TECHNOLOGY ASSESSMENT AND RESEARCH PRIORITIES FOR WATER SUPPLY AND SANITATION IN DEVELOPING COUNTRIES

(with special reference to rural populations and small communities)

International Development Research Centre

Ottawa, Canada

22 November, 1973

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ACKNOWLEDGEMENTS

This report could not have been prepared without the assistance and cooperation of many individuals and organizations. Especially we wish to thank those working in the "front line", and grappling with the day-to-day problems of trying to improve the quality of water supply and sanitary conditions in developing countries. We have corresponded with well over a hundred such persons and have benefitted greatly from their ideas and insightful comments on various of our papers and drafts. When you are dealing with situations that are often frustratingly intractable and always complex, it is not an easy task to respond with equanimity to a request for information which comes from thousands of miles distance, and seems to reveal little or no appreciation of local circumstances. Yet our correspondents have shown a remarkable understanding and sympathy with our aims, even though many of them will find that their ideas are not expressed in the way they would approve, and some will wish to disagree strongly with certain of our findings and conclusions.

We are also heavily in debt to the many hosts who welcomed us on site visits, and made our field missions such a valuable learning experience. They supplied information in response to many demanding requests and provided transport and other logistic support in enabling us to visit villages and rural areas. Site visits were made to India and Guatemala (Yves Maystre) Ethiopia, Kenya and

Ghana (Emanuel Idelovitch) and Colombia, Peru, Chile and Argentina (Ian Burton).

The International Bank for Reconstruction and Development, the Pan-American Health Organization, UNICEF, and the United Nations Development Programme provided information or commented on draft papers, as did a number of bilateral agencies for external or overseas aid. The World Health Organization has been extremely helpful in giving access to unpublished information, commenting on draft documents and facilitating contact with environmental health engineers and regional staff throughout the world. To those organizations and to the staff who have often gone out of their way to help we are especially indebted. In addition the World Health Organization International Reference Centers for Community Water Supply (The Hague) and for Wastes Disposal (Dübendorf, Switzerland) have also provided information and comments, and helped us to get our tentative ideas widely reviewed.

Fourteen people including some of the most eminent international experts attended a seminar in Ottawa (August 17-18, 1972) and twenty-three came to a seminar in Lausanne (May 29-June 1, 1973). They gave unstintingly of their advice and time, and in a number of cases prepared helpful background papers upon request. Lists of participants and background papers are given in Appendix 1 of this report.

The School of Environmental Sciences, University of East Anglia, provided a comfortable base with congenial colleagues where Emanuel Idelovitch and Ian Burton worked from September, 1972 to October, 1973. We were accorded all the usual assistance afforded without corresponding demands being made on our time; an unusual priviledge and one that was greatly appreciated.

Finally we wish to express thanks to our own institutions, the Ecole Polytechnique Fédérale de Lausanne, Tahal Engineering Ltd. and the University of Toronto for their willingness to make the unusual arrangements which have facilitated our working together in this venture.

Yves Maystre
Emanuel Idelovitch
Ian Burton

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PREFACE

A clean and adequate supply of water to meet daily needs remains beyond the reach of over a quarter of mankind. According to World Health Organization estimates 77 per cent of the population of 90 developing countries surveyed in 1970 lacked adequate water supplies.[1.] This does not mean that they have no water. Some daily intake of water is essential for continued survival and very few people, even under drought conditions, actually die of thirst. It is the case, however, that in varying degrees and in many different ways, people are forced to rely upon sources that are a constant threat to their health, or which yield insufficient quantities or which are so far removed that hours each day may be spent in obtaining water for household use. In some circumstances all three of these limitations apply simultaneously, and there are few where none of these obtains. For most people in these circumstances there seems little prospect of improvement.

Although comparable data are not available it is known that an even larger proportion of the human family does not have access to the basic means for the safe and sanitary disposal of human wastes. Lack of adequate sanitation can lead to contamination of food and by the contamination of water supplies at their source, or in transport, or in household use, can negate the beneficial effects of hard-won improvements.

These stark and unpalatable facts become increasingly difficult to accept in an age of powerful science and effective technology, and considerable accumulations of wealth. In recognition of these circumstances the Planning Group on Science, Technology and Development established by the Organization for Economic Cooperation and Development asked for a report on the present state-of-the-art in water supply and sanitation and an assessment of how research and development might most effectively contribute to a substantial acceleration in the rate of improvement.

This task was accepted by the International Development Research Centre (Ottawa) which has commissioned the present study and facilitated the work necessary for its execution. In particular the International Development Research Centre provided for the services of two of the present authors, Professor Ian Burton of the University of Toronto and Mr. Emanuel Idelovitch on leave from Tahal Engineering Ltd. In addition Assistance Technique Suisse expressed its willingness to help and provided the consulting services of Professor Yves Maystre of the école polytechnique de Lausanne.

The team started out with a particular inspirational bias. We were asked to focus particularly on the potential role of research and development in science and technology. There are good reasons to do so. For one, research on technologies suited to the needs of developing countries has been neglected. About 98 per cent of all research and development funds are spent in the rich countries, and very little of this has been done with the special circumstances of developing countries in mind. Where such research has been undertaken, as in the support of the Rockefeller and Ford Foundations in developing the new high-yielding food grains, and the work of the International Rice Research Institute in the Philippines in rice cultivation and processing, the results have often been spectacular.

We have partly been engaged, therefore, in a search for the potentially dramatic or fundamental breakthrough, a sort of instant solution. "Just add water...." Whatever illusions we may have harboured of this sort have been largely although not entirely dispelled. It seems most unlikely that any fundamental scientific breakthrough lies just around the corner. While belief in the likely emergence of a panacea is unwarranted we are convinced that important and significant opportunities do exist for technical research and development. This is in contrast to an oft-expressed view in the water industry that "we have all the technology and know-how we need, if only they would give us the money". Further we are convinced that unless an expanded programme of research and development on technology is undertaken forthwith, many hundreds of millions of people will still be without improvements in water supply and sanitation facilities by the end of the century.

We are equally sure however, that an expanded programme of research and development, will by itself, have little effect unless accompanied and followed by a series of other steps which we outline. One conclusion that emerges very forcefully from the experience of the last decade is the multivariate complex interlocking nature of the water supply and sanitation issue. Not only technology and hardware is involved, but a wide range of factors including economic and financial, social and political, behavioral, health science, management and administration, education and manpower. In any one of these areas the full benefits of a 'solution' or an 'improvement' cannot be expected without correspondingly favourable circumstances obtaining in others.

We have been led therefore, into a rather wide interpretation of our mandate, considering not only technology, but also how the technology is related to local needs, and how it is made available. We have been helped in this task in three ways which should briefly be mentioned in this preface.

First we asked to have prepared an annotated bibliography on the major literature in English together with some of the most readily accessible materials in Spanish from Latin America. The bibliography is completed and is being published and distributed by the International Development Research Centre.[2.] It has already been of great help to us and to others.

Second, in view of the breadth of the analysis presented here we have not gone into nearly as much detail as is possible and desirable on individual components of water supply and sanitation systems or items of equipment. These are covered in somewhat greater detail in an unpublished M.Phil. thesis written by Emanuel Idelovitch at the School of Environmental Sciences, University of East Anglia, Norwich, England,[3.] as well as in a long list of other publications either cited in the thesis or listed in the annotated bibliography. It is expected that arrangements will be made for later publication of this material. Even so, much will remain to be done on the assessment and evaluation of technological components.

Third, we have held two working seminars (Ottawa, Canada, 17-18 August, 1972 and Lausanne, Switzerland, May 29-June 1, 1973) for which background papers were prepared and at which the ideas and findings have been discussed. The

Lausanne seminar in particular strengthened the basis of our judgements, and came to an agreement on some research priorities that we have adopted with minor modifications.[4.] The diverse group of specialists that attended the seminars (including economists and engineers, environmental scientists, geographers, medical and health scientists and social and behavioral scientists) was extremely helpful in creating a broad perspective, and in the light of our experience it is a practice that we would recommend.

This report focusses on a broad assessment of the suitability of technology in relation to local or user-needs. It pays little attention to management and economic aspects partly because we have been aware of other efforts in these directions. On the design and management of national water supply and sanitation programmes a study is being prepared for the World Health Organization by Mr. W.E. Wood and has already been circulated in draft form.[5.] We have benefitted from consulting this manuscript. On the financial and economic side, including the question of public health benefits, a study is being prepared for the International Bank for Reconstruction and Development by Professor R.J. Saunders.[6.] We have also had an opportunity to use this document in draft form and have been considerably helped in the development of our thinking.

The first section of this report briefly reviews what is known of the present global situation and likely trends. We then explain the rationale of an approach and the development of criteria for the assessment of technology. These criteria are dependent to a large degree upon the accuracy of the diagnosis we offer. The available sorts of technology are then reviewed in the light of the criteria established, before we proceed to the questions of how the technology is and could be made available.

NOTES TO PREFACE

1. World Health Organization, Twenty-Fifth World Health Assembly. Community Water Supply Programme. Progress Report by the Director-General. Document A 25/29. Geneva. April, 1972. p.4 Table 3.

2. Anne U. White and Chris Sevior, Selected Annotated Bibliography on Rural Water Supply and Sanitation in Developing Countries. (with an introduction by Anne U. White). International Development Research Centre. Ottawa, Canada. Forthcoming.

3. Emanuel Idelovitch, "The Technological Frontier in Rural Water Supply in Developing Countries", Unpublished M.Phil. thesis. School of Environmental Sciences, University of East Anglia, Norwich.

4. "A Note on the Second International Development Research Centre Seminar on Rural Water Supply and Sanitation". Lausanne, Switzerland. May-June, 1973. International Development Research Centre. Ottawa. Unpublished. June, 1973.

5. W.E. Wood, "Rural Water Supply and Sanitation Programmes", Guidelines on the planning of national programmes in developing countries. Unpublished draft report. World Health Organization. 1972.

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SUMMARY AND RECOMMENDATIONS

Significant opportunities for research and development in the technology of water supply and sanitation are found to exist. They include especially the development of roof and ground catchment methods for dispersed rural populations; improved methods of water quality testing in the field; the development of hard-wearing low-cost equipment especially for water lifting and water treatment, and the prevention of pollution and the protection of water sources. Substantial reductions in cost might also be achieved by the development of lower-cost methods of storing water and ways of conserving water in domestic use. A major opportunity exists to develop alternatives to water-borne sewage collection, especially in decomposition methods.

Technical research and development needs to be supported by the collection of information on current successful practice and its evaluation and wide dissemination. Social, scientific, health and engineering experts should be involved in a series of comparative international studies of the impact of on-going programmes, to assess the relationships of water supply and sanitation improvements on health and social and economic development. The available technological choices need to be assembled and ways found of developing user's participation in the choice of technology and the amount of improvement to be sought.

It is recommended that an international initiative be taken to establish a 20 year programme aimed at bringing improved water supply and sanitation to 95 per cent of the population in rural areas by the end of the century. The

20 year programme would be preceded by a 5 year research and development phase under the leadership of a specially created Task Force. The functions of the proposed Task Force would be to guide and coordinate a programme of research and development which would include the following:

1. Technical research and development designed to create new alternatives and to improve existing technology by making it more appropriate to the needs of developing countries.

2. Description and popularization of technological choices for particular habitats in terms and languages suitable for use by sub-professionals and community leaders.

3. Appraisals of recent successes and failures in providing improvements in the urban peripheries and rural areas.

4. Impact studies designed to strengthen knowledge of critical areas in design.

5. The development of techniques for assessing user perceptions and involving the community in the improvement process.

6. Supporting the development of national training and educational programmes and the provision of the sorts of technical information required.

The Task Force would work closely with the World Health Organization and other international agencies, and would have a vital role to play in cultivating an awareness among responsible national leaders of the opportunities and problems presented by the accelerated programme in water supply and sanitation.

Fundamental to the approach would be the adoption of an underlying orientation based on recognition of basic improvements as a right to be claimed rather than an economic good to be purchased. The orientation would also be towards user-participation in a programme of incremental improvements in harmony with community aims and values.

TECHNOLOGY ASSESSMENT AND RESEARCH PRIORITIES FOR WATER SUPPLY AND SANITATION IN DEVELOPING COUNTRIES

(with special reference to rural populations and small communities)

I GLOBAL DIMENSIONS

Of the numerous interactions between man and the natural elements of his environment, none is more intimately expressive of human beliefs and behavior than the ways in which water for daily household needs, is obtained, used and removed. The human ecology of water use has not been subject to detailed and accurate description except in a few localities. Enough is known, however about the range of variations to warrant caution in the formulation of broad global generalizations.

Each time water is drawn from a household tap or a courtyard source; from a pump or standpipe in the street; or from a more distant well or stream, the act expresses a belief and a choice as to what sources of water are appropriate for which purposes: what technology can appropriately be employed, how much expenditure of effort or money is warranted or necessary and the effects that are likely to be felt on health and on social relations in the community and in the household. In many circumstances the choice can also reflect religious convictions or other firmly held attitudes, values and beliefs.

Recognition of the social sensitivity of water use practices should not be allowed to overshadow the technical complexities. The design and operation of systems to supply water and arrange for its subsequent removal must respond to a wide range of other considerations. These include the availability of water as affected by topography, climate and soil conditions, the nature and level of the economy, and the size and distribution of the population group to be served.

Whether the ground is relatively flat or what degree of slope it has affects the amount of pumping required to move water from where it is found to where it is needed. Where groundwater is present at a shallow depth in adequate quantities a much more straightforward situation obtains than when it is absent or deep or confined beneath hard rock layers. Seasonal variability presents severe problems in many sub-tropical regions, where water is abundant for part of the year and scarce the rest. There is also the threat of drought--greater in some climatic regions but a possibility to be considered over very large regions of the developing world.

As far as human use is concerned this is greatly affected by the economy, population density and settlement size. Urban populations with industrial activity varying greatly from rural agricultural or pastoral communities. Four main categories of human settlement useful in relation to water use are:

Cities - Organized urban areas and their satellites including towns of more than 5,000.

Urban peripheries - Disorganized shanty towns, Bidonvilles, barrios and bustees and other "temporary" living areas on the fringes or within organized cities.

Rural-Clustered - Smaller settlements or villages primarily engaged in agriculture and selected pursuits.

Rural-Dispersed - Settlement, primarily for agricultural purposes, of scattered households lacking a central focus or nucleus.

To these others are sometimes added:

Rurban - a category used by Donaldson[1.] to indicate concentrated populations in rural areas having the needs and characteristics of an urban supply.

Nomadic - Settlements that are frequently moved, including those of pastoralists on the desert margins and those of the shifting cultivators in tropical rain forests.

The combination of these many factors of environment and populations is unique at every place.

In the light of this extremely rich diversity of conditions two caveats are important. It would be naive to expect any general, simple and effective solutions to water supply and sanitation problems on a global scale. Moreover, where changes for the better, including even the most obvious improvements, are proposed and imposed from sources external to the community it would be short-sighted in the extreme to assume that such changes will meet with local acceptance and use unless they are designed in the light of sophisticated understanding of local needs and the role which water plays in community and household life. The transfer of technology for water supply and sanitation from a place where it has been successful to a place where it is new, cannot be expected to proceed smoothly unless it is presented in a careful and sensitive way.

Stern and serious as such cautions are they should not be reason for despair or inaction. They do require however, a sober recognition of the dangers of oversimplification and the complexity of the problem. The view from New York or Geneva or even Nairobi or New Delhi can easily lose touch with reality.

PRESENT CONDITIONS AND TRENDS

Attempts to assess the world-wide conditions of water supply and sanitation are of relatively recent origin. It was only in 1959 that the Twelfth World Health Assembly launched a "spearhead" programme to promote the provision of safe water in adequate quantities to communities to communities lacking it. At that time serious shortcomings were known to exist, and the important role of water supply and sanitation in public health was widely accepted. The programme was launched in the absence of estimates of the magnitude of the global deficiencies.

