienced that the development does not occur according to the initial plans and predictions, be it terms of population density, or be it in terms of the pattern of settlement of the respective sub-areas.

The appropriateness of the specific sanitation systems for the various population densities is discussed extensively in sections 3 and 4 above. It should be noted that the cost ranking of the respective systems is not markedly affected by the density of the population. The piped systems (FSW, AP, CB) are not particularly flexible to unplanned alterations in the settlement pattern, whereas the VT-system has great flexibility since it is installed according to demand with a low initial investment.

6. CONCLUSIONS

The analyses and discussions in this paper suggest an approach to evaluation of different types of sanitation systems which provides a better basis for the decision-maker than does a merely financial analysis.

It has been demonstrated that there are viable and lower-cost alternatives to the conventional sewerage system. It is particularly important that these alternative systems do not require an extensive water supply distribution network to function properly.

Such low-cost excreta removal systems are generally less demanding in terms of capital for initial investment and resources as a whole, whereas they involve a higher requirement for operation and maintenance. To a great extent these alternative systems are more flexible to a staged development with respect to the service area, the level of service, and the sequence of implementation of the respective parts of the scheme.

The evaluation includes the application of a socio-economic model to demonstrate the concept of economic costs i.e. the cost to the society as a whole. Though still incomplete such an analysis does improve the insight of the decision-maker on the impact of the installation of sanitation schemes on national or regional welfare.

It appears that the ranking of the four systems in terms of economic costs is unaltered compared with the ranking in terms costs. The results do suggest, however, that the economic costs of sanitation schemes may well be considerably higher than the costs measured in actual prices. This points towards the importance of an attempt to quantify benefits of implementing sanitation (which is difficult) as well as toward the evaluation of *distributional objectives* in order to justify the allocation of resources for community sanitation projects.

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vs market cost
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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.

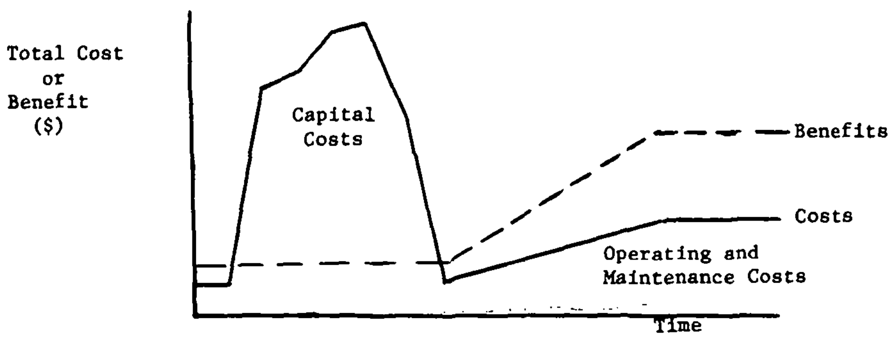

Fig. 1. Cost and benefit streams of an investment with economies of scale

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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TECHNICAL AND MEDICAL PROBLEMS ASSOCIATED WITH INDUSTRIAL EFFLUENTS IN DEVELOPING COUNTRIES

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Abstract
The paper reviews the industrial effluent disposal situation in developing countries and describes the types of medical problem which can result from official inaction. Brief histories of some industrial effluent cases having health implications are discussed with reference to rural and urban locations. Suggestions are made as to how Governments might proceed to manage industrial pollution problems so that the impact of industrialization on health will be minimized.

INTRODUCTION

Attempts to locate well documented case histories of industrial effluent problems with health implications in developing countries were not successful, even though a wide range of literature was searched. This might suggest that there have been very few problems of this nature but is more likely to indicate that the reporting of such incidents in international journals and textbooks is not common. Even though industrialization is in its infancy in most developing countries, the adverse environmental effects of whatever industries have developed are already manifest. The author's experience in Southeast Asia has left no doubt that many incidents have occurred where the public's health has been threatened by the irresponsible discharge of industrial effluents. This paper will attempt to review the health orientated aspects of industrial effluent disposal in developing countries and suggest sensible approaches which are considered advisable with the present state of knowledge.

THE SITUATION IN DEVELOPING COUNTRIES

Although industrial development has been relatively slow in many developing countries, it has generally outpaced legislation designed to reduce the environmental impact of effluent discharges. Little or no control of industrial emissions has been imposed until very recently and, inevitably, responsible authorities have frequently acted in an ad hoc way, reacting to crisis situations. One important factor has often been a lack of planning control on the part of Government, allowing industrial activities to take place on sites which are clearly unsuitable from an environmental viewpoint. Factories are sometimes found in the most unlikely locations in urban areas, even in high-class residential areas. and water-using and-polluting industries may be allowed to develop on a short reach of stream without proper consideration being given to their combined effect on water quality or the health of downstream communities. The fact that industrial plants are often sited in peripheral areas of large population centres where piped water supply is not readily available gives rise to situations where serious health risks are involved. An almost total lack of sewerage in most urban areas leaves industry no alternative but to discharge liquid effluents to surface waters. Urban watercourses in developing countries are notoriously polluted with domestic wastes but the health implications may be much more serious if certain types of industrial pollutant are also present.

In many developing countries, the pressing desire to develop economically has resulted in a policy of rapid industrialization and the authorities responsible for public health and environmental protection have not been equipped to handle potential problems. Industrial applications have not received the detailed attention which would allow hazardous raw materials, products and wastes to be identified and provisions made for their safe handling. Importation of dangerous materials is not regulated to any extent and documentation on quantities and destinations of even toxic chemicals is rarely adequate. This, together with laxness in the control of industrial discharges, has given rise to the introduction into developing countries of "dirty" industrial operations which may be environmentally unacceptable in more developed countries. Quite often, an industry in a developing country which exports most of its products, perhaps after importing its raw materials, will be in this category. Sometimes, of course, the reduced cost of environmental control in developing countries will make the location of particular industries attractive but there will inevitably be an increase in the release of residuals to the global environment with the potential to affect the health of local residents. This is not meant to imply that multinational corporations are environmentally irresponsible, they are not. However, they do react to free market forces and will take whatever advantages are offered them in managing their worldwide production. With environmental control costs reaching as high as 40 percent of the capital investment and maybe 15 percent of operating costs for some industrial processes in Europe or North America, it is not surprising that there are significant economic benefits, other than the availability of cheap labour, to be gained by locating in a developing country.

Regulatory authorities in most developing countries are understaffed with poorly qualified personnel and this seriously limits their ability to meet the demands for environmental and health protection against an expanding industrial sector. Their limited resources and staff make the monitoring of industrial effluents impossible and there are few control regulations to enforce, even if this were feasible. Official inexperience and, sometimes, corruption have been impediments to the promulgation and enforcement of appropriate legislation for the control of industrial effluents. Where regulations are in force, they are frequently too general to meet the requirements of a rapidly-changing situation and nearly always rely on conventional administrative approaches applied in developed countries. Few authorities have introduced measures which are specifically related to the local situation and phased to meet rational priorities of concern.

INDUSTRIAL EFFLUENT PROBLEMS RELATED TO HEALTH

Surface water pollution

Untreated or partially treated industrial wastewaters will frequently cause pollution when discharged to surface waters and this might well have health consequences if the water is subsequently used for public supply. However, even if the resource is not used for water supply, there may be secondary impacts on public health. Where a receiving water has previously been used for recreation (say bathing), the loss of such an amenity through pollution might cause psychological problems with a low-income population having few relaxing pastimes in a hot climate or other medical problems will arise if the recreational use is continued. Another possibility is that the ecological impact of waste discharges is such that an important food source, such as fish or shellfish, is affected and the nutrition of the population suffers. This may be through elimination of the organism itself or due to contamination of the organism by concentration of pollutant in passage through the food chain. These indirect health damages are difficult to quantify and assign cause but they are nevertheless important.

The most obvious health risk from industrial effluent discharges to surface waters, however, is when they are used for potable supply. In developing countries, surface waters are regularly used untreated, or after only household storage to settle out large particles, and the danger of industrial pollution is more serious than in developed countries where piped supplies are widespread. Contamination of the water with bacteria, virus or parasites will generally be less important than in the case of domestic waste discharges, except when animal-processing industrial wastewaters are discharged without treatment. Water pollution due to biodegradable organic matter will result in dissolved oxygen depletion and render the water unsuitable for normal household use. However, of much greater health concern will be the presence of toxic materials, such as heavy metals or known poisons, in industrial effluents. Modern industry uses and produces a wide range of dangerous chemicals, many of them synthetic and persistent (non-biodegradable), which might well be present in waste discharges even in very low concentrations. Although some of these may have clinical or sub-clinical effects, others might have chronic effects which are difficult to ascertain using current toxicological evaluation techniques. Only rarely in the case of industrial effluent discharges, and then usually after accidental spillage, will large concentrations of dangerous materials be present. Agricultural runoff will carry fertilizers and crop protection chemicals into surface waters but, again, these will generally be in minute concentrations unless poor handling and application practices are prevalent. A major problem with trace levels of potentially dangerous materials in industrial effluents has been their analysis. Although instrumental techniques have been refined in recent years, this expertise has yet to be transferred to most developing countries. Consequently, it will be difficult to monitor effluents for complex chemicals until the analytical capability of controlling authorities has been improved.