The first estimates were made for the year 1961[2.] and a second set of estimates have been released for 1970.[3.] The 1961 estimates were for 75 developing countries and the 1970 figures relate to 90 developing countries which together account for 44 per cent of the total world population. The major significant omission is China.

Some of the results of these two questionnaire surveys are compared in Figure 1 and are shown together with targets suggested by the World Health Organization for 1980 at the end of the United Nations Second Development Decade. For statistical purposes the population is divided into urban and rural categories according to whatever definition is used in each country. Urban services are grouped according to whether the population 1) has a water connection within the house, 2) must carry water from a public standpipe or 3) neither. Rural dwellers are classified according to whether or not they have "reasonable access to safe water". Lack of detailed and precise information about rural water supplies makes the application of a very specific definition impossible. The guidance given for interpreting the phrase "reasonable access to safe water" is that reasonable access means "when a housewife does not have to spend a disproportionate part of the day in fetching the family's needs for water". Safe water "includes treated surface waters or untreated but uncontaminated water such as from boreholes, protected springs and sanitary wells. Others of doubtful quality will be classified as "unsafe".

The statistics are subject to several sources of error. They underestimate population served insofar as the reporting agency is uninformed as to local conditions or as to the activities of other government agencies. An agency may also consider a user lacks access to water because the agency did not provide the source. The reports overestimate the population served insofar as they assume that once a community system is installed by the builders it is used or operated by the consumers as intended. Many a traveller in a developing country has encountered an unused well or a distribution system where the treatment plant no longer functions. On balance, the statistics probably over-report the community services and under-report the achievements of individuals and informal local groups. For one country they may be far off, but the aggregate is probably moderately near the present situation.

On the basis of these data the World Health Organization concludes that for 90 countries about 70 per cent of the urban population and 12 per cent of the rural population, accounting for one-quarter of their total population are served by improved supplies (Figure 1). The 1970 situation marks a slight increase in proportion of rural population served between 1961 and 1970, after allowing for growth of 32 percent in total population, and a more marked improvement in urban areas.

Change was far more rapid in Latin America than in Africa and Asia. For the total of 26 Latin American nations the proportion of urban users served from house connections and public standpipes increased from 60 per cent to 78 per cent, while the proportion of rural people

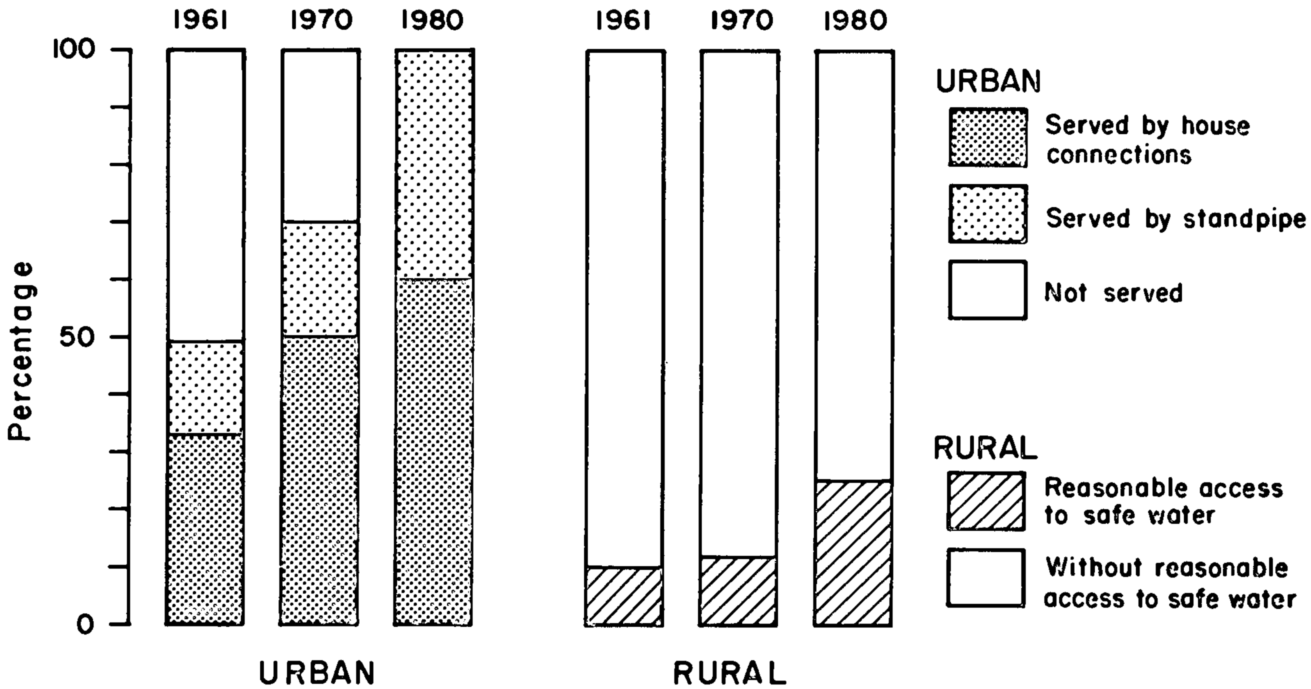

Figure 1 World Health Organization estimates of percentages of populations in developing countries provided with "safe and adequate" water for 1961 (75 countries), 1970 (90 countries) and targets for 1980 (90 countries).

with improved supplies mounted from 7 per cent to 24 per cent.[4]

These data do not permit a more detailed classification by settlement types. It is clear, however, that most of the unserved urban population are in the unorganized "temporary" settlements of the urban peripheries. As Figure 1 makes clear the major outstanding population in need of improved supplies is in the rural areas. It appears that only 12 per cent of the rural population is "adequately served". The distribution of this population among dispersed and concentrated settlements or in small towns of up to about 5,000 people is not known.

Considering what is possible within the Second United Nations Development Decade 1970-80 the World Health Organization has set a target of attempting to double the percentage of those receiving adequate supplies in rural areas. Many would say that the prospects of reaching such a figure are not high. By World Health Organization estimates it will require the design, financing, construction, placing in operation and maintaining of new rural water systems to supply an additional 20 million people each year. By the end of the decade it is hoped that 200 million additional people will have been served at a cost of $2,000 million for construction alone, at an average cost of $14 per capita. Average annual construction costs 1970-80 would be $280 million. This compares with the 1970 level of expenditure for construction estimated at $138 million, to supply 10.6 million people. In other words the 1970 rate needs to be more than doubled if the target is to be achieved.

Despite the ambitiousness of the target and assuming that it can be reached, it is expected that the number of those not served adequately will actually increase from 1,026 million to 1,081 million. (Table 1). The increase is not large in relative terms and given the margin of error that must be allowed in these data they may well imply no significant change. What this means is that in spite of great efforts the problem remaining at the end of the decade will be about the same as it was at the beginning. In at least one respect the problem will be worse. It is a common practice to bring improvements to those communities that are most accessible and most easily served. Hence the unserved population in 1980 is likely to be less easy to reach, and the average cost of supply is likely to be greater.

A linear extrapolation of the progress in the 1961-70 period, and of the 1970-80 programme for rural areas is shown in Figure 2. It is clear that a continuation of the 1961-70 performance would not advance the situation appreciably. The ambitious goal set out for 1980 will, if reached and continued, lead to some improvement for about 50 per cent of the rural population by the year 2000. This forecast depends on a number of unknowns not least of which is the future course of population growth. Nevertheless it seems clear that if those responsible continue to deal with the situation in this decade as they have in the last, the prospect is that by 1980 the people of the world will be little better off in enjoying potable water supplies than they are now. In the longer range view to the year 2000, substantial new efforts will be needed if any radical change is to be brought about. Whether any such change is thought possible depends upon a diagnosis of the obstacles to more rapid improvement and how they might be removed.

Table No. 1

Programme for Rural Water Supply in 90 Developing Countriess 1970 - 1980

(Population in Millions)

Type of Supply	1970		1980		Increase 1970-80	
	No.	Per cent	No.	Per cent	No.	Per cent
Access to safe water	140	12	357	25	217	155
Without access to safe supply	1026	88	1081	75	55	5
Total population	1166	100	1438	100	272	23

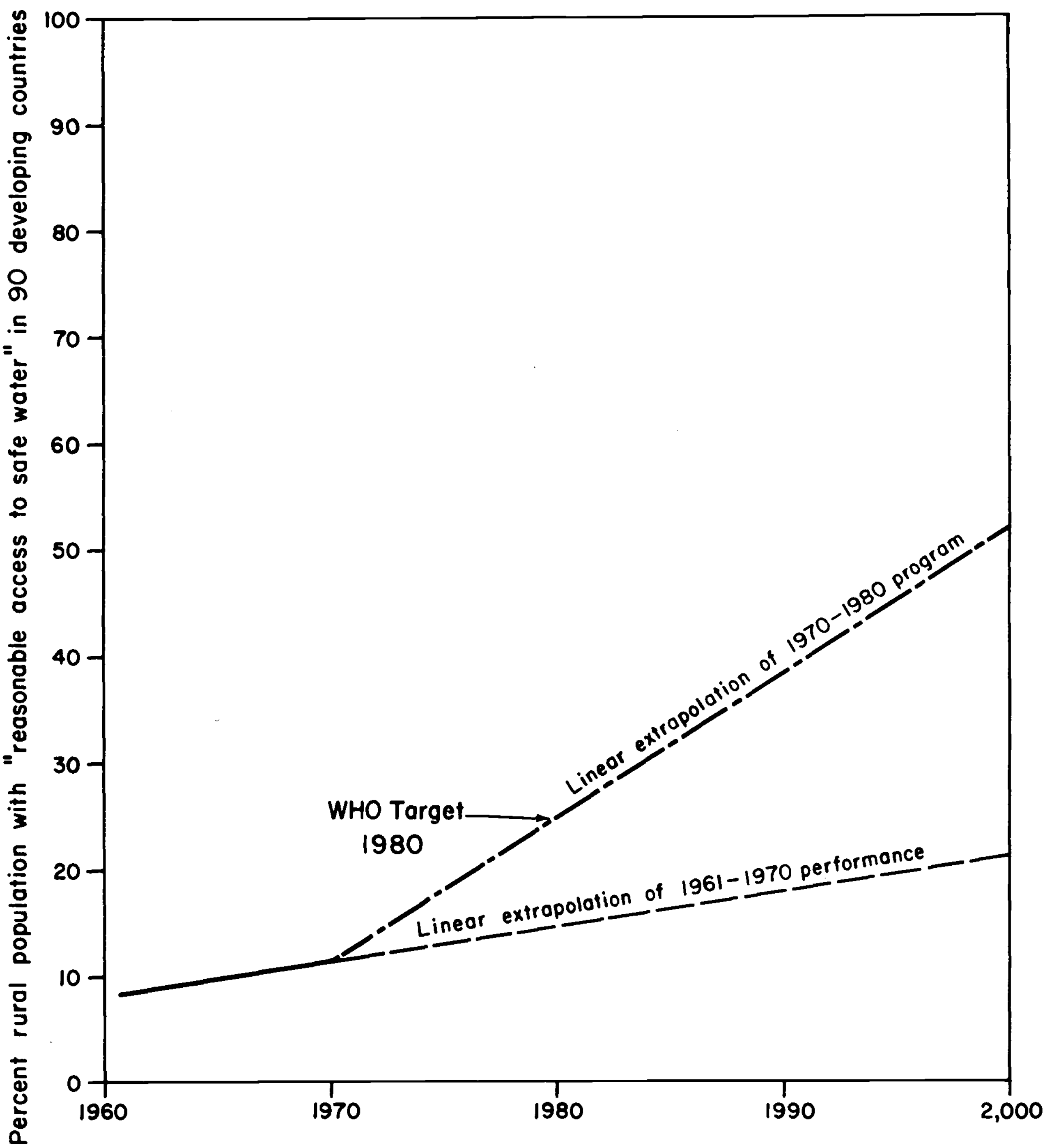

Figure 2 Linear extrapolations of rural populations with "reasonable access to safe water" under 1961-70 performance and 1970-80 programme.

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1. David Donaldson, "Progress in the Rural Water Programmes of Latin America (1961-1971)", Pan American Health Organization, Pan American Sanitary Bureau. Washington, D.C. 1973.

2. Bernd H. Dieterich and John M. Henderson, Urban Water Supply Conditions and Needs in Seventy-Five Developing Countries. Public Health Paper No.23. World Health Organization. Geneva. 1963.

3. World Health Organization, Twenty-Fifth Health Assembly. Community Water Supply Programme. Progress Report of the Director-General. Document A 25/29. Geneva. April, 1972.

4. Donaldson, "Rural Water Programmes".

II A DIAGNOSIS

We have sought evidence to permit a firm diagnosis of the water supply and sanitation problem to be made. We lay claim to having gained a number of valuable insights, but have not come to the point of being able to make definitive pronouncements. The word "diagnosis" is chosen with deliberate intent to reflect that what is displayed here is a "best judgement" rather than a set of proven research results or conclusions. We are not alone in confessing some puzzlement. It is widely shared by experts and experienced personnel. There is no need to be misled by the fact that such uncertainty can often be hidden by strong and categorical assertions to the effect that the problem is essentially one of money, or manpower or organization or that the key factor is political motivation. Pronouncements of this form abound and cover virtually every conceivable explanation. It is likely that they all reflect some truth drawn from experience here and there. Together they do not form a recognizable pattern. It must be admitted that systematic analysis and evaluation of what has been attempted is largely lacking. There has been a natural reluctance to build careful and detailed retrospective evaluations into on-going programmes. Not to do so is to neglect the opportunity to learn from experience in an organized way. There is much that is simply not known about the effectiveness and performance of water supply and sanitation programmes.

Why is it that in so many low income countries the concern of the people to improve the basic amenities of water supply and sanitation has been insufficient to force governments to provide minimal improvements for all? A common assumption is that it is a question of wealth. Only when per capita income rises to some threshold level will it be possible to meet the basic human right to clean water. This explanation is not well supported by the facts. Some countries with substantial gross national product per capita still fall far short of the goal, and others with lower income do substantially better. When the percentage of population served with improved water supply, (rural areas only) and sewerage systems, in 23 Latin American countries is compared with estimates of per capita income a very irregular pattern appears (Figures 3 and 4). Argentina, for example, reports only 16 per cent of its rural population served with improved water supplies, and the highest figure reported for a large nation in Latin America is 46 per cent for Venezuela.

The variation on a global scale would probably be much larger. It is reported, for example, that in the People's Republic of China with a GNP per capita in the region of only $150 the basic needs of a very large proportion of the rural population appear to have been met.[1.] The income argument is not, by itself, convincing. To achieve a satisfactory diagnosis we must look to a range of other "obstacles".

OBSTACLES TO IMPROVEMENT

One simple approach is to review the literature and to ask informed people their opinions. By this action we have arrived at a summary of the most frequently cited obstacles. This accords very closely with a similar list obtained by the World Health Organization from its 1970 questionnaire to 90 developing countries.[2.] Taken together these two sets of information suggest the following list of reasons for failure to make more rapid progress:

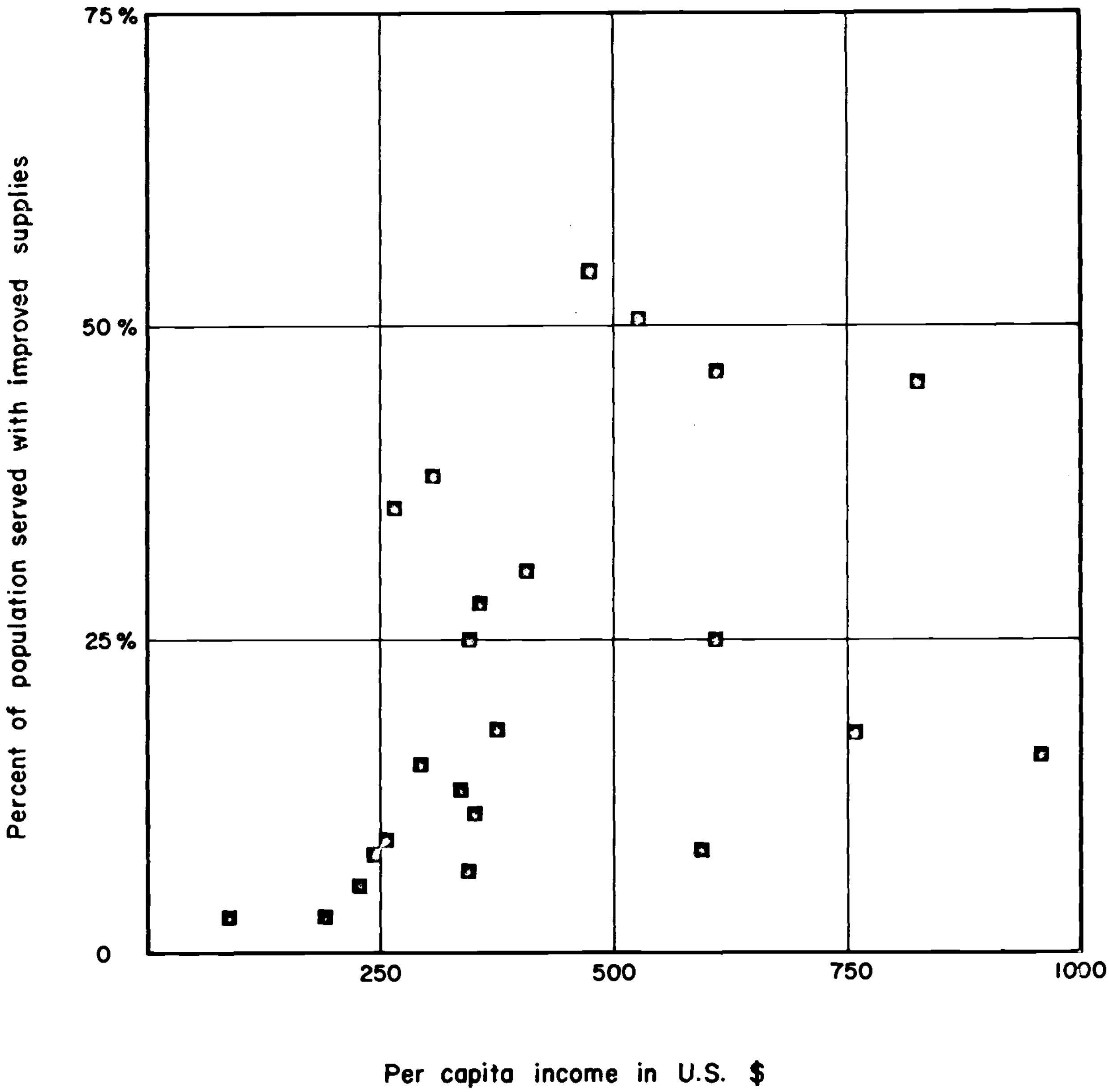

Figure 3 Improved Water Supply in Rural Areas and Per capita income in 23 Latin American Countries.

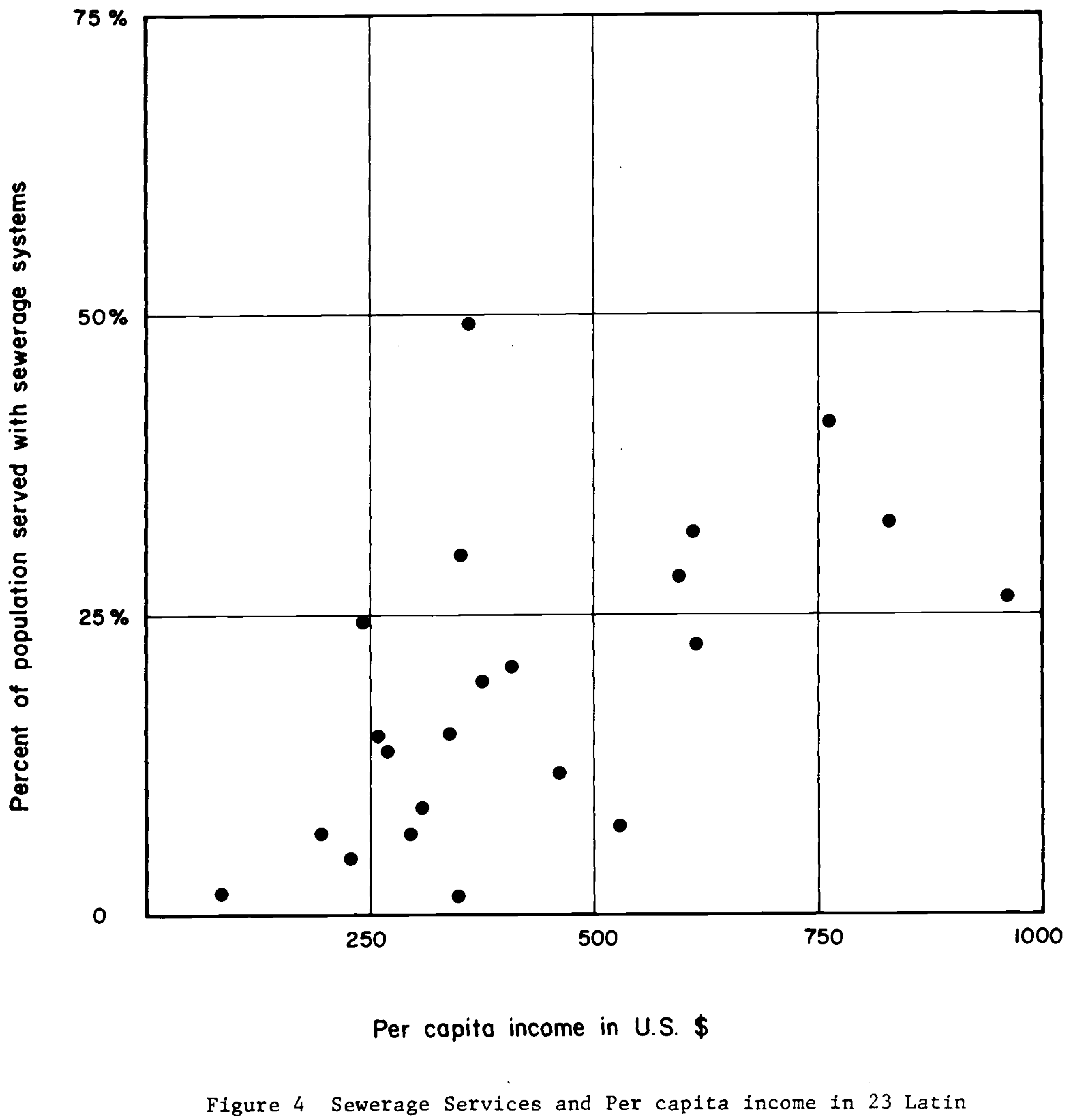

Figure 4 Sewerage Services and Per capita income in 23 Latin American Countries.

1) Insufficient national or internal funds, a lack of national priority.

2) Lack of trained personnel or manpower.

3) Weaknesses in the organization and administration of national programmes, inappropriate administrative structures or the lack of national programmes.

4) Insufficient external funds.

5) Difficulties of operation and maintenance, shortage of supplies, equipment and spare parts and insufficient local production.

6) Inadequate or outmoded legal framework.

All of these reasons can be substantiated with some evidence and shown to be at least partly true for some countries. Certainly efforts to remedy these deficiencies have been and are being made. We are sceptical that such efforts by themselves will be well rewarded, however, because the list of obstacles neglects two aspects of water supply and sanitation that give quite a different perspective. First, a high degree of confidence is implicitly expressed in the expert's view of what is needed and what is best. This seems unwarranted in the light of recent experience, certainly in relation to rural areas. Second, it is assumed that there is little room for technological innovation or improvement and that such an item is of low priority.

The stance that is adopted at the international and often at the national level also, is to the effect that "we have the technology and know-how and we understand what is needed--give us the money and the backing, and we will see that the job is done". Admittedly this is somewhat of a caricature, but it captures the essence of a position that has considerable merit and has proved impressively successful in the industrial nations and in some metropolitan areas in developing countries. It seems unlikely to be successful, however, in rural areas and small communities in the developing countries where the major need is now to be found. It is also less appropriate for the urban peripheries.

The most frequently cited reason for the lack of more rapid progress in achieving water supply and sanitation improvements is the insufficiency of national funds allocated to this end or the lack of priority accorded in national plans. Such an assertion reflects only one aspect of the situation however, and can more accurately be considered in relation to the technology commonly employed. The more costly the engineering methods and equipment used the smaller the number of people that can be served for a given expenditure. Hence a trade-off situation exists between funds available for investment and the cost of the technology. At the present time the technical solutions used are expensive and the available funds are low in relation to the need. Under these circumstances severe limits are imposed upon what can be achieved. The cry for more funds may reflect a judgement that it is easier or more practicable to increased financial resources than to lower the cost of technology.

Reasons for this judgement are not far to seek. Allocation of more funds can seemingly be done quickly at the stroke of a pen. It is known that the available technology works and has brought dramatic improvements in health to large populations and has reflected credit on those responsible for its design and operation in many industrial nations. By comparison research and development of new low-cost technology or an adaptation of existing technology is likely to take more time. Furthermore, it costs money that might otherwise go directly into project planning or capital works. Also the results may be disappointing or negative, hence to direct money to technological research and development is risky, whereas to invest in what is known and tested seems much safer. To risk the development and application of new low-cost technology may threaten the reputation of the innovator and undermine the credibility of field operations. Conventional technology may be inappropriate because it costs too much but adapted low-cost technology may be unacceptable because it lacks prestige and fails to confer a sense of status or importance on the operators and managers. Insofar as low-cost technology is feared to involve a reduction in safety margins or a greater risk of spreading disease, added cause for caution is found.

In spite of these fears many engineers grappling with water supply and sanitation problems in trying circumstances would be anxious to experiment with new techniques and equipment if given more backing and encouragement. Often, however, planning and design operations leave little or no room for innovative approaches. Budgets are tight and allow liitle possibility for experiments that are meant to develop or test new ideas. There is often little more a field engineer can do than pull out his drawer full of standard and conventional techniques knowing that there is an accumulated wealth of experience to back up his decisions, and an international supply of the equipment he will need to purchase.

High cost is not the only way in which technology can be inappropriate. As discussed earlier it should also be compatible with local or user needs. The evidence suggests that much of the technology presently available is not only expensive but also imposes high demands for operation and maintenance on local organization and skills. It is so demanding in these respects that the population in many rural areas is unable to make use of the technology available. When improved systems are built they are subject to frequent failure. We estimate that as many as one third of the village systems constructed in the last two decades are completely inoperative and that another third function defectively. It is not uncommon to see modern water supply systems abandoned while people resort to the traditional methods and sources.

Technology can also be inappropriate if it uses large amounts of capital to perform functions automatically in an economy where capital is scarce and labour is plentiful. It can also require the use of limited amounts of foreign exchange for the purchase of equipment and spare parts when local materials are present that might be developed and put to use, including the development of local manufacturers.

A reason for the allocation of insufficient national funds, therefore, can stem from a concern to use limited resources wisely and not to squander them on extremely expensive technology that will lead to the creation of systems that are difficult to operate and maintain; subject to too frequent collapse; replace local labour with imported machinery and equipment; and serve as a continual drain on foreign exchange without helping to build up local capacities.

Viewed in this light the failure of national governments to accord high priority or to allocate funds in sufficient quantity can be seen as a victory for common sense. Only as more appropriate technology is made widely available and is accepted by both the engineering profession and the users, will substantially larger investment seem warranted.

CRITERIA FOR APPROPRIATE TECHNOLOGY

What criteria would more appropriate technology have to meet? A few of the more important ones have already been suggested. Others relate to the capacity of the local managerial organizations and the needs of the users. The technology should be suitable for local maintennce and operation by relatively unskilled manpower. If it is to be compatible with local values and preferences it probably should be capable of incremental adoption and improvement. Our field experience suggests that difficulties are prone to arise when attempts are made to take a community from an unimproved water supply to a very modern and sophisticated system. It might be better therefore to allow for gradual and incremental change that can proceed at a comfortable pace according to user demand. We confess, however, to considerable uncertainty on this score and think that there is need for research into ways of fitting the technology to local preferences and needs. We have little knowledge or experience of how this might be done.

Another characteristic of observed projects is that they seem to lack a strong diffusion capacity. Improvements that are made in one village with outside help do not spread contagiously to other villages. There are no doubt many good reasons why this is so. It seems however, that a criterion for appropriate technology would be its capacity to produce a contagion effect.

On the basis of this diagnosis ten criteria for the development or selection of technology are suggested. This is by no means an exclusive list, but it contains those which an informed concensus of experienced personnel would accept plus some others that represent our best judgment at this time.

The water supply and sanitation technology chosen (or developed by research) for rural areas and small communities should:

1) Facilitate significant improvement in quality and quantity of service without necessarily seeking to obtain the near-perfect.
2) Be low in cost; as low as possible without jeopardizing the effectiveness of the improvements sought.
3) Facilitate operation and maintenance by local populations and users without demanding a high level of technical skill.
4) Make as much use as possible of locally available materials, and rely as little as possible on imported supplies, spare parts and equipment.
5) Make use of locally available labour, including unskilled labour and not try to replace labour

with capital equipment unless it is clearly imperative to do so, e.g. when local labour is scarce.

6) Encourage the growth of local manufacture to supply the need for equipment and parts, under the leadership of local entrepreneurs.
7) Be compatible with local and user values, attitudes and preferences.
8) Provide opportunity for incremental adoption and step-by-step improvement.
9) Have a capacity for producing a contagion effect and so diffusing to other communities and individuals.
10) Facilitate community involvement and participation.

In the next section we describe existing and needed technology and provide an evaluation in terms of the criteria suggested. The aim is to suggest how research and development might best contribute to the pace of improvement. The subject is large and it would be much easier to write several volumes on the subject than a short report. No claim to exhaustive treatment is made and emphasis is placed primarily on the needs of rural areas. Much of what we report is illustrative rather than definitive, but an attempt has been made to single out certain directions in which research and development gives promise of making a significant contribution.

NOTES TO SECTION II

1. G.F. White, "Domestic Water Supply: Right or Good?", in CIBA Foundation symposium volume, Human Rights in Health. London. Forthcoming.

2. A list of "constraints on progress" is given in the World Health Organization, Twenty-Fifth World Health Assembly. Community Water Supply Programme. Progress Report by the Director-General. Document A 25/29. Geneva. April, 1972.

III WATER SUPPLY

Water supply systems can be divided into four components.

1) Water source and intake
2) Pumping
3) Quality improvement and protection
4) Storage and distribution

All components are not necessarily always present in all systems. Most, however, even the most simple and rudimentary community supplies will have some elements of these major components.