Hazardous waste disposal

In addition to the fairly large volumes of relatively dilute wastewaters released by industry, certain types of processes produce small quantities of very concentrated wastes containing hazardous materials. These should not be discharged to surface waters but are often irresponsibly dumped on land. Unsatisfactory land disposal may cause surface water pollution through surface runoff and is likely to result in groundwater contamination. Land disposal sites for such hazardous wastes are rarely chosen with care in developing countries,giving due consideration to the hydrogeology of the area. Instead, a minimum cost solution will normally be found and health hazards overlooked. Even if the authority responsible for solid waste disposal accepts such a waste, it will not be handled in a controlled manner considered necessary in developed countries. Again, no regulations apply to the disposal of hazardous wastes and landfill practices are primitive in most developing countries. The danger of public exposure to dangerous materials in refuse dumps is ever present because scavenging is common.

MEDICAL PROBLEMS WITH INDUSTRIAL EFFLUENTS

The greatest hazard of industrial operations is not connected with the water environment but is the accidental pollution of air by toxic gases or vapour clouds which may be explosive, flammable or toxic. Chemical and petrochemical installations give rise to the greatest risk in this respect and there is a growing awareness of the dangers from hazardous activity in the industry. A long list of past incidents (Ref. 1) include:

Flixborough, U.K., 1974, when 28 people were killed, 104 people injured, 3,000 people evacuated, 100 homes damaged and the river closed to shipping after an explosion and fire caused by cyclohexane.

Seveso, Italy, 1976, when one of the most toxic gases known to man, Dioxin, caused the complete evacuation of the area (which has continued up to the present time) and large investment in unsuccessful decontamination activities.

India, 1977, when 20 people were injured by a hydrogen vapour explosion.

Colombia, 1977, when 30 people were killed and 22 injured as a result of the release of ammonia gas.

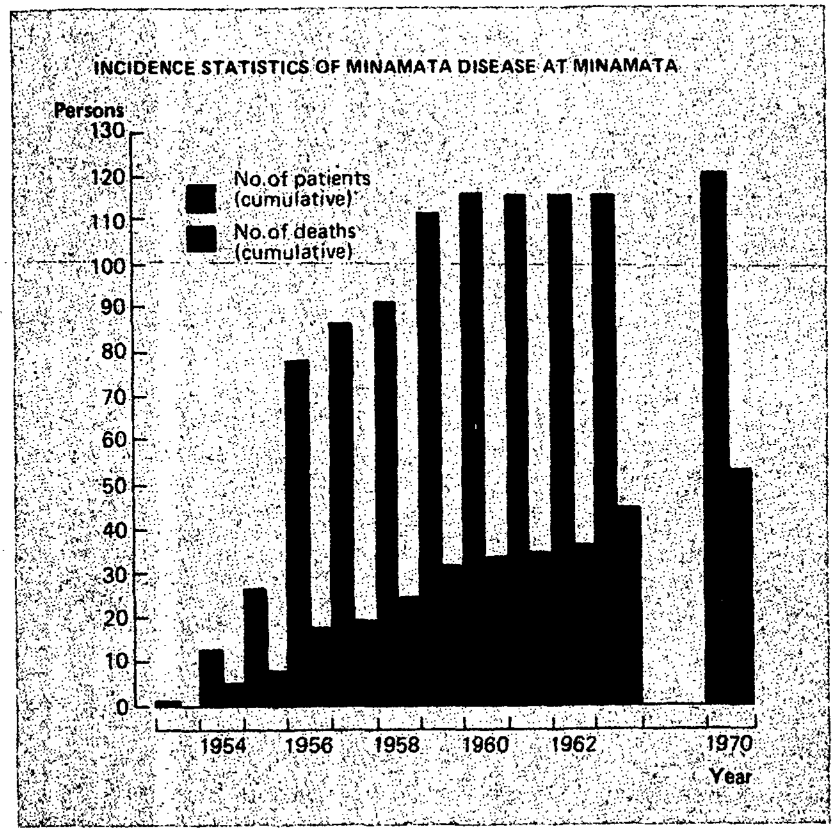
The number of such incidents has increased in recent years and the inclusion of a few developing countries among the sites reflects the increasing industrial activity in them and provides a general warning for the future.

Even so, this paper is primarily concerned with the effects of liquid industrial effluents and in this context no other country in the world has had greater medical problems than Japan (Ref. 2). Since the Second World War, Japan's industry has been rebuilt and production expanded at the expense of serious and rapid environmental disruption. Accelerated industrial development has occurred without adequate safeguards to control effluent discharges and the health consequences have been catastrophic. The danger of this being repeated in many developing countries is very real at this moment in time and Governments are well advised to take positive but structured steps towards the control of industrial effluents.

Minamata disease has a vital place in the history of industrial pollution in Japan and, in 1956, the Japanese were the first to observe the several neurological symptoms whose cause was then unknown. The main victims, who suffered irreversible damage and pain, were fishermen from the Minamata Bay area and their diet relied heavily on fish caught in the bay. A large chemical factory producing fertilizers, PVC resins, plasticizers and other organic chemicals had been discharging untreated wastes into the bay for a long time and their was heavy contamination by heavy metals and metaloids. The simple cause-effect relationship took more than six years to establish but the offending pollutant was finally identified as methyl mercury, which accumulated in marine biomass. Fatalities assigned to the disease are shown in Fig. 1 and it can be seen that deaths were still occurring in 1970 even though the factory stopped discharging organic mercury in the early 1960's. Congenitally transferred cases of the disease were also discovered in 1958 and babies born with brain damage now have a sub-human existence as adults. An unfortunate aspect of the case was a complete denial of responsibility by the Company concerned and this not only led to official epidemiological investigations but also to the establishment of citizens groups to support and act with the victims. However, a second outbreak of the disease in Niigata in 1968 brought to light the fact that there had been no administrative action taken to prevent the same occurring elsewhere in Japan.

About the same time that Minamata disease was being investigated, heavy metal mining pollution was also being suspected of causing Itai-Itai disease in the basin of the Jinzu River in Japan. Eventually, cadmium was identified as the cause of this unfortunate disease which causes bones to decalcify and disintegrate. After twenty to thirty years of exposure, there is spontaneous fracture of bones and, ultimately, the patient finds it impossible to eat or sleep, making death inevitable. The source of cadmium was wastewater discharges and runoff from waste slag deposits released by a mine producing copper, lead and zinc and located on the head waters of the Jinzu River. Downstream, the river water was used to irrigate rice paddy as well as for drinking and cadmium accumulated in the rice as well as in the aquatic organisms. Body tissue analysis in 1960 revealed that, up to 3800 ppm of cadmium was present in the bones of patients and in one suicide case, a female previously engaged in processing cadmium metal and displaying symptoms of the disease, the kidney ash contained 20,000 ppm of cadmium, the concentration of metal typical of cadmium ores. Again, the mining company involved attempted to evade responsibility by claiming a lack of scientific evidence on cause and effect.

Perhaps typical of a developing country situation where industrial effluents can disrupt the rural environment was the case of the Mae Klong River pollution in Thailand. A sudden expansion of cane sugar refining factories on a short reach of the river resulted in serious deterioration of water quality in the river. Large quantities of river water were used for cooling purposes on a once-through basis and no treatment was afforded wastes before return to the river at each site. From an upstream quality of 31^{o} C temperature, 7.5 mg/l dissolved



oxygen (DO) and less than 10 mg/l chemical oxygen demand (COD) the river water during low flow periods very quickly deteriorated to 36.5° C temperature, 0 mg/l DO and nearly 200 mg/l COD. In addition, the surface of the river was covered with floating oil from the direct discharge of bearing lubricating fluid. Unfortunately, the milling season coincided with low flows in the river and all fish were killed. Riverside dwellers not only lost an important food source but, perhaps even more important, were denied their traditional water supply. It took several years of social action and government experimentation with waste treatment before these benefits were restored to the rural residents and no provisions were made during this period to compensate for their loss. Similar occurrences are happening all over the world in tropical developing countries as agro-industries develop in rural areas to process agricultural produce at source. The health consequences of this case were not investigated but Governments must be prepared to shoulder the responsibility for protecting the community from gross misuse of natural resources by industry.

Examples of industrial effluents discharged to waterways affecting water supply are common in urban areas of developing countries. Soft-drink bottling plants, breweries and distilleries are typical industries responsible for organic pollution and dissolved oxygen depletion of urban streams used as sources of drinking water for low-income communities. Metal finishing operations are often carried out in small installations in concentrated areas of large cities and untreated plating wastes pose a serious health problem where receiving streams are used for water supply. Chemical factories, however, tend to be larger and have the greatest potential for causing medical problems in urban areas.