SOURCE AND INTAKE

Water may be withdrawn for human use at any point in the hydrological cycle. (See Figure 5). The technology required for doing so varies greatly from one stage of the cycle to another. Four types of sources may be identified according to the point in the cycle at which water is withdrawn. These are:

i) oceans and atmosphere
ii) rainwater
iii) surface water
iv) groundwater

OCEANS AND ATMOSPHERE

Use of sea water requires desalinization which is technically possible on a large scale. It is a costly process, however, both in capital for the desalinization plant and in operation for the high quantities of energy needed. These limitations mean that for the foreseeable

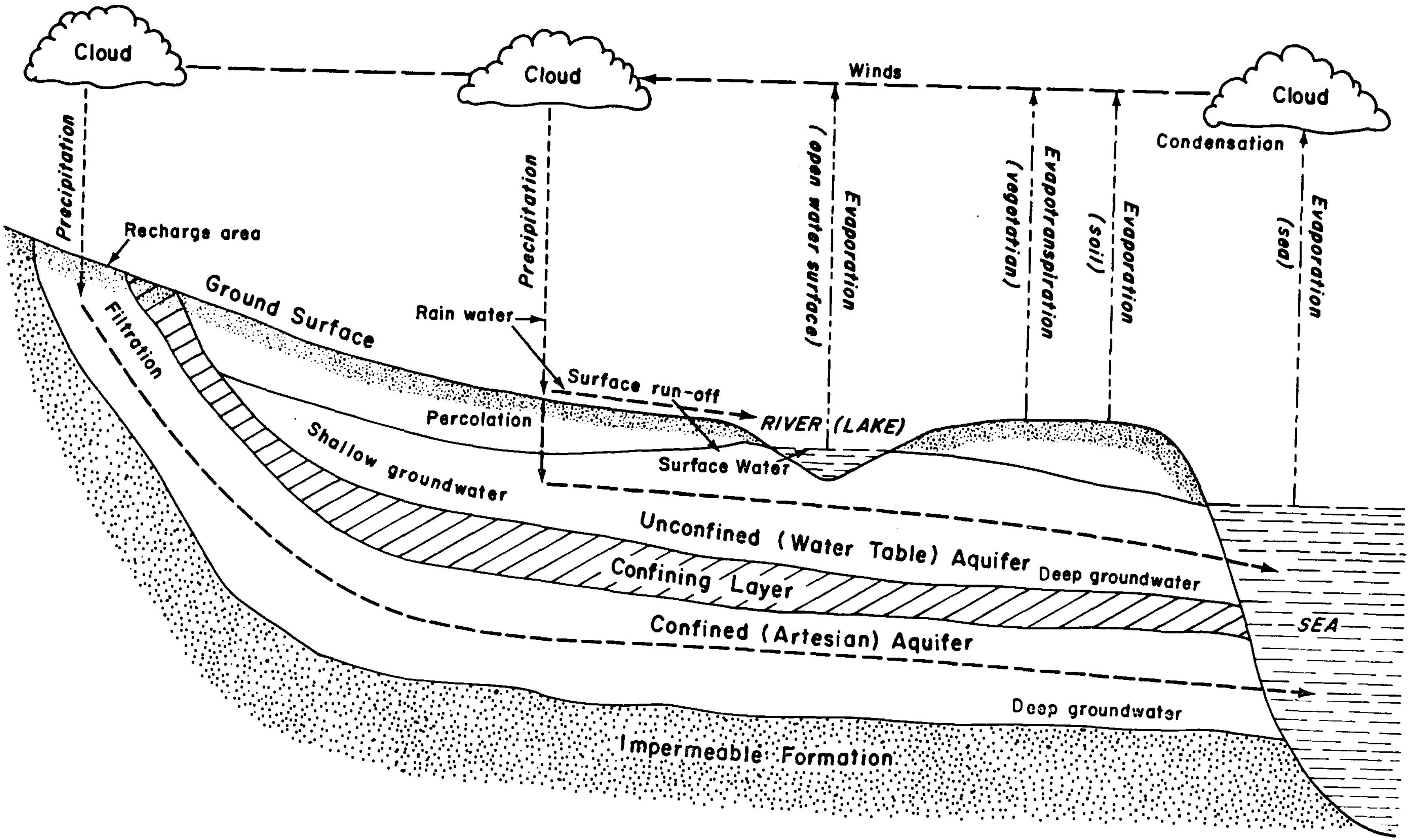

Figure 5 Schematic Diagram of Hydrological Cycle and Water Sources.

future the use of de-salted water is likely to be confined to those users who have no alternative supplies at lower cost and who can meet the high costs. Urban and industrial users in extremely arid environments best qualify, especially in certain Middle East localities where oil revenues permit heavy investments in infrastructure in the building of modern cities. For most of the developing world including especially rural areas, desalinization does not enter the realm of practical consideration. Considerable research and development has been supported into desalinization and continues. This has had the effect of bringing down the price that would have to be paid for water obtained from an economically viable plant. It still remains comparatively high compared with other sources. To the extent that the cost of water from other sources rises and to the extent that desalinization may be achieved more cheaply, there is a prospect of a slow widening of the places and populations for whom desalinization will represent a feasible alternative. There is no widely applicable solution for water supply problems, however, to be found in desalinization.

Water is present in the atmosphere in vapor form and in large quantities. If a cheap and reliable method for "getting water out of the air" could be found the effects would be dramatic. Such a possibility however, appears remote. Condensation units such as some kinds of air conditioning units do yield a quantity of water, but the energy cost per unit of water produced is very high so that such methods don't seem to merit serious consideration except perhaps in extremely unusual circumstances.

The most practicable means for extracting water from the atmosphere is by cloud-seeding. Such techniques can marginally increase rainfall in deficient areas and have been extensively used in the western United States. They have also recently been used in an attempt to offset the effects of the Sahalian drought. As a means of increasing rainfall for agricultural purposes cloud-seeding has been the subject of considerable controversy which still continues[1]. It is not sufficiently reliable for use in the domestic water supply field except as an emergency procedure.

RAINWATER CATCHMENT

An obvious but more neglected source is rainwater. There is only limited scope for municipal supplies except where other alternatives are lacking, usually on islands or isolated peninsulas (e.g. Bermuda, the Bahamas, Gilbraltar). Rainwater could be an extremely important source in rural areas, however and especially so for dispersed populations.

A rainwater catchment scheme, sometimes also referred to as a "percipitation harvesting" scheme, consists of two basic parts: the catchment, where the water is collected and the storage, where the water is kept and drawn upon. In some cases simple treatment may be added such as sand filtration or chlorination. The storage element of the system is either a tank or a well.

There are two distinct types of catchment:

a) Catchment of rainwater before it reaches the ground, generally on house roofs.

b) Catchment of rainwater immediately after it reaches the ground, on a limited, controlled watershed on which the runoff is artificially increased to the point that little or no rainfall escapes into the ground.

Roof Catchment

Roofs made of rigid materials which provide smooth, impervious and clean surfaces are widely used for rain-water catchment. The roofing materials most extensively used are concrete, asbestos-cement, galvanized iron and corrugated iron. In the eastern region of Ghana, for example, many of the larger buildings in villages and scattered settlements which have metallic roofs are fitted with such catchments. The roof is provided with troughs which lead the rainwater to a steel or concrete storage tank by means of a gutter.

This type of catchment is not as widely applied as it might be due to the fact that its main element -the tin roof- is not readily available in many rural areas. Thatched roofs and mixtures of mud and vegetation materials including most wooden roofs are not suitable for rainwater catchment. Some pilot experiments have been carried out in the southern savannah area of Ghana with locally produced clay tile roofs that are cheaper than tin roofs.[2.]

Ground Catchment

A controlled catchment area, protected against external polution and treated so as to increase runoff and eliminate losses, can provide water for supplying domestic needs, mainly in areas of water scarcity. The various types of surface cover of the catchment area in order to increase runoff may be classified into three major groups as follows:

i) Improvement of soil surface, by clearing vegetation and loose material, smoothing and compacting the surface or changing vegetation patterns.

ii) Chemical treatment to reduce soil permeability.

iii) Lining with waterproofing materials including: rigid materials surface-binding treatment or flexible coverings.

A detailed classification and a full discussion of various aspects of rainwater catchment is given by Grover.[3.]

Improvement of Soil Surface: This is the simplest and cheapest method of rainwater catchment. By removing obstructions to runoff, by smoothing and compacting the soil surface or by replacing brush vegetation with grass a considerable increase of runoff can be achieved. The main problem associated with this type of catchment is the water quality, especially as soil erosion will increase. Studies by Lloyd Myers[4.] on gravelly, sandy loam soil near Phoenix, Arizona have shown that by clearing and smoothing a plot to a uniform slope of five per cent runoff increases from 20 per cent to 35 per cent, while experiments carried out by Hillel and associates in Israel[5.] have increased runoff from 5 per cent to 21 per cent on a permeable clay-loam soil having a slope of four per cent.

Chemical Treatment: By these methods, the soil is treated so as to have lower permeability and, thus, to increase the runoff coefficient. Sodium salts, which cause the swelling of the clay in the soil, can be used for this purpose, but erosion is greatly increased and water quality is consequently poor. Another chemical treatment is provided by water-repellent materials which reduce permeability and create hydrophobic soils, such as the sodium methyl silanolate, a material used to waterproof concrete. Experiments carried out by Lloyd Myers[6.] on sandy loam soil with a five per cent slope produced an increase of the overall runoff co-efficient from 76 per cent to 94 per cent.

Lining: Some of the materials that can be used for lining a rainwater catchment surface are: sprayed asphalt, iron sheets, plastic materials and gravel-covered plastic sheets.

Asphalt sprayed on the soil surface has been experimented in various place, especially in the U.S.A., Australia and the Caribbean Islands. The materials found to be suitable for this type of lining are[7]: asphalt hot mix made of sand, gravel and asphalt (about 10 per cent) which is spread at a high temperature and rolled with a hand or mechanical roller; asphalt cold mix made of sand, gravel, portland cement (about 10 per cent) and water, which are mixed together until the cement and aggregate are wet, to which emulsified asphalt is added; asphalt panels consisting of special panels of different sizes, laid and joined together with a cementing material; and cement lining. The major problem related to the use of asphalt for catchment linings is that water is coloured by the asphalt oxidation products and this colour is not removed by common filtration. Research is needed for development of special asphalt or other materials that would prevent or remove development of oxidized asphalt compounds.

Galvanized iron or corrugated iron sheets of the type used for roof catchment can be used on the ground as well, if protected against wind. One large catchment in Gibraltar is covered with corrugated, galvanized iron sheets attached by screws to timber piles and rafters.[8]

The latest developments of plastics have opened new ways for incorporating modern materials into a traditional method of water supply. Plastic materials can be used both for covering the catchment area in order to increase runoff and for sealing underground storage cisterns, to reduce water losses and prevent external pollution. When plastic sheets are used for covering the catchment area, they must be covered (usually by gravel) as a protection against natural damage by sun and wind. The most common plastic materials used for catchment covers are polyethylene, polyvinyl chloride and butyl rubber.

A very simple system for intercepting and storing water for livestock but which could also be used for domestic supply has been developed by Lauritzien and Thayer.[9.] It is referred to as the "raintrap" and it consists of a square plastic sheet for the catchment lining and a storage plastic bag, both made of butyl, a tough synthetic rubber which resists heat and chemicals.

In Ethiopia in the Chilalo sub-province of the Arussi province, about 200 km. south of Addis Ababa, some 40 rainwater catchment systems have been constructed within the CADU rural development programme promoted by the Ministry of Agriculture and consultants from SIDA (Swedish International Development Authority). Annual rainfall in the area is above 1000 mm. in most years.[10.] Water is collected on corrugated iron roofs or on the ground, in controlled areas, grassed or lined with plastic sheet covered by gravel. It is stored in hand-dug wells, about 3m diameter, made of masonry, sealed with clay, plastic sheet or galvanized iron sheet and provided with a wooden cover. Water is withdrawn from the well by rope and bucket or by hand pumps. In some of the roof catchments a barrel filled with sand to half the height was installed on the top of the tank to serve as sand filter for the water flowing from the roof. A roof catchment serves one family whereas a ground catchment can serve several.

Larger catchment systems using plastic materials, mainly polythene, for lining the catchment apron and an interesting system for constructing storage tanks from a special sand-cement mixture shaped in "sausages" was developed in the Sudan by Michael Ionides[11] and an experiment in transferring the method to Botswana has been carried out by the London-based Intermediate Technology Development Group. Descriptions of this method are available from ITDG.[12]

There is considerable merit in rainwater catchment schemes and the methods merit further research and development and dissemination, especially for rural dispersed populations, in semi-arid areas.

Rain water is not bacteriologically pure since raindrops come in contact with dust which contains bacteria, but in rural areas there are usually much less bacteria in the air than in cities. According to Topley and Wilson[13] in a town there are several thousands of organisms per litre of rain, while in the open country there are only about 10 to 20 organisms per litre. Rain water is not exposed to major bacteriological contamination if collected before reaching the ground; the probability of such contamination when rainwater is collected on the ground surface can be reduced by undertaking measures for controlling the catchment area and its surroundings. An exception is the hazard related to contamination by faecal deposition of birds, against which preventive measures must be undertaken.

In terms of the distance of the consumers from the source, in case the scheme is to serve one household, the convenience of supply is very great - similar to that of a single tap house connection. If the scheme serves several households the distance between the consumers and the source would be similar to the case of supply from wells.

The difficulty related to withdrawal of water depends on the type of catchment and storage. In case of roof catchment and tank storage, it merely means the opening of a tap in the tank; in case of ground catchment and some roof catchments where rainwater is stored in underground cisterns or wells the withdrawal of water is identical to that from cisterns or wells.

Rainwater catchment schemes are simple to design, construct and operate. They can be built rapidly and cheaply. They are suitable for construction in stages and in conditions of uncertain initial data on water use. The major technological problem of such schemes is the proper sealing of the catchment and of the storage well to reduce water losses as well as to avoid external pollution.

One important difficulty with roof and ground catchments occurs in areas of pronounced seasonality of rainfall. It is then necessary to construct storage tanks to store enough water to give reasonable assurance of lasting through the dry season. The larger the tank the more expensive the method becomes. Even in areas where the dry season is not so pronounced difficulties arise with proper sealing of the catchment tank to avoid loss through leakage and proper protection to avoid contamination from external pollution.

There are significant opportunities for research and development here. Low cost and reliable methods of collecting and storing rainfall from roof and ground catchments, if available, would permit the extension of the method into more arid areas and increase the reliability of supply. The main problems to be solved include:

1) the provision of suitable low-cost materials for the catchment surface including roofing materials.
2) the design, construction and materials for the storage tank to provide supply through the dry season, to avoid loss through leakage or evaporation

and to protect the water from possible contamination on site.

The little work along these lines that has been done, is not widely known. A modest expansion of effort seems warranted together with efforts to disseminate knowledge of the methods more widely.

SURFACE WATER

The most obvious and readily available supplies of water are those that occur at the surface, either naturally or man-made. Four main kinds are:

a) Ponds and tanks for runoff catchment
b) Rivers and streams
c) Natural lakes and man-made reservoirs
d) Irrigation canals

A pond or tank is a type of surface supply best suited for livestock. Use of ponds and tanks for domestic purposes, however, is not uncommon especially in places where other supplies are intermittent. Rivers and streams as well as lakes and reservoirs may be used directly by riparian residents or others who come to draw water from some distance. They are mainly suitable for piped water supply schemes to concentrated settlements. The scarcity of natural lakes and the high cost and technical skills required for reservoir construction are such that these sources can provide a suitable solution in only a few favoured localities. Small reservoirs formed by the construction of small earth embankments especially on intermittent streams are an exception. Irrigation canals provide a ready source of water in some agricultural areas.

The major types of intakes for use in rural areas and smaller communities are:

i) diversion canals
ii) submerged pipes
iii) diversion dams
iv) pumping stations

More costly and elaborate types of intake such as intake towers, submerged structures and diversion tunnels are appropriate to large scale urban schemes.

If the elevation of a source is such that gravity supply is possible, it would be preferred, other things being equal, to a pumped supply from another source as it simplifies the operation of the system. Many other factors do affect the selection of the water source.

Diversion canals: are open lateral canals of trapezoidal or rectangular section usually provided with gated structures which divert water from a river or from a reservoir into the water supply system.

Submerged pipes: provided with cribs or screened bell mouths are utilized as intakes from rivers or lakes. The cribs can be made of timber and rocks and are usually provided with a screen which prevents large objects from entering the intake.

Diversion dams: are small dams constructed on streams with the purpose of raising water levels in periods of dry-weather flows in order to ensure the necessary water depth for the intake canal or pipe. They also serve as a barrier which prevents the entrance to the intake of flowing obstacles and as silting basins for sediments carried by the stream.

If the supply from a source cannot be assured by gravity flow, a pumping station has to be utilized in combination with the intake. The pumping station may be a fixed structure constructed on the shore of the river or lake or may consist of pumps installed on a floating pontoon. Table 2 illustrates the possible intake types for the various surface water sources:

Table No. 2

Possible Types of Intake for Various

Surface Water Sources

Intake Type / Source	Diversion Canal	Submerged Pipe	Diversion Dam	Pumping Station
River (perennial)	x	x	x	x
Stream (intermittent)	x		x	
Lake (natural)	x	x		x
Reservoir (artificial)	x	x		x
Irrigation Canal	x			x

Surface waters can vary considerably in reliability and convenience of supply. Normally lakes are a permanent source of supply. Perennial rivers are a very good source of supply if the dry-weather flows are large enough for supplying the needs, whereas intermittent streams require impounding reservoirs to store water for that part of the year when they are dry, or alternative sources of water for the dry season. Impounding reservoirs, if properly designed, should provide water in most years, with the exception of those in which precipitation is lower than the design figures. In any event, from point of view of water availability, a reservoir is a more reliable source than the stream which it impounds.

In terms of water availability, runoff ponds present the same major problem as rainfall catchment, i.e. water stored at the end of the rainy season has to supply the needs of the dry season, after allowing for evaporation and seepage losses. The main factors to be considered in the design of a pond in order to ensure permanent water availability are the same as for an artificial impounding reservoir, i.e. the demand curve and the supply curve which determine the water balance in the reservoir. The demand curve can be determined in accordance with best estimates of the water use components that have to be supplied by the pond, considering distance to consumers and availability of other sources in the areas. The supply curve is a function of rainfall, catchment area and runoff co-efficient. Evaporation losses and seepage losses must be accounted for. Good knowledge of the climatic and soil conditions at the pond site and in the surrounding area is necessary. Irrigation canals are a usually reliable source. As irrigation needs are generally much higher than domestic needs, the amounts of water needed for domestic consumption can easily be supplied since part of the irrigation facilities are idle. At peak irrigation periods, the amounts of water needed for domestic consumption are only a small fraction of the irrigation flows and can be supplied either by slightly increasing the system capacity or by providing adequate storage.

No safe generalizations can be made about the convenience of surface supplies or about the level and cost of associated intake technology. Both extend across a wide range.

The major question in relation to surface supplies is water quality. Open and easily subject to contamination, surface supplies are generally viewed as the least desirable from a public health standpoint. It is not easy to protect surface supplies, and although pure and clean streams do exist these are usually confined to small watersheds in upland or mountainous areas. Whereever population density is high, surface waters are likely to be contaminated with sewage bacteria and chemical and physical wastes. It is a common experience moreover that previously high quality surface water is subject to rapid deterioration as population density rises and development occurs. For these reasons surface waters are generally regarded as being "unsafe" until proved "safe". Certainly the risks are high in resorting to the use of untested and untreated surface waters.

Nevertheless this is what many people are obliged to do. A substantial proportion of the estimated 1,026,000,000 people without access to safe water in 1970 use surface supplies, and many are likely to continue to do so for some time. There are three important areas for research in this connection. First, simple and reliable tests of water quality, especially bacteriological quality, are needed that can be carried out in the field with quick results. Such an improved set of techniques, would form part of the programmes of surface water quality surveys or monitoring.

Second, there is little knowledge of how people choose among various sources of water and how they respond to scientific information about water quality or safety. White, Bradley and White have shown in East Africa[14]. that people do discriminate very carefully among available sources of water according to their perceptions of the health effects of various characteristics such as taste, colour and odor, although these perceptions can differ greatly from the advice likely to be produced by a more scientific appraisal. If people are to be assisted in making wise choices among water sources of various qualities it is important to ascertain what preferences exist, how they are formed and then to ask how they can change when subjected to new experience or information. If methods and procedures for such investigations could be developed and tested in comparative studies, it is likely that they would be widely adopted in the development of water supply schemes and would contribute significantly to the prospects of success.

A third area of research that is suggested by the surface water situation is methods of low-cost treatment. This is considered below in the section on quality improvement and protection.

GROUNDWATER

Where groundwater is present at a shallow depth it is often the ideal source of water in villages and small communities. It is often of high quality and if suitably protected from surface contamination a good supply can be provided easily without complex or costly technology. Deep groundwater shares in the same characteristics except that there can be more confidence in the quality, and that greater costs are involved in its exploitation since it has to be lifted further, and may be harder to reach especially if an impermeable layer has to be penetrated as in the case of confined aquifers.

Groundwater is a relatively reliable source. Caution needs to be exercised, however, to sensure that the safe yield of the aquifer is not overdrawn. In this case the level of the groundwater table may fall and wells may run dry. Water table levels are also sensitive to seasonal climatic variations and shallow wells may dry out in drought periods. Deep groundwater is a more reliable source and is not normally affected by seasonal climatic changes.

Of all the alternative sources of water for domestic supply, deep groundwater provides the best quality water; in most cases it is potable without treatment. The good bacteriological quality of groundwater is due to the filtering action provided by the soil layers through which it must pass, and to the lack of oxygen and nutrients which makes it an unfavourable media for the multiplication of pathogenic bacteria. As a result of slow filtration through the soil, the physical quality of groundwater is also good; deep groundwater is generally colourless and of low turbidity. The chemical quality of groundwater varies, in accordance with the minerals found in the area, which are dissolved during the water movement through the soil. In some cases the mineral content of water affects water palatability and may also occasionally present a health hazard.

The water quality of shallow aquifers is poorer than that of deep aquifers, as filtration time through soil layers is shorter, and danger of external pollution is greater, for example, from excreta disposal systems. However, if properly constructed so as to be protected against bacterial contamination, systems based on shallow well water are adequate for supplying domestic needs.

In terms of distance to consumers, groundwater is general and shallow aquifers in particular are convenient sources of supply as they are suitable to construction in small units, well distributed among consumers. The difficulty in withdrawing water depends on the depth from ground surface, with the exception of springs which are natural outcrops of groundwater at the ground surface.

For the withdrawal of water from shallow groundwater hand methods for constructing wells and easily operated lifting devices are available. Development of deep groundwater is a technical enterprise which requires careful planning, skilled implementation and cautious supervision by specially trained manpower.

The most common systems for withdrawing water from aquifers are:

i) infiltration galleries for shallow aquifers
ii) spring collection
iii) shallow or deep wells, according to the depth of the aquifer.

A brief description of infiltration galleries and springs is followed by a more detailed discussion on wells.

Infiltration Galleries

An infiltration gallery is an almost horizontal well collecting water from a shallow aquifer over its entire length. Such galleries are generally located near the banks of rivers or lakes and are constructed by digging a trench or tunnel into the water-bearing soil or rock.

Water is collected in a perforated pipe or gallery which leads to a central casing from which it is pumped out. The walls of the infiltration galleries may be lined with masonry or porous concrete. A type of infiltration gallery extensively used in Iran for both irrigation and domestic purposes is the "ghanat" which consists of a tunnel constructed into a water-bearing stratum.

Springs

Springs are outcrops of groundwater emerging at surface as water holes or wet spots; they can be of two types--gravity springs, which occur when groundwater flows over an impervious layer onto the ground surface, and artesian springs, which occur when water from a permeable formation confined between two impermeable layers rises under pressure to ground surface.

Being of shallow groundwater origin, gravity springs present the same problems as shallow wells from the point of view of water quality and contamination possibilities, while artesian springs have generally better quality, similar to deep groundwater. However, any type of spring collection and storage of water should be protected against possible contamination. Water from springs can be collected by a basin intercepting the source or by a system of collection canals or pipes and a storage tank. Provisions can be made for preventing surface water from entering the tank by means of diversion ditches, and when possible, by covering the storage tank; for cleaning the storage tank; and for overflow. The walls of the basin or tank are constructed from reinforced concrete in the upper part and from stone or brick in the lower part where water enters the tank, supported by gravel and sand which reduce the movement of fine material into the tank.

Wells

Wells are among the oldest, most common and most effective intakes for ground water. Simple hand dug wells generally have a large diameter-- one meter or more from which water can be withdrawn by rudimentary lifting devices or by hand pumps.

In addition to the traditional hand-dug well there are also tubewells and boreholes. Tubewells consist of perforated pipes introduced into shallow aquifers by boring, jetting or driving. Small diameter tubewells may be provided with hand pumps, whereas large diameter tubewells are usually fitted with mechanical pumps. Boreholes are a more complex type of construction consisting of small diameter pipes drilled into deep aquifers by specially manufactured drilling equipment. The two main drilling methods are rotary (or hydraulic rotary) and percussion (or cable-tool percussion). A classification of well types is given in Table 3.

Hand dug wells. Hand dug wells can provide a reliable and safe supply of water in areas of shallow ground-water, and provided that they are adequately lined and protected from surface in-flow. The construction of hand dug wells is relatively simple, though slow, and can usually be carried out by unskilled labour using locally available materials. Lining materials consist of masonry, brickwork, concrete or reinforced concrete. A detailed description of a method for construction of hand dug wells as utilized in northern Nigeria is given in Wagner and Lanoix.[15]

Table No. 3

A Classification of Well-Types

and Aquifer Types

Well Type			Aquifer Type		
	Construction Method	Diameter	Shallow Groundwater Non-Artesian Aquifer	Deep Groundwater Non-Artesian Aquifer	Artesian Aquifer
<u>Shallow Wells</u>					
Hand-dug Wells	Digging	Large	x		
Tube-wells	Boring Driving Jetting	Small	x		
<u>Deep Wells</u>					
Boreholes	Drilling	Small		x	x

Tubewells.

Bored wells: Boring of small diameter tubewells can be carried out in soft formations by means of a simple instrument-hand augur-up to depths of about 50 feet. The hand augur consists of a shaft provided with a bit with blades at the bottom and with a wooden handle at the top. If any small stones are to be encountered during the boring, a spiral augur has to be used instead of the normal cutting bit.[16.] The method is simple and requires little skill but its use is limited to certain depths.

A simple method for tubewell boring utilizing bamboo pipes and unskilled labour which has been used in Bangladesh is referred to as the "sludger method".[17.]

Driven wells: By this method, a well-point fitted to the lower end of a pipe is sunk into the aquifer by a hammer or another driving tool. This type of well is limited in use to unconsolidated formations, relatively free of stones, and boulders. The maximum depth that can be reached is about 30 feet if driving is done by hand, and 50 feet if a machine is used. Diameters are between 1" and 4".

Jetted wells: Tubewells can be drilled by using the force of a water jet to loosen the materials and to move them upwards. The efficiency of the method can be increased by using a drill bit which can be both rotated and moved vertically. This method is suitable for sandy formations; depths of about 50 feet can be reached easily.

Boreholes:

Rotary Drilling: In the rotary drilling methods, a rotating bit is used for cutting the borehole, whereas a continuously circulated fluid (water or air) is used for removing the cuttings simultaneously. A rotary drilling rig consists of a derrick or mast to hold the drilling equipment, a hoist, a power-operated revolving table to rotate the drill stem and the drill bit, a pump for forcing the drilling fluid via a hose and a swivel to the drilling stem and bit, and a power unit or engine.

Percussion drilling: In the percussion (or cable-tool) drilling, a heavy bit is raised and dropped in the borehole to loosen and penetrate the soil, and cuttings are removed periodically by means of a bailer, or another similar tool. Tools for drilling and bailing are carried on separate cables. A cable tool (percussion) drilling rig consists of a power unit for driving the reels carrying the drilling cable and the bailing cable, a spudding beam for imparting the drilling motion to the drill tools; all mounted on a frame which carries a derrick or mast of suitable height for the use of a string of drilling tools.

Boreholes, also referred to as "drilled wells", constructed by any of the two methods described above, require skill and experience, as well as specialized manufactured equipment, and are, therefore, less suitable. However, if shallow groundwater or surface water are not available, the need for drilling deep boreholes becomes imminent and a suitable drilling contractor has to be employed for carrying out the job. Drilling is known as a field in which failure has often occurred due to lack of experience or knowledge of local conditions of the drilling contractors. A careful study of the previous experience of the contractors is needed in order to make a proper selection and to reduce the risk of failure.

It is possible to combine hand-dug wells with boreholes for the exploitation of deep, artesian groundwater [18]. A large diameter well is sunk by hand to a certain depth, then a borehole is drilled from the bottom of the well to the aquifer; water will rise from the aquifer to the hand-dug well which serves as storage reservoir.

The main characteristics of the various types of wells and their suitability to rural areas in terms of construction and maintenance difficulty, cost, use of unskilled labour and local materials, etc., is illustrated in Table No.4 for typical conditions of developing countries. It should be stressed that some of these characteristics depend to a large extent on the particular conditions of a certain area and the assessment should be regarded as illustrative only.

A wide range of methods is available for gaining access to groundwater Those most adapted to conditions in rural areas are most applicable in conditions where shallow groundwater supplies are available. Good methods for digging shallow wells by hand are in use in many places, but elsewhere there is ignorance of proper techniques. Information regarding methods in currently successful practice should be collected, evaluated and distributed widely.

Table No. 4

An Illustrative Assessment of the Main Characteristics of Well Types

Well Type / Characteristic	Hand-dug Wells	Tubewells			Drilled Boreholes	
		Bored	Driven	Jetted	Percussion	Rotary
Maximum depth (meters) under average conditions	30	30	15	30	300	300
Diameter	3-20'	2-30"	1¼-2"	4-12"	4-19"	4-24"
Geological Formations	Clay, silt, sand, gravel, boulders, soft sandstone, soft and fractured limestone	Same as for hand-dug wells but boulders smaller than well diameter	Clay, silt, sand, fine gravel, thin layers of sandstone	Clay, silt, sand, ¼" pea gravel	Clay, silt, sand gravel, boulders in firm bedding, sandstone, limestone igneous rock	Same as percussion but more difficult in boulders
Cost	Low	Moderate	Moderate	Moderate	High	High
Construction	Simple	Simple	Simple	Relatively Simple	Difficult	Difficult
Maintenance	Simple	Relatively Simple			Difficult	Difficult
Advantages	Use of local unskilled labour; suitable for rudimentary lifting methods as well as for pumps	Can be fitted with either hand pumps or mechanical pumps			Suitable for large depths, rapid construction in any soil formation including impermeable rock	
Disadvantages	Exposed to contamination; limited depth	Limited depth	Limited depth, limited mainly to unconsolidated soil formation	Limited depth and soil formation; low efficiency	Require specialized skill and experience; especially manufactured equipment of high cost, mostly in foreign currency.	

Source: Manual of Individual Water Supply Systems, U.S.

SUMMARY OF RESEARCH NEEDS

Methods of obtaining water from atmospheres and oceans do not appear well situated to the needs of rural areas in developing countries, with few exeeptions. Research in these areas is likely to be pressed forward in developed countries and no special effort with the needs of developing countries in mind seems warranted.

Roof and ground catchment methods are especially suited for suited for dispersed populations, and a high pay-off seems possible from modest research expenditures. Research is needed on the development of suitable low-cost materials for the catchment surface including roofing materials. Attention is also needed to the design, construction and materials for storage facilities.

In relation to surface waters research is needed as improved methods of water quality testing in the field. This is related to a need to understand the formation of user-preferences and how they can change in the face of new experience or information, not only in relation to surface waters but for all available water sources.

Good methods for gaining access to ground supplies are in use in many places, including digging shallow wells by hand. Elsewhere the knowledge is not widely available. The need here is primarily for the collection of information on methods in current successful practice, evaluation and wide dissemination.

PUMPING AND LIFTING

Since water cannot always be supplied by gravity, an important part of the system consists of the pumping facilities or other methods of water lifting. Water supply systems based on groundwater withdrawn by wells usually incorporate well pumps.[19] Systems based on surface water sources may include a pumping station, in many cases. This may be located next to the intake, before any treatment facilities, as a "raw water pumping station" or it may be placed after the treatment plant, a "clean water pumping station". If pumping from the source to the distribution system is done in two separate stages, there is usually a "low-lift pumping station" and a "high-lift pumping station". When utilized for increasing pressure in a certain zone of the distribution system, under conditions of irregular topography or for supplying water to an elevated storage tank, the pumping station is referred to as "auxiliary" or "booster pumping station".

Since in rural water supplies, the major use of pumps is in conjunction with wells, the review of pump types concentrates mainly on well pumps, most of which may be used for surface water pumping stations, also.