One example of a chemical factory effluent being forcefully brought to the attention of the controlling authority through the medical consequences of untreated discharges to a river was the case of a caustic soda manufacturing company in Bangkok. In 1973, two neutralization tanks used in the production of hydrochloric acid exploded and the company discharged left-over chlorine to the Chao Phya River over a period of six months. A leading vernacular daily newspaper, Siam Rath, reported that people living in the vicinity of the river were found to be suffering from a skin disease and had diarrhoea. Furthermore, they could no longer use river water for household purposes. Damage to downstream agriculture and fisheries was also said to be significant. On several occasions, the newspaper reported, the factory discharged wastewater containing mercury and caustic soda and this action led to large fish kills. People living along the river collected and ate floating dead fish. Eventually, complaints from local residents led to an investigation of the situation by the Thai Ministries of Industry and Public Health. Analysis of wastewater streams at the factory indicated the concentrations of mercury, chlorine and COD as shown in Table 1.

TABLE 1. Caustic Soda Factory Effluent Analyses

Component	Chlorine Treatment Section Wastewater	Chlorine Purifier Section Wastewater	Chlorine Storage Section Wastewater
Mercury, ppm	0.89	1.67	0.06
Chlorine, ppm	2.5	8.0	75.0
COD, ppm	23	27	29

After initially ordering the running repair of the neutralization tanks and cut-back in production of caustic soda, the Ministry of Industry finally issued an order requiring a complete halt in production at the plant until the tanks were completely repaired. At this stage the company reversed its previous position of protesting innocence to admit that their pollution prevention measures had been defective. Throughout the period of several months during which these events were happening, the Government Ministries did not take firm action and frequently made excuses about the limits of their jurisdiction and deficiencies of analytical equipment. The incident had international repercussions because demonstrations were organized against the parent company in Tokyo protesting about the export of kogai (pollution) and indicating that the Thai Government "was proceeding down the same pollution infested road that Japan had feverishly followed" (Ref. 3).

RATIONAL APPROACHES TO MINIMIZE THE HEALTH IMPACT OF INDUSTRIAL EFFLUENTS

A complete lack of preparedness on the part of Governments to handle the problems of industrial effluent disposal is common in developing countries. Introduction of very severe control measures will divert national resources away from projects contributing directly to economic development into environmental control while a laissez faire attitude will undoubtedly lead to serious health effects, which will be politically damaging. Legislation must be introduced to provide mechanisms for effective control of intractable and potentially dangerous materials and effluents and yet allow flexibility in the handling of relatively innocuous wastes. Environmental quality guidelines should be developed to suit local conditions and health considerations will be paramount in arriving at acceptable limits for hazardous materials. To administer regulations and manage water resources and waste disposal, new institutional structures will usually be necessary in developing countries where there is generally a fragmentation of responsibility for controlling water use and abuse.

Hazardous substances

Each country should have regulations governing the manufacture, import, conveyance, storage, use and release of dangerous substances and developing nations can learn from the progress made in Europe in reducing the hazards of such materials. Adequate information should always be demanded by the authorities from industry when hazardous materials are involved. Thus, the responsible government agency should know exactly which substances are being imported or manufactured and in what quantities, should maintain an inventory of distribution and control their transport so as to prevent accidents. There is already a wide range of international regulations governing such matters and industrial countries are constantly introducing new legislation to improve the safety aspects of living with harmful materials. Typical examples are EEC directives concerning the classification, packaging and labelling of dangerous substances and preparations and the U.K. Health and Safety at Work etc. Act, 1974. Industrial applications for planning permission must be thoroughly investigated by controlling authorities when hazardous materials are to be used or produced. Hazard analysis and risk assessment have recently been introduced in industrial countries in an attempt to anticipate the extent of any problems which might result from industrial growth. Threats to human health and well-being are now considered and, where possible, quantified before proposals are allowed to proceed. Any planning application which presents a risk considered unacceptable when compared with normal risks to which people are exposed in their everyday lives would not be approved. However, risk assessment also allows safety measures to be introduced before a project goes ahead if hazards can thereby be reduced to an acceptable level.

Wastewater discharges

The general tendency in developing countries faced with increasing water pollution has been to come down hard on industrial effluent discharges and disregard existing domestic wastes. Effluent standards devised in developed countries have frequently been adopted even when receiving water quality has allowed advantage to be taken of natural assimilative capacity. When an industrial effluent contains only biodegradable organic materials and harmless solids the use of stream standards or, better, guidelines will permit flexibility in managing water quality and minimizing pollution control costs. Economic approaches to pollution control, such as the use of incentives and effluent charges, will also be worth investigating in many instances. Consideration of the local impact of this type of water pollution and control alternatives should form part of the decision-making process in water quality management. Downstream water uses must be determined and, where possible, the damages associated with different levels of pollution assessed. It would be unrealistic to impose costly waste treatment if downstream damages were low or could be overcome at little cost. Even where a rural community's water supply was likely to be polluted, it might be more economical (to society) to put in water treatment for the public supply rather than treat the industrial effluent. In the case of the introduction of effluent standards to a polluting industry which works on very low profits , common in rural areas of developing countries, the economic and social impacts might be serious. A study of the effects of imposing effluent limitations on the tapioca starch industry in Thailand (Ref. 4) revealed that most second-grade mills would be forced to close, thereby reducing the industry's production by 10 per-cent and resulting in about 350 lost jobs in one part of the country.

The greatest problems might be expected to arise when toxic or hazardous materials are released in industrial effluents. Here again, a stream quality guideline will generally be the most rational approach to control, providing the distribution and uptake of the offending materials are well understood and reliance can be placed on toxicological data. However, more intractable or less understood materials must be controlled at source and their discharge prevented if at all possible. To achieve this the controlling authority must be authorized to apply consent conditions to all industrial effluents. In meeting any imposed condition, a conventional technological approach to industrial effluent control will be appropriate even in the case of hazardous materials. The first possibility is to change or modify the inputs to the industrial process in an attempt to eliminate the offending material. Occasionally, a change of process will be necessary to accomplish complete elimination. Careful process control and good housekeeping will sometimes reduce losses of specific materials in liquid effluents, while segregation of particular waste streams may allow the hazardous material to be isolated and handles in more concentrated form. Treatment of the combined liquid effluent from an industrial process will rarely be the most economic control approach but it will often be necessary. Reclamation and reuse of certain toxic materials, such as heavy metals in plating, may sometimes prove to be profitable. In addition to the need for appropriate technology, the approaches to industrial effluent control already outlined rely on strong legislation and well organized institutions for their success. Many Prevention of Pollution Acts and the Control of Pollution Act, 1974 have allowed legislation to be developed to suit the changing needs for water management in the U.K. and set up appropriate institutions. Around the world, regional water authorities are thought to provide the best mechanism for administering water pollution legislation and developing countries will be well advised to consider this form of centralized responsibility. If implemented, such an arrangement must empower water authorities to control all abstractions from and discharges to water resources and equip them with the staff and resources to enforce water pollution regulations. Budget appropriations to water authorities and/or revenues authorized to be collected by them should be adequate to allow them to carry out their broad range of functions with efficiency. Properly equipped analytical laboratories within an authority are essential if effluent monitoring is to be an effective tool in water pollution control

Concentrated hazardous wastes

Very often, concentrated hazardous wastes and sludges are produced by industry in relatively small quantities. Uncontrolled dumping on land or even proper disposal in sanitary landfill at an unsuitable site may cause serious toxic pollution of surface or ground waters and be a hazard to public health. To prevent such occurrences, again legislation is essential and administrative responsibility for control must be assigned to particular authorities, usually local solid waste management organization. In the U.K. the Deposit of Poisonous Waste Act, 1972 and the Control of Pollution Act, 1974 together with site licensing legislation has revolutionized hazardous waste disposal in recent years. Producers of hazardous wastes are bound to notify the local waste disposal organization of the type and quantity of waste which is to be disposed of and the proposed method. Specialized waste disposal contractors have developed sites for handling these types of waste and a great deal of research effort has gone into establishing safe techniques and minimizing the medical risks involved in the collection and disposal process.