A CLASSIFICATION OF WELL PUMPS[20,21]

The most common classification of pumps is that based on the mechanical principles involved in its operation, but from a practical point of view another important classification is that based on the limited suction lift. For the purpose of this study, a combination of the two classifications is made, with emphasis on the most common types of pumps used in rural water supplies. According to the mechanical principles involved, pumps can be classified into two main types:

- constant displacement pumps or positive displacement pumps, or, simply, displacement pumps.
- variable displacement pumps referred to also as velocity pumps.

The constant displacement pumps are those which discharge the same volume of water regardless of the pressure head against which they operate; the power required is, however, directly proportional to the pressure in the system. The variable displacement pumps are characterized by an inverse relationship between the discharge rates and the pressure head against which they operate, i.e., the pumping rate increases as the pressure head decreases and vice-versa.

According to the suction lift, pumps are classified into:

- surface-type pumps, which are placed at or above ground surface, and
- deep well pumps, which are placed within the well.[22.]

In order to appreciate this classification the term suction lift and its implications have to be made clear. A pump has to perform two operations: to lift water from a low level to the pump intake (suction section) and then force the water in the pump to its final destination (delivery section). The original water level in the well referred to as the "static water level" is exposed to the atmosphere and the pressure on its surface is, thus, the atmospheric pressure. In order to lift water from the static water level of the well to the pump intake through the "suction pipe", a pressure below atmospheric pressure has to be applied by the pump. Water will then rise within the suction pipe above the original water level to a level called "suction lift". At the same time, water level in the well will be drawn down to a level called "dynamic water level". Theoretically a pump can create within the suction pipe an absolute pressure of zero (total vacuum) and therefore the suction lift is that which corresponds to the atmospheric pressure, i.e., 34 feet of water at sea level and slightly less at higher altitudes. However, from a practical point of view, there are losses in the suction pipe as well as other efficiency factors which reduce the suction lift to an average of 15 to 20 feet and a maximum of 25 feet. The last figure is usually taken as the limiting suction lift for surface-type pumps. If groundwater depths exceed 25 feet below ground surface the pump has to be lowered within the well. Surface type pumps are, thus, used mainly for shallow wells in which groundwater depths are less than 25 feet, whereas deep-well pumps are used for wells in which groundwater depths exceed 25 feet.

The constant displacement pumps may be divided into three types:

- <u>reciprocating or piston pumps</u>
- <u>rotary pumps</u>
- <u>helical or spiral rotor pumps</u>

In addition there are many rudimentary lifting devices that can be classified with constant displacement pumps.

These "rudimentary devices" refer to all the simple, elementary types such as the rope and bucket, the chain bucket, the beam and bucket, which are mainly used in shallow wells. The reciprocating or piston pumps are the most common type of pump and are used as both surface type pumps and deep well pumps. The rotary pumps are usually surface-type pumps, whereas the helical rotor type is mainly used for deep wells.

The variable displacement pumps are of two major types which will also be described further: jet pumps and centrifugal pumps. Jet pumps are in fact a combination of surface-type centrifugal pumps and ejectors to lift water from greater depths than it would be possible without ejectors. Although possible, the use of jet pumps in shallow wells is unlikely, and, from a practical point of view, they may be considered deep-well pumps. The centrifugal pumps are the type of largest use, both in groundwater wells and for surface water pumping. They are of two types: volute pumps and turbine pumps. The volute pumps are commonly used in surface type pumps where pump size is not a limiting factor and design heads are low. The turbine pumps are more suitable for deep wells where the pump diameter is limited by the diameter of the well casing.

Deep-well pumps in general may also be classified in accordance with the position of their power source, into:

- vertical lineshaft pumps, when the power source is located at or above the ground surface, the transmission being done by a long vertical shaft connecting the motor with the pump, and
- Submersible pumps, when the electric motor is fitted immediately below the pump and is therefore submerged in the water.

Although this classification applies theoretically to all types of deep-well pumps, it mainly refers to the centrifugal turbine pumps. The other types of deep-well pumps are, generally, either unlikely to be used with submersible motors (reciprocating or jet pumps) or used exclusively with submersible motors (helical rotor pumps).

Based on the above classifications and comments, it is considered useful to base the pump classification for rural water supply, first on the "suction lift" criteria classifying pumps into shallow well (or surface type) and deep well, and, then, on the mechanical criteria. Such a classification is shown in Figure 6. The air lift pump, which is operated by a compressor is a special type of pump which, due to its high cost and low efficiency, is unlikely to provide a suitable solution for rural water supply and is, therefore, excluded from this classification.

DESCRIPTION OF PUMP TYPES

The following is a brief description of the principles involved in the operation of each type of pump.

Rudimentary Lifting Devices

All simple, rudimentary types of pumps, operated by man or animal power are included under this heading. The most common types are:

The rope and bucket type: in which water is withdrawn from the well by a bucket attached to a rope which is rolled around a pulley or a windlass. In one system two pulley wheels and two buckets may be used to increase efficiency.[23]

The chain bucket type: in which a series of buckets attached to a vertical revolving chain are raised and emptied when reaching the top.[24]

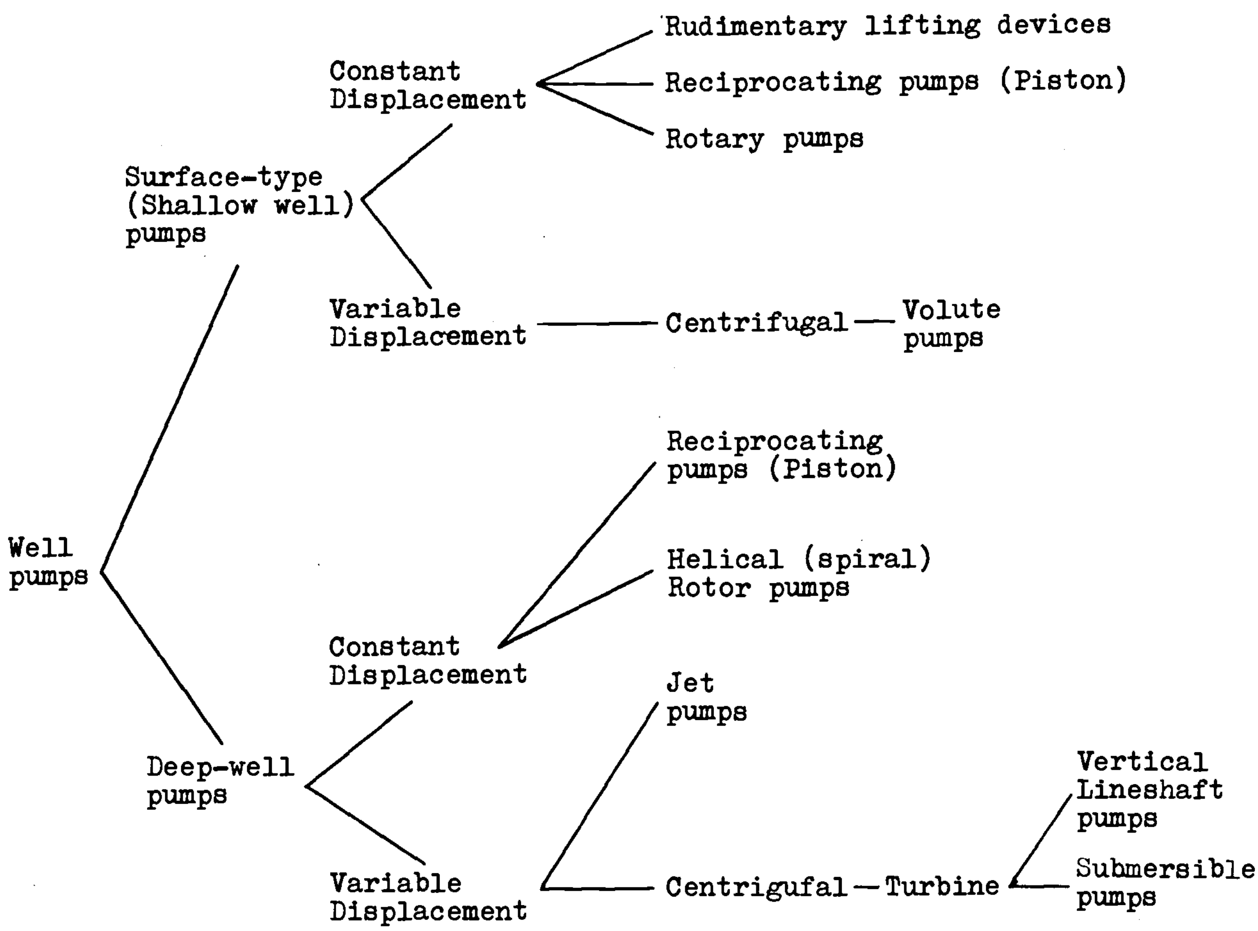

Figure 6 A Classification of Well Pumps.

The beam and bucket type: consisting of a post or tree and a swinging beam provided with a rope or rod and a bucket at one end and a counter weight made of clay, stone or wood at the other end (the shaduf is of the same type).

Water wheels: consisting of a wheel provided with buckets raised by a flowing stream or by man or animals. Some simple water lifting methods still in use for domestic, livestock or irrigation supply are the Indian Dall and Mot.[25.]

The Indian Dall: consisting of a swinging beam and a trough hinged at one end above a canal and with the lower end into the water of a stream; when the beam raises the trough, a valve is closed and water is discharged into the canal.

The Indian Mot: Water is raised in a large leather or canvas bag, of nearly 20 gallons capacity, by means of two bullocks that walk away from the well down an inclined track; at the lower end of the track, the operator pulls a cord by which the water on reaching the surface, is discharged into a trough.

The syphon: which can be used for withdrawing water from shallow wells located on a slope. It can raise water to a height of 20-25 feet, if it is then led to a point which is much below the original water level.

Detailed descriptions and illustrations of these devices as well as many other water lifting methods are given by Bjorling[26.] in a series of articles published in 1902, and in 1956 by Molenaar[27.] in a Food and Agriculture Organization paper in connection with irrigation.

Reciprocating Pumps

These pumps are operated by the movement back and forth of a piston or a plunger which displaces water in a cylinder, the flow being controlled by check valves. The piston can be driven by hand, animal, wind or power. Because of its simplicity it is the most widely used type of pump in small rural water supplies. In a shallow-well type, the cylinder together with the pump body are located above the ground; in the deep-well type, the cylinder is submerged below the water level in the well.

Rotary Pumps

This type of pump is operated by a system of rotating gears which create a suction at one side and force the water out at the other side (discharge side). A common pump of this type is referred to as the semi-rotary hand operated pump which can raise water to suction lifts of a maximum of 20 feet.

Helical (Spiral) Rotor Pumps

This pump is a modification of the rotary pump and consists of a metal rotor or screen which rotates excentrically within a stator provided with cavities, through which water is pushed out. At the same time water serves as a lubricant between the rotor and the stator.

Centrifugal Pumps

Centrifugal pumps are based on the well known principle of the centrifugal force which is exemplified by the swinging of a bucket of water in a circle at the end of a rope. The pump consists of a rotating impeller mounted on a shaft and turned by a power source and a casing into which water is discharged and which converts its velocity head (kinetic energy) into pressure head. There are two types of centrifugal pumps - volute and turbine - which differ from one another mainly in the way the velocity head is converted into pressure head.

In a volute pump the impeller is located in a spiral casing; the flow is radial, the velocity of water being gradually reduced while pressure increases.
In a turbine pump the impeller is surrounded by diffuser vanes which provide gradually enlarging passages, through which water passes at gradually reduced velocities and increasing pressure heads. The turbine pumps usually consist of a number of stages installed on a shaft which is rotated by the power unit. The general flow direction is parallel to the pump shaft.

THE HYDRAULIC RAM

Most types of well pumps previously described and mainly the centrifugal pumps are also utilized for other purposes such as pumping of surface water or raising pressure in the distribution system. In addition there are other pump types used in water supply, one of which - the hydraulic ram - can be used efficiently in small rural water supplies, if the topographical conditions are suitable and the capacity of the water source exceeds the water need. The supply source has to be located above the pump level, the power being obtained from the water hammer produced by the water fall. The force of the water is captured in a chamber where air is compressed and released when the compressed air expands, pushing a small amount of the water to a higher elevation than that from which the water originated. At each compression and decompression of air in the chamber a certain quantity of water is raised up, the rest being wasted.

POWER SOURCES FOR PUMPS

The possible sources of power for pumps are:

- man and animal
- wind
- internal combustion engines
- electricity

An interesting idea of using heat energy from sunlight for operating a shaduf instead of manpower was suggested by Murrow.[28] It is based on the principle of the "drinking bird" toy, scaled up to perform low-lift pumping for irrigation or domestic purposes.

Man and Animal Power

This is the oldest source of power and, in some places, the only available one. It provides an intermittent supply, which may be complemented by storage provisions. The upper limit for manpower use is a discharge of 10 gpm and a head of 20 feet. The major problem of hand-operated pumps repeatedly used by a variety of people is their maintenance.

Wind Power

It is a very cheap source of power, when feasible. It requires a wind speed of at least 5 miles per hour during 60 per cent of the time. Towers 15 to 20 feet high are generally used for increasing wind availability to the mill. It is a suitable system for wells that can be pumped during many hours. Storage capacity for several days must be provided to assure the supply against the risk of calm periods with no wind. Windmills are usually used for the reciprocating type of pumps, the piston rod being extended upwards to connect the pump with the windmill. Windmills are usually produced by manufacturers and imported by developing countries.

Internal Combustion Engines (gasoline, diesel, kerosene)

These are used when electricity and wind are not available, but they are expensive and difficult to maintain. Diesel engines are in general the most adequate power source within this group; although relatively expensive in initial cost, their operation and maintenance costs are low and service lifetime is large.

Electricity

Electricity is the safest source of power since it provides a continuous and controlled source of supply, but it is not always available in rural areas of developing countries. Electric generators require skilled operation and trained maintenance personnel which is generally scarce in such areas.

ASSESSMENT AND RESEARCH

A preliminary listing of some characteristics of various types of pumps is provided in Tables 5 and 6. Pumps are assessed according to performance data, initial cost, operation and maintenance, power sources and general advantages and disadvantages.

A wide range of pumps and lifting devices is available, to suit a variety of water source conditions and levels of need. Evaluation and assessment of such technology, except on the general basis presented here, is lacking. We have the impression that field engineers often have too much theoretical choice available and little to guide them in the choice. Perhaps this accounts in part for the case of the Rajasthan pumps as reported by a World Health Organization-United Nations International Children's Emergency Fund enquiry into rural water supply:

"The hand pump programme in Rajasthan has not been a notable success. None of the four hand pumps observed in the villages of Sapetia and Palari were in working order even though the installations were in some cases only a few weeks old. The first casualty was usually the

Table No. 5

Main Characteristics and Assessment of Shallow-Well (Surface-Type) Pumps and Lifting Devices

Pump Type / Main Characteristics	Constant Displacement			Variable Displacement
	Rudimentary Lifting Devices	Reciprocating Pumps	Rotary Pumps	Centrifugal Volute Pumps
Well depth Pumping head Capacity Efficiency	Low Low Max. 15 gpm Low	20-25 ft. 100-200 ft. 2-25 gpm 25-60%	22 ft. 50-250 ft. Good	10-20 ft. 100-150 ft. 25-500 gpm 50-85%
Cost	Low	Low	Moderate	Moderate
Operation	Very simple	Simple	Relatively simple	Relatively simple
Maintenance	Easy and simple	Easy, does not require skilled attention		Relatively easy, but requires skilled attention
Power source	Man, animal, wind	Man, animal, wind, combustion engine, electric motor		Combustion engine, electric motor.
Advantages	Simple to design and construct. Easy to operate and maintain	Suitable for hand operation		Reliable service life. Wide range of capacities and heads.
Disadvantages	Low efficiency Limited use	Short service life of plunger and valves. Low efficiency. Use limited to low capacities and moderate to high head		Unsuitable for hand or animal power
Remarks		Lower capacities and haads with hand or animal power, higher limits attainable with wind or motor power.	The hand operated type is commonly referred to as the "semi-rotary hand pump" and is used for low lifts only	High efficiency for capacities above 50 gpm

Table No. 6

Main Characteristics and Assessment of Deep Well Pumps

Pump Type / Main Characteristics	Constant Displacement		Variable Displacement		
	Reciprocating pump	Helical Rotor pumps	Jet pumps	Centrifugal Turbine	
				Vertical Lineshaft pumps	Submersible pumps
Well Depth Pumping Head Capacity Efficiency	Max 600 ft. Max 600 ft. 2-25 gpm 25-60%	50-500 ft. 100-500 ft. Good	25-150 ft. 80-150 ft. 5-125 gpm 40-60%	50-300 ft. 100-800 ft. 25-5000 gpm 65-80%	50-400 ft. 50-400 ft. 25-5000 gpm 65-80%
Cost	Moderate	Moderate	Moderate	High	High
Operation Maintenance	Simple Relatively easy; difficulties arise because cylinder is placed within the well		Relatively simple Easy	Difficult Difficult; requires careful, skilled attention	Difficult Very difficult; requires careful skilled attention
Power Source	Man, animal, wind, combustion engine, electric motor	Combustion engine	Combustion engine, electric motor	Combustion engine, electric motor	Combustion engine, electric motor
Advantages	Suitable for hand operation	Good efficiency	Moving parts above ground. Adaptable to use in wells down to 2" diameter	Reliable service life. Wide range of capacities & heads. Good efficiency.	Wide range of capacities & heads. Good efficiency.
Disadvantages	Short service life of plungers and valves. Low efficience. Use limited to low capacities.	Short service life	Air intrusion stops pumping	Requires careful lubrication and adjustment of shaft	Motor and pump have to be removed from well for repairs. Uncertain service life.
Remarks	Operated by 1 man: 1.5 gpm, 100 ft. Operated by 2 men: 4 gpm, 100 ft.		Common jet pumps are limited in use to capacities of 25 gpm. Ejector nozzle should be covered by at least 5 ft. of water.		

steel pump handle, which could after some delay be repaired by welding. With the failure of the cylinder, however, for whatever reason, the pump is abandoned and the protective well cover is reopened with return to the old reliable bucket.

The pumps furnished by United Nations International Children's Emergency Fund for this project are from a reliable English manufacturer, but they are of relatively light construction and were never intended for the heavy duty to which they are subjected at a public well in Rajasthan. During the emergency in Bihar and Uttar Pradesh (1968) a number of these pumps were transferred to that project. The report of the World Health Organisation consultant for the emergency well drilling project made note of the fact that the pumps were totally unsuitable and that failures occurred after one week of operation."

With the long experience that India has had in hand pumps, including the development of indigenous heavy duty types, an occurrence of this type is indeed surprising. It is in fact difficult to divine why imported pumps has to be used in this programme.[29.]

Experiences of this type have helped stimulate research and development for the improvement of pumps. While some progress has been made the world is still without a hard-wearing, long-lasting, easily-repaired, locally-manufactured, hand pump. Volunteers for International Technical Assistance (VITA) provides details for the construction of an "inertia hand pump" and handle mechanisms for hand pumps in general.[30.] Experiments are undertaken by SIDA in Ethiopia for the local manufacturing of special handle mechanisms for animal operated pumps as well as for hand pumps. A hand pump has been developed in Ghana by the University of Kumasi, and an evaluation study of shallow-well hand pumps has been carried out in India by the All India Institute of Hygiene and Public Health with the sponsorship of the World Health Organization.[32.]

A major operation for the development of a reciprocating hand pump for either shallow or deep wells was undertaken by the Batelle Institute sponsored by the Agency for International Development (AID)[33.] and the pump has already been constructed in Bangladesh[34.] and Nigeria.[35.] This research is important and merits fuller support and the wide dissemination of results.

An important need in the pumping and lifting component of water supply systems is for evolution of current equipment and practice. The World Health Organization proposal to prepare a guide or handbook for hand pumps is a step in this direction. More than a description of models and their specifications is needed. In the matter of pumps (and in other areas of water supply technology) it is desirable to conduct field tests and evaluations, and to combine this with information on current successful practice. Such information should be evaluated and then distributed widely. Social, scientific and engineering experts should be involved in the investigations and evaluations. The research should include publication of simply-written and well-illustrated handbooks which should also be translated into languages of the likely users.

QUALITY IMPROVEMENT AND PROTECTION

In order to transform raw water into potable water conforming usually with quality requirements, some treatment processes are required. Treatment is generally carried out for health reasons in order to remove harmful bacteria or dangerous substances and for aesthetic reasons, in order to make the water palatable.[36] In some cases treatment may be carried out for economic reasons, such as water softening, or for other special purposes. The treatment processes to be carried out for a certain water supply system depend on the raw water source and its quality, on the quality requirements for the treated water, and on local conditions and economic possibilities.

Since treatment affects physical, chemical and biological properties of the water, it is necessary to relate these properties to the effects of the various treatment processes in use. This is followed by a description of the treatment processes applicable to rural areas.

Water quality may be obtained not only by water treatment, i.e. corrective measures, but also, and preferably, by preventive measures for the sanitary protection of water sources, which are also described.

EFFECT OF TREATMENT PROCESSES ON PROPERTIES OF WATER

The effect of the most common treatment processes on the physical, chemical and biological properties of water are shown in quantitative terms in Table 7.

Fair, Geyer and Okun[37] have analysed the effectiveness of various treatment processes in more quantitative terms, indicating the positive effect as well as the adverse effect of each treatment operation on quality characteristics. Their analysis points out clearly that the bacteriological quality of the water is mainly affected by filtration and by chlorination, and that slow-sand

Table No. 7

Effect of Treatment Processes on Properties of Water

	Properties of Water		
Treatment Process	Physical	Chemical	Biological
1. Boiling	Changes taste	-	Destroys pathogenic organisms
2. Straining (screening)	Removes large impurities	-	-
3. Microstaining	Removes algae	-	Removes some micro-organisms
4. Plain sedimentation	Reduces turbidity & colour	-	Reduces number of bacteria
5. Aeration	Controls taste and odour	Precipitate iron & manganese; expels carbon dioxide	-
6. Coagulation and Floculation	Reduces turbidity & colour	-	Reduces number of bacteria
7. Filtration	Reduces turbidity & colour	Removes iron & manganese	Reduces greatly number of bacteria
8. Disinfection (mainly chlorination) (a)	Destroys some taste and odour-producing compounds	Oxidates iron, manganese and hydrogen sulfide	Reduces greatly number of bacteria
9. Treatment for other purposes (b)	Improvement of some physical properties	Improvements or change of some chemical properties	-

(a) Other disinfectants used on limited scale are ozone, iodine and bromine.

(b) There are some 50 chemicals used in about 20 treatment processes, with various purposes directed at improving mainly physical and chemical characteristics of water. Example: activated carbon for algae control, colour removal and taste and odour control; calcium hydroxide or lime $Ca(OH)_2$ for softening, colour removal, corrosion control, iron and manganese removal, pH adjustment and coagulation; sodium carbonate or soda ash ($Na_2 CO_3$) for softening, corrosion control and pH adjustment.

filtration is the single process with the greatest range of effects on water properties.

DESCRIPTION OF MAIN TREATMENT PROCESSES[38.39].

Plain Sedimentation

This is the process by which suspended particles settle by natural gravity, while water is retained in a natural or artificial basin. Plain sedimentation is very efficient in reducing turbidity of surface waters, containing large amounts of suspended matter, mainly coarse materials such as sand and silt. For sedimentation of fine clay colloidal matter an excessive amount of time would be needed which makes plain sedimentation not practical. Plain sedimentation also reduces the total number of bacteria in water simply by storing the water because the bacteria die off faster than they multiply in a water environment. Other functions of the plain sedimentation are that it improves the colour of the water and that the settling basin can also serve as a storage reservoir. Provision is usually made for the removal of the sludge deposited in the basin. The most common settling basins are rectangular; their simplest and cheapest construction is by excavation without lining or by an earth dam which forms an impounding basin.

Sand Filtration

In this process, physical, chemical and biological characteristics of water are improved by passing water through layers of sand. The process of sand filtration is very complex, involving straining, sedimentation, absorption, oxidation, electrical effects and biological action. As a result, large particles together with small suspended particles are removed, mainly at the surface of the sand and in the upper layers. A thin gelatinous layer referred to as Schmutzdecke is formed on the sand surface and it is there that most biological and chemical processes occur. There are two types of sand filters - slow sand filters in which water flows by gravity at a slow rate and the main purifying action is obtained by absorption on the surface layer, and rapid sand filters which are designed to operate at a much higher rate and are more suitable for water that has already passed some pre-treatment such as coagulation and sedimentation. The rapid sand filters can be of two types: gravity filters in which the water flow is by gravity, and pressure filters which can filter pumped water up to a pressure of about 10 atmospheres without dissipating the pressure.

Slow Sand Filters:[40.] Slow-sand filters were extensively used in water treatment in the nineteenth century, but in the twentieth century the rapid filters became increasingly popular. The main advantages of the slow-sand filters are the following:

- they are easy to construct and operate
- they improve all characteristics of water and give efficient bacteriological improvement (up to 99 per cent reduction of total bacterial count and of E. Coli)
- they can be used either as single treatment processes in combination with plain sedimentation and chlorination.

The disadvantages of slow-sand filters are the following:

- they require a large area, a large structure and large volumes of sand, which might make their initial cost high, mainly in areas where land is costly.

- they cannot be used efficiently for water of high turbidity (more than about 50 ppm)
- they require a considerable amount of labour for cleaning, since most of it is in general done manually.

For rural areas of developing countries it seems to be the most suitable single treatment process for surface water and a very efficient treatment process when combined with chlorination (and sedimentation, if necessary). The materials suitable for constructing the filter walls are masonry, brick or concrete (if vertical) or puddled clay protected by some lining (if sloping). The shape of the filter box can be circular or rectangular. A drainage system is provided below the sand layers in order to support the sand and to evacuate the filtered water. This can be made of porous or perforated pipes of concrete or burnt clay, bricks or concrete slabs. Operation and cleaning of the filter have to carried out carefully and timely, otherwise the filter bed can provide a favourable media for bacteria growing.

In the absence of suitable quality sand other materials might be used. For example the use of local materials mainly coconut husks and rice husks, for constructing simple and inexpensive filters, has been investigated by Frankel at the Asian Institute of Technology in Bangkok.[41]

Several types of simple filters, among which a cloth filter, have been experimented by Mann in Uganda.[42]

Aeration

This is the process whereby water is put into contact with air and as a result of which tastes, odour and undesirable gases such as hydrogen sulphide are removed; oxygen from the atmosphere is added and serves in removing iron and manganese. There are two basic types of aerators: those forming drops of water which are exposed to the atmosphere, among which are spray, waterfalls and cascade aerators; and diffused air aerators forming bubbles of air which rise in the water. The spray aerators are the most effective ones, since they consist of nozzles which produce a fine spray, and therfore, the total surface area of the drops in contact with the atmosphere is very large. Waterfall aerators consist of several steps or traps, usually perforated with small holes, through which water is passed. Cascade aerators which are less effective than the other types, consist of small baffles which direct the flow so as to create many criss-cross currents in order to increase the surface which comes in contact with the air. Diffused-air aerators consist of perforated pipes or porous tubes placed within a basin which release bubbles of compressed air rising through the water. If aeration is carried out after filtration, it should be followed by chlorination, since during aeration water is exposed to contamination with bacteria found in the air.

Chlorination

Chlorination is the most common method of water disinfection, carried out mainly for bacteriological purification of water. The chlorine is toxic, but it is used in such concentration that it kills most pathogenic bacteria in water without affecting man. The danger of chlorine overdosage which would be dangerous to man is controlled by the taste given to water. At dangerous concentrations the taste of chorine is so strong that water will be unacceptable for drinking. Chlorine is very active and reacts rapidly with organic and inorganic matter found in water. Effective chlorination has to provide a dose of chlorine suitable for making the reactions possible in the specific water to be disinfected and to leave enough residual free chlorine for bacteriological purposes. The chlorine residual is usually checked by means of the orthotolidine test in which the yellow colour indicates the presence of residual chlorine; the amount of residual chlorine can be determined by colour standards. A residual chlorine of 0.5 ppm after a period of 30 minutes is considered sufficient for disinfection purposes. The minimum period of contact should be 10 to 15 minutes. The common chlorine compounds in use are sodium hypochlorite solution and bleaching powder or chloride of lime. Simple equipment for feeding chlorine solutions is available; feeders are generally made of ceramic, glass, rubber or plastic materials in order to avoid corrosion produced by the hypochlorite solutions. According to Cox[43]. chlorination as the only treatment process is limited to water with

- moderate and uniform bacteriological pollution
- turbidity not exceeding 5 to 10 units
- iron and manganese content not exceeding 0.3 ppm
- relatively constant chlorine demand to permit adjustment of chlorine dose
- no taste and odour-producing substances.

There should also be a contact period of at least 15 minutes between the point of chlorination and the house connection of the consumer first supplied. When chlorination is carried out prior to filtration, it is referred to as prechlorination, and when it comes after filtration as postchlorination. The prechlorination can be done in wells, sedimentation basins or raw water tanks. High chlorine doses can be applied (5.0 ppm or more), the period of contact can be of several hours and thus the disinfection can be very efficacious. Postchlorination is done in filter plants or in clear water tanks. It has the advantage of requiring less chlorine and constant doses since water had already been filtered.

Pot chlorination: A simple method for chlorination of well water is that based on the use of a sealed porous pot containing chlorine which is lowered into the well.[44.] Powdered chlorine of lime may be used in which case water from the well enters through the porous sides of the pot, forms the solution with the powder and diffuses chlorine into the water. When liquid chlorine is used, the pot walls are provided with holes, through which the liquid will pass, or two pots one inside the other can be used, or slotted pipes can be used instead of pots. Variants of this system have been experimented and used in Bulgaria, India and Iran.

Other Disinfection Methods

The various disinfection methods available may be classified into three groups.[45.]

Physical methods: These include: heat, sound, and ultra-violet light. Boiling is one of the most popular sterilization methods in cases of disease outbreaks, which destroys very efficiently pathogenic bacteria. Ultrasonic vibrations and ultraviolet light have a lethal effect on bacteria, which is very effective if combined with heat treatment.[46.]

Physico-Chemical methods: These include: treatment with carbon dioxide under pressure and heat; and storing of water in vessels lined with cement containing radioactive minerals or concentrates (which might be dangerous to health).

Chemical methods: including:

i) halogens (chlorine, bromine, iodine)

ii) ozone

iii) metals

Chlorination is the most popular method which has the disadvantage of the bad taste it leaves in the water. It has already been described in the previous section. Bromine does not leave any taste in the water but has high costs and presents handling problems. Iodine is sometimes used for disinfection of swimming pool water but its use as drinking-water disinfectant is limited to emergency cases, because of the high costs involved and the danger of toxicity.[47]

The ozone is a very effective sterilizer which may be generated in situ; its destruction of bacteria is seven times more rapid than that of chlorine. However, it is costly and requires skilled operation.

Based on the idea that Phoenician and Greek ships used water vessels made of silver because water did not putrefy in them, the "Katadyn" process has been developed based on the bacterioidal activity of silver and the "Cumasin" process based on the sterilizing of silver ions.[48]

At the household level, the possible methods of disinfection are: boiling, use of tincture of iodine, potassium permanganate and commercial tablets based on chlorine or iodine. The use of these methods is usually limited to the cases of natural disasters such as large-scale disease outbreaks or earthquakes.

ASSESSMENT AND RESEARCH

A wide range of processes is available for improving or conserving the quality of water. These range from such actions as boiling or hygienic transport and storage at the household level to complex methods of treatment designed to remove bacteria and chemical substances.

The more complex and expensive methods are inappropriate for many rural areas. The most practical choices include sanitary protection of sources and a limited number of low-cost treatment processes.