Industrial countries are finding it difficult to allocate land for new disposal sites and available landfills must be managed with increasing efficiency. As sites become fewer and control regulations increase in severity, the costs of hazardous waste disposal are rising. Although developing countries may not have the same problem of finding landfill sites, there will still be the suitability of site for hazardous waste disposal to consider. The choice of technique for hazardous waste treatment should be based on minimizing the health risks and environmental impact. Available technology includes incineration of chemical wastes and chemical fixation of hazardous materials. The former treatment may well give rise to air pollution and both methods, although reducing the volumes for land disposal, will result in increased disposal costs which might militate against their use in developing countries at the present time. Land disposal will continue to be the most economical and preferred method for hazardous waste disposal but advantage should be taken of the latest information on this system. A recent publication (Ref. 5) has presented research findings on the behaviour of hazardous wastes in landfill sites. The two alternatives in landfill are "contain and concentrate" or "dilute and disperse" and there is still technical discussion on the merits of each approach. Although the former method, depending on an impermeable site, will normally prevent contamination of groundwater, experience has shown that there is still a great danger of surface water pollution at times of high precipitation. With the latter method, a "controlled" level of local contamination is permitted on the assumption that natural processes of oxidation, reduction, decomposition, absorption, adsorption, etc. play a part in attenuating the levels of pollutants in passage of leachate through the underlying strata. The assimilation capacity of the strata between the landfill and the aquifer will provide protection to the groundwater but concern is being expressed about the long term effects of continual use of the system. There will obviously be sites where only one of these techniques can be adopted but decisions on landfill disposal techniques must be taken after complete details on the hydrogeology of the site and nature of the hazardous waste have been considered.

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LOW COST METHODS OF TREATMENT OF AGRICULTURAL EFFLUENTS IN WARM CLIMATES

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INTRODUCTION

Control of pollution by biological purification of organic type wastes is particularly relevant to environmental protection in warm and tropical areas.

The economy of these areas is often predominantly dependent on the production and processing of agricultural products such as fruit, milk, meat, vegetables, grapes, sugar and wood products.

In such processing operations large quantities of water are used, large tonnages of product are handled and large quantities of high organic type wastewaters are generated per unit of raw product.

It is important to the preservation of quality of receiving waters that this organic content be destroyed under controlled treatment conditions.

It is characteristic of most of these situations that the monetary value of the product from food, beverage or paper production is relatively low, with low capital involvement, and it is an important consideration that methods used for purification should be relatively low in capital cost. Because of energy costs it is also desirable that low energy processes be used wherever possible. In view of the concern of this Symposium with public health it is important to consider the public health aspects of these low cost processes which from economic considerations would appear peculiarly appropriate.

This paper describes a number of situations where low cost, low energy processes have been successfully used to cope with situations where very high pollution loads from processing of agricultural products need to be destroyed.

It considers the conditions requisite for successful application of such processes under a variety of conditions. It also gives consideration to the public health aspects of the processes involved.

LOW COST METHODS OF TREATMENT

Methods particularly appropriate to application in warm and tropical countries are anaerobic and aerobic lagoons, oxidation ditch, trickling filter, anaerobic fermentations and irrigation.

ANAEROBIC-AEROBIC LAGOONS

The waste is passed successively through two or more ponds in series. The initial or anaerobic units are often built 6-8 ft. or more deep. The later or aerobic units do not need to be more than 3-4 ft. deep. The exact layout is governed to some extent by the topography. Solids accumulate and digest in the first pond and by anaerobic methane fermentation achieve

70-90% B.O.D. reduction of the wastewater. In the later aerobic ponds a profuse algal growth normally develops and by the photosynthetic production of oxygen purification is completed. The final effluent will usually be green with algal cells. Better performance is achieved at higher temperatures.

OXIDATION DITCH

This is a variation of the complete mix extended aeration activated sludge process. The wastewater usually without primary removal of solids discharges to a loop shaped aeration cell, where the mixture of waste and activated sludge is aerated usually by horizontal shafted cage aerators which also move the contents around the loop to continually renew the aeration. The aeration units can be constructed in concrete or as a boat shaped section in earth. The aerated contents flow over a weir to a clarifier and the activated sludge is returned to the aeration tank. The purification capacity of the tank is related to its cubic contents and the aeration capacity of the rotors.

TRICKLING FILTER

Trickling filters essentially consist of a bed of stone or plastic media of various depths over which the waste is distributed. There develops an active slime on the media and the organic matter is converted to CO_2 and water and so purified. It is particularly applicable for the completion of purification of relatively low strength wastes or high strength wastes previously partially purified by anaerobic processes. Apart from any pumping to distribute the waste over the filter it requires very little energy input.

ANAEROBIC FERMENTATION

The digestion of raw sewage sludge solids under anaerobic conditions with the conversion of organic matter to methane and CO_2 has been an established practice for many years. More recently Parker (1971) it has been shown that under suitable conditions this fermentation can be adapted to the conversion of high strength soluble organic wastes, similarly, to methane and CO_2. This can be achieved in anaerobic lagoons or confined in closed tank structures. The process is particularly temperature dependent proceeding at higher rates at higher temperatures up to 37°C., or by utilization of thermophilic group of bacteria, up to 50-55°C. It is obviously more effective under warm or tropical conditions.

The process, as with aerobic processes, requires the presence of adequate content of nitrogen and phosphorus in proportion to the organic carbon in the wastewater. The methane fermenting organisms essential to the fermentation process are relatively slow growing and need to be retained in the system at high concentration. This is best achieved by a high retention of solids in the system.

The process is also critical with regard to pH. A first stage involves breakdown of organic sugars carbohydrates or starches to volatile fatty acids, by a variety of saprophytic bacteria, and these fatty acids are then broken down to methane and CO_2 by the methane fermenters. While the first group are active over a wide range of pH the methane fermenters only metabolize within the pH range 6.0-8.5. It is essential that the rate of methane formation keep pace with the acid production to ensure that pH remains within the growth range of the methane fermenters. Where climatic conditions are warm or tropical or where the raw waste is delivered at an elevated temperature, conditions are particularly favourable to maximum activity, and energy requirements minimal.

IRRIGATION

The use of irrigation for the purification and disposal of agricultural type effluents has been used in many situations and the spreading of solid residues from processing fruit, vegetables or other organic debris is also common, sometimes with most unacceptable consequences.

Controlled distribution of water or wastewater onto land by flood or spray irrigation or by overland flow (or grass filtration) and its subsequent passage through soil to drainage, or passage through grass cover to run off, can achieve almost complete destruction of organic matter by soil organisms. By incorporation of nutrients into pasture, almost complete removal of nutrients can be achieved.

There are three principal procedures available for distribution of wastewater onto land :-

Flood irrigation

The wastewater is distributed often through earth channels into prepared levelled and graded irrigation bays according to a watering cycle which permits irrigation over the whole area without any surface run off to adjacent water courses. The water drains through the soil, B.O.D. and suspended solids are reduced to very low values and nitrogen and phosphorus is largely built into the grass cover.

A comparison of composition of raw wastewater and drainage water for a controlled operation on a suitable soil is shown in Table 1.

TABLE 1. Wastewater Purification By Land Filtration

		Raw Waste	Drainage Water
B.O.D.	mg./l.	520	10
Suspended solids	mg./l.	440	13
Total Nitrogen	mg./l.	60	3
Total Phosphorus	mg./l.	25	1.0
E. Coli	orgs./100 ml.	6×10^7	12×10^5

Grass filtration

This has been developed and extensively practised in Melbourne for the treatment of settled sewage under wet weather conditions. The waste water is distributed by Header channels into prepared, graded, and grassed irrigation bays. However, in this process there is continuous application of the wastewater with continuous overland outflow. Experimental use of this process for the treatment and disposal of tomato processing wastes has also been used by these Laboratories.

The use of spray application also with continuous outflow has also been reported by Gilde (1970). Typical analyses for the composition of applied and effluent flows with both methods are shown in Table 2.

Spray irrigation

This involves the distribution of the wastewater over land by overhead sprays. The rate of application and operating cycle can be controlled to either achieve complete retention of water on the area watered, or a controlled run off. Where there is no run off the composition of drainage can be considered comparable with that shown in Table 1. Where run off is permitted it can achieve a lower land flow effluent as shown in Table 2, Gilde (1970).

TABLE 2. Wastewater Purification By Grass Filtration

	Flood Irrigation		Spray Irrigation	
	Raw Waste	Drainage Water	Raw Waste	Drainage Water
B.O.D. mg./l.	520	20	616	9
Suspended solids mg./l.	440	25	263	16
Total Nitrogen mg./l.	60	25	17.4	2.8
Total Phosphorus mg./l.	25	17	7.6	4.3
E. Coli orgs./100 ml.	6×10^7	3×10^5	--	--

For effective application of these methods a number of factors need to be considered.

The slope of the land, all other factors being constant, will determine the permissible rate of application without run off. Land of steeper slope is obviously more appropriate to spray than flood irrigation.

The soil type and drainage has a considerable bearing on the suitability of land for irrigation, permeable friable soil with good drainage will accept more water per unit area than tight clay soils. The chemical composition of the soil also has a bearing on its suitability. High lime alkaline soils are more suitable than acidic type soils.

Climatic conditions such as rainfall and evaporation are also relevant, low rainfall high evaporation areas can accept greater amounts of water, however, even in high rainfall areas, where the soil profile is suitable and there is good drainage, successful irrigation schemes can be implemented. Where disposal by grass filtration or spray irrigation with overland flow is contemplated soil type and soil conditions are not particularly relevant.

The extent and the type of grass cover can significantly improve the quantities that can be applied. Where continuous flow is contemplated the grass cover needs to be water tolerant. By experience in Melbourne with grass filtration for part of the year a mixture of predominantly Italian rye grass has been found suitable.

In Texas with spray irrigation and overland flow a cover predominantly of Reed Canary grass is found suitable provided it is cropped regularly.

The continued operation of schemes involving irrigation with drainage and no run off need consideration from the point of view of possible long term effect of waste composition on the chemistry of the soil and its physical behaviour. Wastes particularly food effluents may be high in sodium from the use of caustic soda for peeling operations. The long term application of wastes with high Na/Ca+Mg ratio can lead to a change in the composition of the clay fraction, and the conversion of calcium to sodium clays can reduce their permeability and rate of acceptance of water. Such wastes are more suitable for overland flow systems which are not detrimentally influenced by such waste composition.

The amount of organic content needs to be considered as this can have a bearing on odour development. High B.O.D. wastes are best handled by spray methods of distribution to avoid localized high concentrations of organic matter and consequent local development of anaerobic conditions and odours.

As with other biological processes mentioned earlier, the nutrient content with regard to carbon/nitrogen/phosphorus ratio has a bearing on performance.

With regard to performance this is assessed in terms of quantity of water applicable per unit area per unit time. It is also necessary to assess performance in terms of B.O.D. and suspended solids reduction between applied wastewater and the composition of any drainage or run off. Because of the ability of such processes to fix, remove and retain nitrogen and phosphorus, performance may well need to be stated in terms of percentage removal of these constituents as well as for B.O.D. and suspended solids removal.

CASE HISTORIES

Example A

Load - The total load is contributed from a domestic population of 20,000 together with wastes from a large cannery (peaches and pears) a vegetable processor (soups and general products), a milk products processor (milk powder casein and butter) and a slaughter house. The total peak load condition is a population equivalent of 5-600,000 persons. The individual contributions are as shown in Table 3.

TABLE 3. Individual Contributions To Total Waste Load (A)

Source	Period of discharge	Peak load period	Flow Imperial gallons	B.O.D. load lbs/day
Domestic	continuous	constant	1.2 m.g.d.	3,500
Fruit	January-April	February-April	2.5 m.g.d.	60,000
Vegetables	continuous	February-April	0.9 m.g.d.	4,500
Milk	continuous	August-December	0.2 m.g.d.	7,000
Meat	continuous	constant	0.4 m.g.d.	6,000

The characteristic seasonal variation in load, and its influence on the total load are shown in Figure 1.

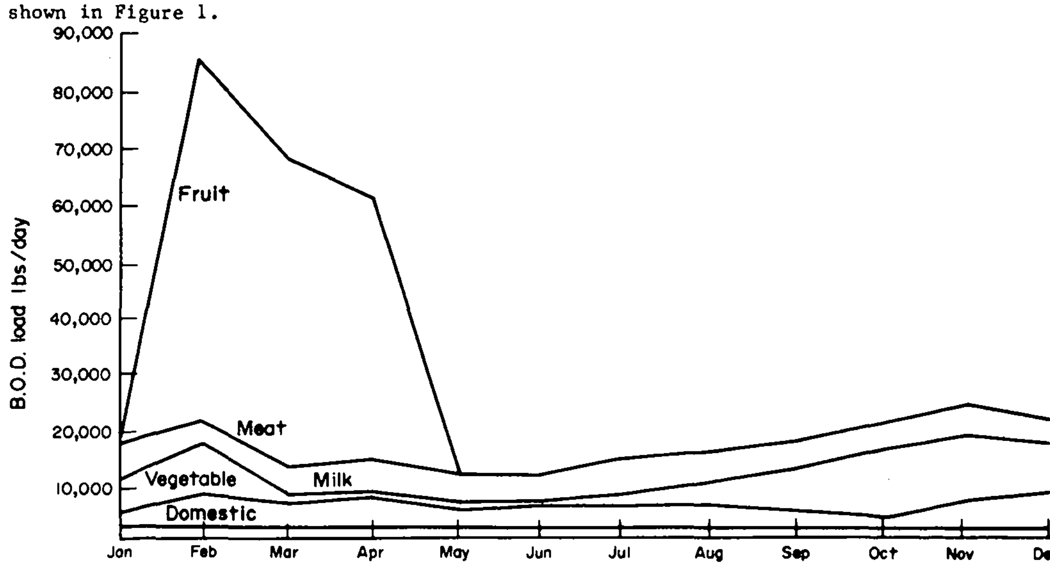

Figure I. Seasonal variations in load (A)

To cope with this load there was developed after detailed investigation by pilot plant, an anaerobic-aerobic lagoon facility consisting of 108 acres of anaerobic followed by 132 acres of three stage aerobic lagoon units. The layout is as shown in Figure 2.

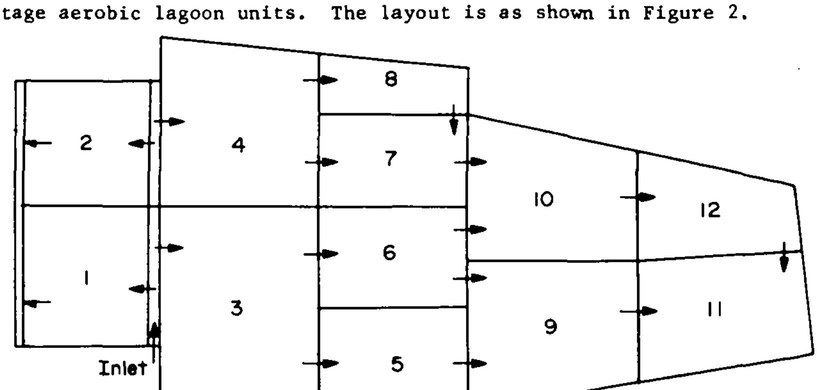

Figure 2. Lagoon layout—Example A

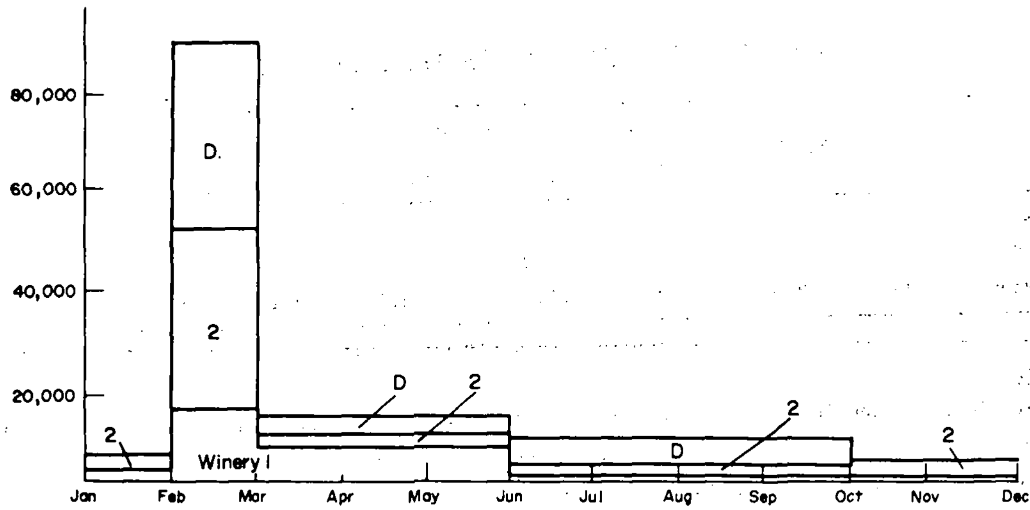

Figure 3. Seasonal variation in load (B)

The discharge is to a significant river with continuous flow (min. 100 cusecs) and with stringent effluent discharge E.P.A. licence conditions. Wastes are screened and pH adjusted prior to factory discharge.

Design load conditions were

Anaerobic units - 600 lb. B.O.D./ac./day
for 85% B.O.D. removal

Aerobic units - 60 lb. B.O.D./ac./day
80% B.O.D. removal

Discharge condition requirements are -

B.O.D. (filtered) ≯ 10 mg./1.
Oxygen depletion of river ≯ 1.0 mg./1.
Ammonia-N increase in river ≯ 0.1 mg./1.

The performance of the installation obviously needs to comprehend the varying load through the year and has been designed for the peak load summer conditions.

The installation has been in operation for seven years and typical performance during the off peak and two yearly peaks February-April (due to fruit cannery) and August-November (due to milk) is shown in Table 4.

TABLE 4. Lagoon Performance (A)

PERIOD		INFLOW m.g.d.	B.O.D. LOAD lbs/day	LOAD Anaerobic lbs/ac/day	LOAD Aerobic lbs/ac/day	ANAEROBIC LAGOON B.O.D. Inf. mg/l	ANAEROBIC LAGOON B.O.D. Eff. mg/l	% Red	AEROBIC LAGOON B.O.D. Inf. mg/l	AEROBIC LAGOON B.O.D. Eff. mg/l	% Red.
Fruit Peak	February-March	5.0	80,000	660	69	1410	170	88	170	70	59
Milk Peak	September-December	2.2	24,000	220	30	1090	170	84	170	57	66
Off Peak	May-July	2.0	12,000	110	16	600	105	83	105	33	69

The composition of the effluent discharge to the river is shown in Table 5.

TABLE 5. Composition of Discharge to River (A)

	B.O.D. mg./l.	Filtered B.O.D. mg./l.	Suspended Solids mg./l.	Ammonia-N mg./l.	Phosphate-P mg./l.	pH	Dissolved Oxygen mg./l.	E. Coli orgs/100ml
Fruit Peak	70	11.4	170	2.0	6.0	7.5	3.0	3,500
Milk Peak	57	10.0	100	25.0	11.0	7.9	15.0	100
Off Peak	33	2.0	65	25.0	5.2	7.1	7.8	100

* filtered through 8 micron filter

Example B

This installation is to treat the combined load from two wineries and a brandy distillery with no domestic component. Here also there is a very marked seasonal variation in load. The two wineries discharge a peak load during vintage (April-May) but have a minor discharge from bottle washing and wash out of vessels during the rest of the year. The distillery operates seven months from the beginning of vintage in April to October. The load from various operations is shown in Table 6.

TABLE 6. Seasonal Load from Various Operations (B)

	Crushing Capacity Tonne/day	PERIOD February-March (Vintage)		May-June		July-October		November-February	
		Flow G.P.D.	B.O.D. lbs/day	Flow G.P.D.	B.O.D. lbs/day	Flow G.P.D.	B.O.D. lbs/day	Flow G.P.D.	B.O.D. lbs/day
Plant No.1 Winery	200	35,000	1,650	14,000	800	9,000	240	9,000	240
Plant No.2 Winery/	200	19,000	3,500	8,000	200	8,000	200	8,000	240
Distillery	-	14,000	3,900	1,000	400	1,000	400	-	-
TOTAL	400	68,000	9,050	23,000	1,400	18,000	840	17,000	480

The seasonal variation in B.O.D. load is shown in Figure 3.

Both winery wastes are screened and local settling units remove diatomaceous earth used for filtration, prior to discharge. Analyses revealed a deficiency in nitrogen, and ammonium sulphate is added to the raw waste.

In the early stages of operation soda ash is dosed to maintain pH in the anaerobic ponds. Purification is effected by a two stage anaerobic-aerobic lagoon system.

The anaerobic stage consists of 4 cells of 8.5 acres and 20 feet deep followed by one aerated lagoon of 0.5 acres 12 feet deep.

The effluent from the aerated lagoon passes to a final settling and storage lagoon from which effluent is recirculated to the primary lagoons or discharged for irrigation.

The design data is as follows :-

Flow		68,000 g./day		
B.O.D. load peak	-	872 lb./ac./day	113 lb./acft./day	
off peak	-	46 lb./ac./day	6 lb./acft./day	
Lagoon loadings				
Anaerobic	-	600 lb. B.O.D./ac./day		
Aerated	-	400 lb. B.O.D./ac./day		

The installation is operated with all flow from both wineries and distillery to the anaerobic units. There is a variable level discharge to control the flow to the aerated lagoon and sufficient storage in that and the storage lagoon to give flexibility in the quantity and time of return of purified effluent for recirculation.

The flow diagram is shown in Figure 4.

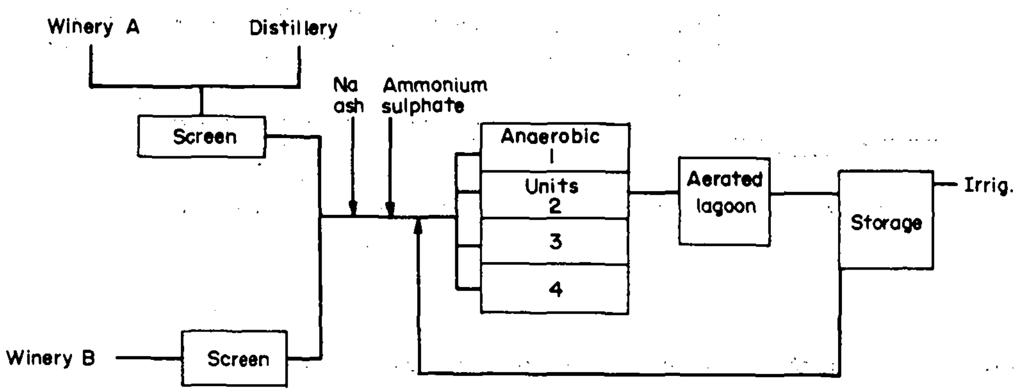

Figure 4. Flow diagram Winery waste treatment B

The installation is currently handling its first full season vintage. It is expected meaningful performance data should be available for presentation at the time of the symposium.

It is expected that by this operation the contents of all anaerobic units will be kept at a B.O.D. of 100-150 mg./l. and pH in excess of 7.0 and that a prolific algal population and low B.O.D. will be maintained in the aerated lagoon for recirculation and disposal.

Example C

This installation was designed to treat the wastes from milk processing to cheese, milk powder and casein, with milk separation for butter production at another factory. Maximum milk intake is 130,000 gallons/day, but shows a considerable seasonal variation, with peak intake in September-October and minimum intake June-July.

The cheese whey and casein whey are disposed of to pigs and by drying. The factory effluent consists of casein wash water and wash down of vessels and floors.

The wastes can be conveniently separated and handled in two streams, the high strength casein wash water (flow 35,000 gallons/day, B.O.D. 12,000 mg./l) and the general factory waste (flow 130,000 gallons/day, B.O.D. 2,500 mg./l.).

This installation uses methane fermentation for treatment of the high strength casein wash. Detailed laboratory and pilot plant operation has shown that casein whey and wash water as well as cheese whey can be fermented to methane and CO_2 at high rates in closed heated fermentation units (2 x 125,000 gallons) provided sufficient active seed sludge is developed and maintained in the fermentation mass.

The low strength factory waste together with the outflow from the fermenters is treated in a 14 acre facultative lagoon at a B.O.D. loading of 200 lb. B.O.D./ac./day producing on effluent of B.O.D. 200-250. Final purification of this total waste is achieved by oxidation ditch before discharge to a drain or to irrigation over pasture. Waste activated sludge is returned to the lagoon.

The flow diagram is as shown in Figure 5.

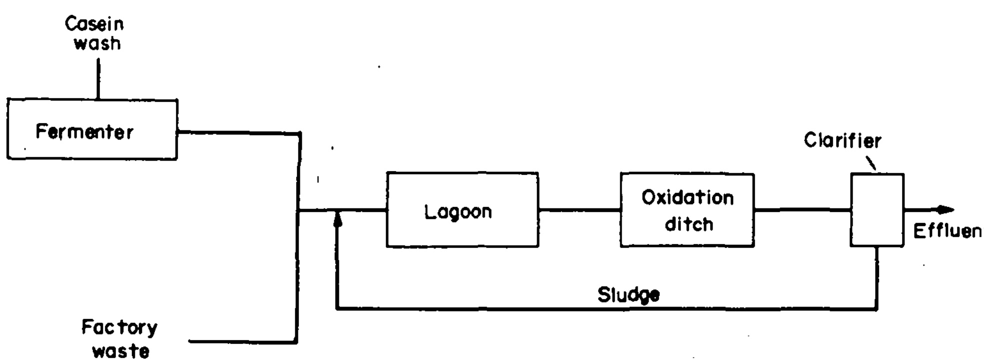

Figure 5. Flow diagram Milk waste treatment plant (C)

Typical load and performance for the various units are shown in Table 7.

TABLE 7. Milk Waste Treatment (C)

Fermenter	
Flow gallons/day	35,000
B.O.D. load lb./day	4,200
Detention (days)	7
Temperature °C.	35
Effluent B.O.D. mg./l.	2,500
Gas Yield cft./day	59,000
Lagoon	
Flow gallons/day	130,000
B.O.D.	
influent mg./l.	2,500
effluent mg./l.	220
load lb./ac./day	230

TABLE 7. (cont.)

Oxidation Ditch	
Length feet	130
Width feet	2 x 12
Rotors	(2 x 7½ H.P.)
Flow gallons/day	130,000
B.O.D. load lb./day	290
Influent B.O.D. mg./l.	220
Effluent B.O.D. mg./l.	40

Example D

Here it is necessary to find a means of biologically purifying the high strength wastes arising from the lye peeling of potatoes and other high strength wastes arising from the processing potatoes to french fries. It is necessary to reduce the strength to a level acceptable for discharge to the local sewerage Authority for further purification by trickling filter to a final B.O.D. 20 mg./l., Suspended solids 30 mg./l.

Laboratory and pilot plant operation in these laboratories, and by others show that this waste and other high strength organic wastes from meat, Steffen (1961), sugar, Lettinga (1978), and distillery, Shea (1974), can be fermented to methane and CO_2 in heated fermenters.

The scheme of treatment developed is as shown in the flow diagram Figure 6.

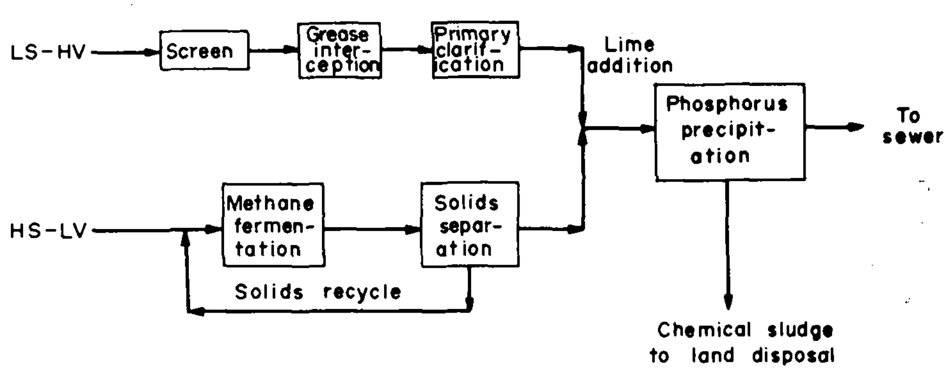

Figure 6. Flow diagram - Potato processing wastewate treatment

The composition of individual flows at various stages of treatment is shown in Table 8.

TABLE 8. Composition of Individual Wastes (D)

	B.O.D. mg./l.	Flow gallons/day/shift
High Strength		
Peel Scrubber	100,000	5,000
Brusher Washer	23,000	6,000
Blancher	18,000	1,200
Low Strength	3,000	66,000

Full scale plant has been designed and is being constructed to implement these findings.

COST CONSIDERATION

Accurate evaluation of costs of treatment and particularly comparison of costs for different situations, is difficult. Difference in location, topography, climate, type of waste, effluent requirements, all introduce considerations that make generalizations difficult. Even agreement on the most acceptable units for comparison i.e. capital cost, operating cost, annual charge, unit cost per unit B.O.D. or suspended solids, per day or per year is difficult.

Based on Australian experience of actual construction cost figures (1970) for examples A and C, and tender cost figures for example D the following assessment of annual cost expressed as cents per lb. B.O.D. removed, for various processes is shown in Table 9.

TABLE 9. Cost Comparisons Various Treatment Processes

Example A (Anaerobic-Aerobic Lagoons)		Example C	
Land		Grass Filtration	
Area 300 acres cost (A)	$90,000	20,000 g./ac/day at B.O.D. 500 for 6 months	
Pond construction (A)	$90,000	Land cost (per acre)	(A) $300
Annual charge (at 17½% capital cost)	$31,500	Annual cost (at 17½%) per acre	(A) $ 50
Actual Annual Charge	$30,000	B.O.D. load purified (per acre) lbs./6 months	18,000
B.O.D.load purified lbs./year	9,500,000	Cost per lb. B.O.D.	(A) 0.3 cents
Cost per lb. B.O.D.	(A) 0.3 cents	Irrigation	
		4,000 g./ac/day at B.O.D. 500 for 6 months	
		Land cost (per acre)	(A) $300
		Annual cost (at 17½%) per acre	(A) $ 50
Example D		B.O.D. load purified (per acre) lbs./6 months	3,600
Anaerobic Digestion of Potato Processing Wastewater		Cost per lb. B.O.D.	(A) 1.5 cents
		Oxidation Ditch	
Capital Cost	(A) $450,000	Capital cost	(A) $50,000
Annual Cost	(A) $ 75,000	Annual charge (at 17½%)	(A) $ 8,750
B.O.D. load purified lbs./year	3,150,000	B.O.D. load purified lbs./year	260,000
Cost per lb. B.O.D.	(A) 2.4 cents	Cost per lb. of B.O.D.	(A) 3.4 cents

They are based on the capital cost of the treatment unit structures only and local operating values.

DISCUSSION

The hazards to public health and well being from fish kill, general water pollution and persistence of pathogens due to uncontrolled discharge of high strength organic wastes from processing agricultural products, demand adequate means of purification and disposal.

The use of high energy, capital, and running cost conventional aerobic processes (activated sludge and to a lesser extent trickling filter) to purify high strength wastes from processing agricultural products is less and less attractive.

The illustrations given in the paper support the contention that the application of lower cost and lower energy demanding processes of irrigation, lagoons, oxidation ditch and methane fermentation can be successfully applied to the effective control of pollution from such highly polluting wastes.

The use of anaerobic processes in conjunction with low cost aerobic processes of aerobic lagoon, irrigation or oxidation ditch may often be appropriate.

The successful application of these processes is dependent on several local factors such as sufficient land at a reasonable cost, topography with relatively level land, and climate conditions such as rainfall, temperature and sunshine.

As shown in Example A, the cost of artificial nutrient supply can often be minimized if factories are grouped so that the high nitrogen wastes e.g. from meat and milk, can compensate for deficiencies in fruit and vegetables wastes.

The selection of an appropriate system of processes for treatment for a particular situation must be developed with all these aspects in mind.

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TREATMENT AND RE-USE OF INDUSTRIAL WASTE WATER BY PHOTOTROPHIC BACTERIA*

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ABSTRACT

Phototrophic bacteria contribute to the purification of concentrated organic waste solutions and metabolize dimethylnitrosamine which is a carcinogenic, mutagenic, and teratogenic substance. These bacteria also fulfil a role in the sanitary purification of foul water. They have anti-viral properties. They are beneficial to contribute fertilizer to agricultural land in that they suppress plant pathogenic microorganisms.
It is shown that phototrophic bacteria play an important role in the preservation of the environment.

INTRODUCTION

Phototrophic bacteria (PTB) are beneficial microorganisms which can purify foul water. The treatment of waste by PTB and their beneficial use as animal feed and organic fertilizer have been previously reported. (1 - 4)
As shown in Fig. 1, PTB contribute to the purification of environment in the natural microbial ecology system in which PTB grow after heterotrophs, followed by algae.
In the present paper, it is shown that 1) PTB contain anti-virus substances, and 2) that carcinogenic, mutagenic, and teratogenic dimethlnitrosamine is produced in heavily polluted environments and PTB are capable of purifying and treating such substances. And 3) the purification of waste water from a swinery and the values as organic fertilizer of the microbial mass obtained, are demonstrated.

1) Anti-virus Substances in Phototrophic Bacterial Cells

As shown in Table 1, PTB cells contain anti-virus substances. This activity is higher in the light but they have the ability to inactivate virus even in the dark. Since it was shown that the anti-virus activity indicates the ability to inactivate other pathogenic virus than Sindbis virus, it has been evident that the purification of polluting water by PTB is of sanitary significance.

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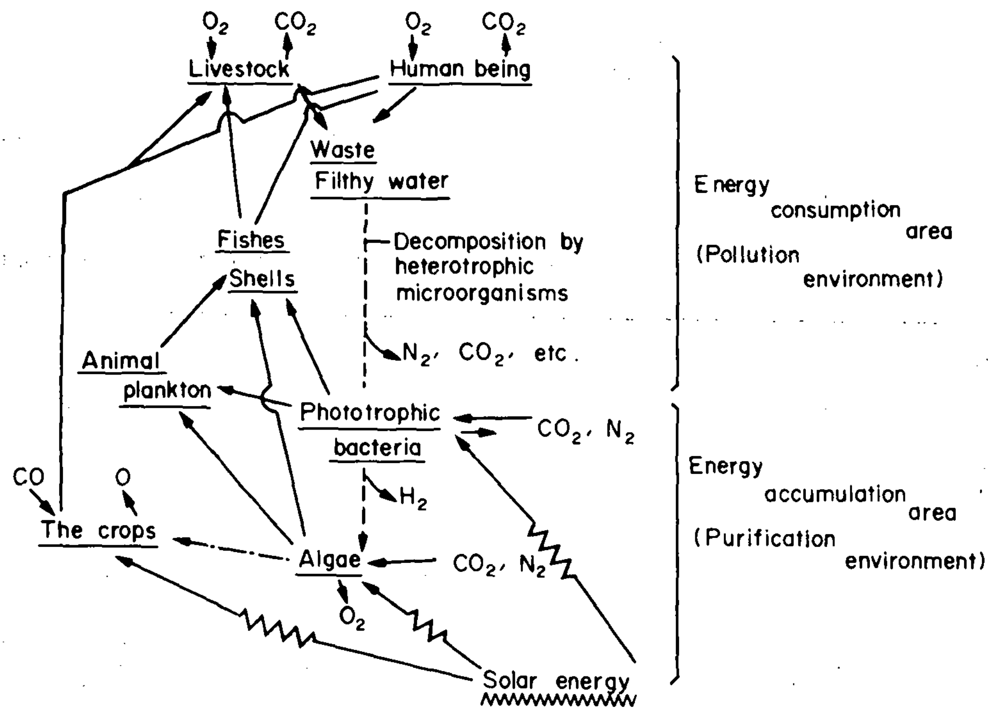

FIG. 1. Diagram showing roles of phototrophic bacteria in natural environment

TABLE 1. Anti-virus activity of phototrophic bacterial extracts

	Plaque counts*				Inhibition (%)
				Average	
Control	752	748	749	750	0
Light	190	185	188	188	75
Dark	484	475	481	480	36

*showed plaque formation for Sindbis virus on plate of chick embryo tissue. This anti-virus substances are very thermo-stable under dark condition. Over the 80 % activity was showed after the heat-treatment at 60°C for 5 minutes.

2) Production of Dimethylnitrosamine in a Polluted Environment and its Purification by Phototrophic Bacteria

From the sludge accumulated in the environment of a heavily polluted watercourse by the waste solution from the canning of fishery products and other dense organic waste waters, carcinogenic, mutagenic, and teratogenic dimethylnitrosamine was detected as shown in Table 2. (5) On the other hand, it was shown that PTB metabolize dimethylnitrosamine, remove it, and thereby purify the organic waste water as shown in Fig.2.

TABLE 2. Production of dimethylnitrosamine on incubation of ditch sludge

Incubation time (days)	0	7	14	21	28
Dimethylnitrosamine (μg/ml)	0	1.5	2.85	0.2	0

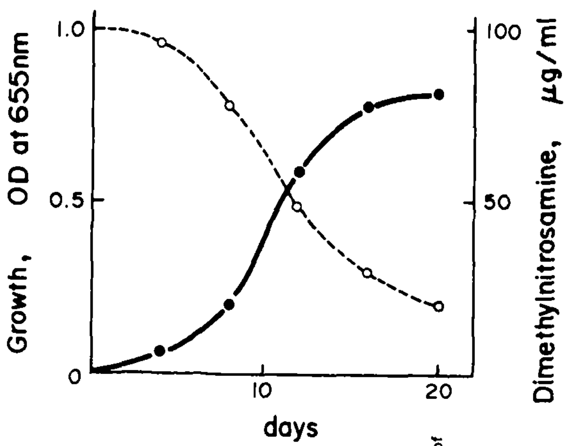

FIG. 2. Growth of phototrophic bacteria and consumption of dimethyl-nitrosamine

—•—•— Growth of phototrophic bacteria
--o--o-- Dimethylnitrosamine consumption

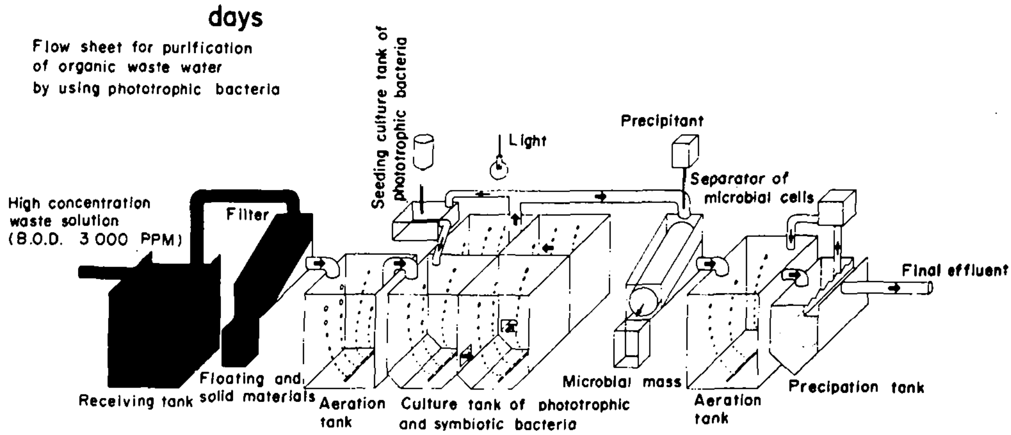

FIG. 3. Flow sheet for purification of organic waste water by using phototrophic bacteria

TABLE 3. Example of purification of waste solution from a swinery

		Original	Supernatant in precipitation tank after PTB* treatment	Purified effluent
BOD	(ppm)	6600	380	15
COD	(ppm)	3364	354	64
SS	(ppm)	6540	450	17
Kjeldahl nitrogen (as N)	(ppm)	915	32.8	7.8
pH		6.8	7.3	7.1

*PTB : Phototrophic bacteria

3) Treatment of Waste Solution from a Swinery and Use of the Bacterial Mass obtained during Treatment

When the treatment of the waste water from the swinery was performed according to the flow-sheet shown in Fig. 3, the foul water was purified as shown in Table 3. Although PTB show an excellent effect on the decrease of BOD, they have not so great an effect on the COD.

The surface oxidation layer (ex. Euro-Matic Bio-Drum) has to be rolled on the water surface in order to defoam in the first tank for aeration and in the second tank for PTB, and to decrease COD of final effluent.

The fungi grown on the surface oxidation layer of the bio-drum multiply well, and promote the decomposition of substances which suppress the formation of a brown color in the discharge.

TABLE 4. Tomato plant growth and the fruit yield by supply of phototrophic and symbiotic heterotrophic microbial cells

	Leaves (dry weight)	Roots (dry weight)	Total fruits number	Total fruits (fresh weight)
	g	g		g
Sand culture/pot				
Control (Inorganic fertilizer:I.F.)	57.7	15.0	14	729
Treatment (I.F.+PTB,etc*)	51.3	20.5	16	805
Soil culture/pot				
Control (I.F.)	58.2	22.1	16	1049
Treatment (I.F.+PTB,etc*)	55.1	30.3	22	1408

*PTB, etc. : Phototrophic and symbiotic heterotrophic microbial cells collected from purification of waste solution.

TABLE 5. Comparison of microbial counts in tomato plant culture supplied with inorganic and organic (PTB, etc. cells) fertilizers (after 3 months)

	Bacteria	Actinomycetes	Fungi	Act./Fungi ratio
Sand culture	counts/g	counts/g	counts/g	
Control (Inorganic fertilizer: I.F.)	3.8×10^5	1.0×10^5	18.0×10^4	0.56
Treatment (I.F.+ PTB,etc*)	9.0×10^5	1.2×10^5	4.0×10^4	3.0
Soil culture				
Control (I.F.)	8.5×10^6	5.2×10^5	5.0×10^5	1.0
Treatment (I.F.+ PTB,etc*)	16.3×10^6	23.0×10^5	15.0×10^5	1.5

*PTB, etc. : Phototrophic and symbiotic heterotrophic microbial cells.

The sewage purification using PTB is useful for treating waste water from palm oil and molasses. When PTB cells which were collected as the secondary product and other co-existing microbial cells were utilized as the organic fertilizer, the growth of plant was promoted as shown in Table4. The research of micro-flora in soil on that occasion indicated that beneficial actinomycetes for agriculture multiply well in comparison with application of chemical fertilizer shown in Table 5. The actinomycetes on agricultural land inhibit the growth of plant pathogenic fungi and preserve a favorable soil condition. Photo. 1) is the microphotograph showing the mycelia of Fusarium oxysporum, a sort of plant pathogenic fungi, and when PTB are added to the medium, Streptomyces fradiae, antagonistic to F. oxysporum, multiplies and causes lysis of F. oxysporum and sterilizes it (Photo. 2).

X 800

Photo. 1. F. oxysporum mycelia.

X800

Photo. 2. S. fradiae attacks the mycelia.

Since PTB inoculated on activated sludge and digested sludge grow well when agitated under illumination, removing hydrogen sulfige, amines, and other smelling substances (ex. mercaptan, etc.) present in these sludges, and change those into the useful organic fertilizer, PTB are very excellent for the re-cycling technique of organic wastes.(1 - 4, 8 - 10)
Recently the disposal of sludge has been difficult. The growth inhibition and disease of crops by Fusarium and other plant pathogenic organisms lowers crop yield (11 - 17)
The purification of waste water from industry and the use of microbial cells which are produced during purification might be expected in the future.

DISCUSSION

PTB assimilate carbon dioxide and fix nitrogen using solar energy.(Fig.1)(6 -10) They contribute to the purification of waste water and the suppression of pathogenic virus. And they purify harmful substances (hydrogen sulfide, putrescine, cadaverine, dimethylnitrosamine, etc.)(2,3,5). The microbial cells produced in the purification of waste water are available for plankton, fish and shell-fish. The microbial mass has agricultural value.
Injury to plants due to the occurrence of plant pathogenic microorganism by continuous cultivation is suppressed. They also cause an increase of crop yield. Thus, PTB are important bacteria from standpoint of re-cycling of resources and economy of energy.

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