The difficulties of water treatment operations as observed in Thailand may be cited as an example of the problems that can arise:

"Laboratory equipment was not available for daily or weekly jar tests to determine proper chemical doses; operators were not sufficiently trained to perform or understand coagulation jar tests results; chemicals were expensive and operators often tried to cut back on chemical use to reduce water treatment costs; chemicals ran short and ordering in advance or obtaining additional chemical deliveries on time was not always a simple task in distant communities; without proper dosages the chemical coagulation-sedimentation portions of the plant operated ineffectively with the result that turbidity loads were almost entirely handled by the rapid-sand filters; understanding of why or when to backwash the rapid-sand filter was generally not known; proper sizing of sand was often overlooked during construction in some areas; good sand was difficult to obtain; and lack of sufficient operating funds often curtailed use of chemicals and limited plant operation to 4 to

6 hours per day of discontinuous production."[49].

These difficulties suggest that the more simple and straightforward methods of water treatment might work better in many situations. There has been a tendency, however, in developing countries to adopt the fashionable methods of chemical treatment and rapid sand filtration. In many instances it would be preferable to build or retain slow sand filtration. It is the single process with the greatest range of effects on water properties and achieves good results with high reliability by a method that is simple to construct and operate. The major disadvantages of slow sand filters, high space and labour requirements, are less crucial in many developing countries and can indeed be an advantage.

Where suitable qualities of sand are not available it is possible to develop and use other local materials. The experimental work conducted by Frankel at the Asian Institute of Technology in testing coconut fibre and burnt rice husks exemplifies what is possible. Further work along these lines should be encouraged.

It is also possible that changes in the design and construction of water treatment facilities including filtration could considerably lower the cost. Research by Ingeniero George Arboleda at the Pan-American Health Organization research centre in Lima (CEPIS) on a simplified design for urban water supply treatment plants could profitably be extended into the smaller scale plants required for rural communities.

In addition to the cost and operational difficulties of treatment methods some encounter resistance among the users. Outstanding in this category is the consumers' opposition to chlorination. At a rural water supply undertaking observed in Chile in May 1973 the chlorinator was found to have been disconnected. The operator explained that it was more than his life was worth to continue chlorination in the face of consumer opposition! There is need for investigation of alternatives to traditional chlorination for the disinfection of rural water supplies, such as iodinization and fixed-bed chlorination.

SANITARY PROTECTION OF WATER SOURCES

In view of the difficulties encountered in water treatment much can be achieved by protection of water sources.

Since pathogenic bacteria that cause water-borne diseases do not originate in water, but are rapidly spread by it, the importance of avoiding contamination of water with human or animal excreta cannot be over-emphasized. This represents indeed the major danger of pollution in rural areas of developing countries, comparable with the danger of pollution by industrial wastes in urban areas of industrialized countries.

The importance of adequate sanitary protection of the sources of supply is stressed by the following facts:

1) Preventive measures are easier to undertake than curative or treatment measures.

2) Water treatment is expensive, requires skill and permanent attention,[50.] and cannot remove all bacteria from water but only a certain proportion from the amount found in raw water.

3) Even if treatment is provided and the quality of the effluent water supervised, chemical and bacteriological examination of the water can only be intermittent; the danger of contamination may thus exist irrespective of the periodic results of chemical and bacteriological tests. As a result, a water source which is not properly protected from a sanitary point of view cannot be considered entirely suitable.[51.]

The sanitary protection of a water source should be regarded as a synthesis between two types of measures:

1) Physical, technical measures, undertaken at the initial construction stage and during maintenance of the system.
2) Social, educational measures for avoiding pollution of the sources by the local population.

Physical measures alone without the support of the consumers will not suffice, while educational campaigns without any technical protection measures will not be efficient.

<u>Surface Water Sources</u>

The protection of a river or a lake is not an easy operation since it should extend over the entire catchment area. External sources of pollution have to be detected and eliminated; soil erosion has to be reduced by reforestation; shallow pools have to be drained out in order to prevent algae growth, taste and odour; and, most of all, the watershed has to be protected from human or animal excreta deposition. This is usually done by a complete sanitary survey of the catchment area, which involves study of the surrounding settlements, the agricultural land, forests, relief, soil composition, underlying rocks, etc.

Some of the conditions a sanitary catchment area should fulfil are the following:[52]

- the watershed should be uninhabited by either man or animals and uncultivated if possible.
- the excreta from man or animal in neighbouring areas or within the watershed, if inhabited, should be disposed so as to prevent contamination of water.
- If the area is cultivated, strict control of artificial substances (fertilizers, etc.) added to the land and of organic matter should be exercised.
- the possibility of underground contamination by means of underground channels carrying water from remote bodies of water should be checked.

Groundwater Sources

Protection of groundwater sources is, generally, easier than that of surface sources, as the area affecting the source is more limited.

In locating a well, the sanitary inspection of the area should consider some of the following factors:[53]

- distance of well from nearby buildings and possible sources of contamination.
- relative heights of water level in the well and level of possible sources of contamination (latrines, etc.).
- slope of ground surface and water table gradient.
- surface drainage around the well.
- lining of the well.
- covering of the well, and
- method of water lifting from the well.

Abandoned wells should be sealed as they provide openings through which surface water may flow into the ground water aquifer, without the filtration which takes place in the process of slow percolation.

Some of the important points to be given attention in the construction of wells are the following:

- casing should continue above ground.
- an apron or platform should be provided around the well.

The well protection can be viewed as consisting of: horizontal measures i.e., ensuring a minimum distance from the possible sources of contamination, and vertical measures which include: the siting of the well at the highest topographical level or, at least, higher than possible sources of pollution; casing at adequate depth and above ground surface; grouting if necessary.

The sanitary survey of a spring should include:[54].

- investigation of the origin of the aquifer from which the spring originates.
- nature of the water-bearing strata.
- topography and vegetation around the spring.

A spring is considered well protected when any surface water has to pass through a minimum of 10 feet of soil before reaching the groundwater, when no man or animal inhabits at a distance of less than 100 to 300 feet from the collection point, and when it is provided with a ditch for diverting surface runoff.

ASSESSMENT AND RESEARCH

Except for sealed pump installations there is frequently severe pollution of ponds and wells by the disposal (often inadvertent) of wastes into the water, or by the use of contaminated receptacles and other means. Studies are needed of the best and most effective means of preventing pollution of water sources, coupled with steps to inform the users about the need for protection and to elicite their cooperation. This implies field studies and evaluation of present methods by groups including social, engineering, economic and health scientists.

STORAGE AND DISTRIBUTION

STORAGE FUNCTIONS

The basic functions of a storage reservoir in a rural water supply system can be divided into two major groups:

"operating" or "equalizing" functions, which include:

a) Supplying the peak demand, when demand exceeds supply.

b) Ensuring the necessary pressure in the whole or part of the distribution system.

"Emergency" functions, which include:

a) Supplying water during breakdown of the system.

b) Supplying water during normal maintenance periods.

c) Supplying water for fire-fighting.

Storage has also a purifying effect on water, as pathogenic bacteria die off faster than they multiply in a water environment.[55.] In areas of water scarcity where water conservation is a major concern, the importance of constructing waterproof reservoirs cannot be over-emphasised.[56.]

STORAGE CAPACITY

It is considered that for small rural water supply systems such as those envisaged within the scope of this study, i.e., simple, low-cost systems which can be easily operated and maintained by the local population, the second group of functions (those for emergency periods) must not be totally fulfilled by storage reservoirs. This may considerably reduce the cost of the storage component and consequently reduce the cost of the whole system, of which storage may be a significant part.

Breakdown Emergency: A common breakdown, mainly in case of ground water supply, may occur in the pump or in the power operating the pump. In simple systems such as rudimentary lifting devices, hand pumps or animal-operated pumps, when such a breakdown occurs, it should be possible to repair it rapidly using local materials and skill. A breakdown of the power source (man or animal) is unlikely to occur, and when it does, replacement can be done immediately.

Maintenance Periods: Maintenance activities for simple, manual systems might have to be undertaken more often than for sophisticated, mechanical systems, but they would be shorter and would consist of simple operations which can be carried out by local, unskilled people. They can be more easily adapted to suit the consumption pattern, i.e., may be performed during the night or during low-consumption daytime.

Fire-fighting: Provisions for fire protection considerably increase a water supply system as they imply not only larger storage capacities, but also larger distribution mains, higher pressure in the distribution system and fire equipment. The fire protection is thus a "luxury" component of the water supply system in many rural areas. In areas of dispersed settlements and of houses made of mud or other non-inflammable materials, the risk of fire outbreak is less.

The volume of storage required could, thus, be only that needed in order to balance the supply and demand curves.

In order to assess the storage volume needed, the patterns of demand and supply have to be determined.

The demand pattern depends greatly on local customs which have to be studies. According to Wagner and Lanoix a typical rural pattern is: 30 per cent of the daily supply between 7 and 8 a.m.; 30 per cent between 5 and 6.30 p.m.; 35 per cent during other hours of daylight; and 5 per cent between sunset and sunrise. But local traditions during certain times of the year may change this completely.

The supply pattern depends on the technology to be adopted. When pumping is operated by electricity which requires little or no attention, 20 to 22 hours of operation per day are usually taken into account; if the pumps are operated by internal combustion engine, a smaller number of hours (8 to 12) results more economic, due to the high operation and maintenance costs involved. If windmills are used, the supply pattern depends largely on the wind pattern. If man or animal power are used, several shifts will be considered during day time only.

Instead of three days' supply or one day's supply as used by standards which take into account the reservoir's emergency functions, a volume of only about 20 to 50 per cent of the average daily supply would be needed to fulfil the equalizing function and only a small part of the emergency functions.

If the supply and demand patterns are such that a larger storage volume is needed, adjustments can be attempted on the demand and supply curves until a reasonable storage volume is obtained. Adjustments of the supply curve can be measured in financial terms and considered versus the cost of the reservoir. Adjustments of the demand curve might imply changes in the habits of the population; the extent to which such changes are possible has to be determined.

Classification

Reservoirs on the distribution system are classified according to their position as "surface" and "elevated" reservoirs.[57.] Surface reservoirs are located at or slightly below ground level; to maintain the pressure needed in the distribution system, water has to be pumped from the reservoirs. Elevated reservoirs or tanks are those located sufficiently high to provide the necessary pressure by gravity. Water has to be pumped into the reservoir. If topography is suitable such reservoirs are constructed on elevated grounds; if not, a special structure has to be provided which increases greatly the cost of the reservoir.

Surface reservoirs are generally cheaper both in initial cost and in operation and maintenance costs; elevated reservoirs have the advantage that the operation of the pump is independent from the supply of water to the consumers. Thus smaller pumps can be used (than in the case no such reservoir is provided) or pumps can operate less hours, an important advantage in man or animal-powered systems.

In systems without piped distribution, the storage reservoir may be provided close to the water source, e.g. for wells, springs, rainwater catchment. The storage function may be fulfilled by the source and intake themselves, e.g. an impounding reservoir constructed on a stream, a surface runoff pond, a basin for collection of spring water or large-diameter, shallow wells. Reservoirs of any type may be either open or covered.

Surface Reservoirs

The most common materials used for the walls of surface reservoirs are: earth (lined or unlined), masonry, concrete and steel. The cheapest are the open earth reservoirs which are constructed by excavation to a certain depth below ground surface and construction of an earth embankment to a certain height above ground surface, utilizing the excavated material.

The most common materials used for lining reservoirs are: concrete, asphalt, soil-cement, rubber and plastic materials. These types of lining have been described above in connection with rainwater catchment schemes.

Elevated Reservoirs

There are two types of elevated reservoirs: elevated tanks and standpipes.[58] An elevated tank is a reservoir supported on a tower. A standpipe consists of a cylindrical shell, built of steel or reinforced concrete, which is supported by a foundation on the ground. The height of a standpipe is usually much larger than its diameter. Elevated tanks and standpipes are usually made of steel or reinforced concrete but may also be made of wood or bricks.

Wooden tanks were extensively used in the United States at the beginning of this century.[59] They were found to be cheaper and easier to construct than steel tanks; they were also found to last 15 to 20 years and to keep water pure and clean.

An illustrative assessment of the suitability of storage reservoirs to conditions of rural areas in developing countries is shown in Table 8.

DISTRIBUTION

When the water source is located far from the consumer a piped distribution system may be provided to convey and distribute the water to the consumers. Conveyance can be done by open canals, covered aqueducts or pipelines. In small rural water supplies conveyance is usually done by a small diameter pipe and is considered part of the distribution system if one is provided.

While in urban supplies the distribution system is one of the important system components which accounts for a large proportion of the total cost, in rural areas the supply is done, in many cases, without piped distribution or with a simple system supplying water to several public standpipes. In these cases, the function of the distribution system is fulfilled by the consumers - mainly women and children. This component of the system is thus only briefly presented below.

A distribution system generally consists of: pipes, accessories such as valves and meters; and service connections.

There are two typical design problems to be dealt with in small distribution systems: the determination of the size of pipe required to convey a certain amount of water that can be delivered by a pipeline of a given size under a given pressure. Tables and diagrams giving these data for various coefficients of pipe roughness are usually available.

Table No. 8

Assessment of Storage Reservoirs

	Surface Reservoirs	Elevated Reservoirs	
		Elevated Tanks	Standpipes
Materials	Earth (lined or unlined) Masonry Concrete Steel	Reinforced Concrete Steel Bricks Wood	Reinforced Concrete Steel Bricks Wood
Lining	Concrete, Asphalt, Rubber, Plastic		
Cost	Low	Medium	High
Technological Level for Construction, Operation and Maintenance	Low	Medium	High
Advantages	Low cost; easy operation and maintenance; does not interfere with village landscape	Pumps must not operate continuasly; short duration breakdown does not affect pressure in the distribution system; pump capacity may be reduced.	
Disadvantages	Fulfills only function of balancing supply and demand	High cost, skilled operation and maintenance; requires architectural design which should suit the taste and ideas of the local population	

Pipes are usually buried at a certain depth below ground surface but in small rural systems they can also be laid on the ground.

The most common materials used for pipes are: galvanized asbestos-cement and plastic. In Indonesia bamboo pipes are extensively used for gravity systems in rural water supply.[60.] They are cheap where bamboo is available, and easy to construct using unskilled labour. Life expectancy is relatively low, about 3 to 5 years. The maximum pressure possible is two atmospheres. It was found that in the first weeks of operation water in bamboo pipes has an undesirable odour, but this disappears later.

Plastic pipes are now widely used in U.S.A., Europe and Japan, and on a limited scale in some developing countries, too. The main advantages of the plastic pipes are its low cost,[61.] light weight and resistance to corrosion and its suitability for local manufacturing, due to the availability of raw materials on international markets and the low cost of equipment required for manufacturing.[62.] Its main disadvantage is that a quality control programme is required to accompany the manufacture and use in order to avoid intrusion of toxic substances into the water.

The service connections are, basically, of three types:

- <u>public standpipes</u> (standpoints, fountains) or communal water points which werve a number of consumers.
- <u>single-tap house (individual) connections</u>, consisting of one tap located in the house,

next to the house or in the courtyard (in South America they are referred to as "patio" connections).

- <u>multi-tap house (individual) connections</u>, consisting of several taps in the kitchen, bathroom, etc.

To reduce wastes either at public standpipes or at house connections in order to reduce the capacity of the system and thus its cost, water use can be limited by special devices. One such device is the "Fordilla faucet", which consists of a spring-loaded mechanism which closes automatically in six seconds and can discharge approximately 1 liter at a time; it was first tested in Asuncion, Paraguay,[63.] and then extended to other countries in South America and Asia, e.g., Argentina, Brazil, Pakistan.[64.] However, experience with this device in Africa has shown that "it is not sufficiently durable, needs substantial pressure to function adequately and is difficult to repair".[65.] In spite of the evident promise of the Fordilla Faucet as a device for conserving water and thus enabling more people to be served with the same level of capital investment it has proved unpopular with both engineers and users. The reasons for this are not fully understood or documented.

The relative lack of success of the Fordilla should not be allowed to discourage the search for other water saving or conservation devices in piped supply systems and more research and development along these lines is desirable.

A device in common use in Argentina is the Skolnick system. A device is filtered into the pipe that supplies a household to reduce the inflow to a trickle. This feeds into a storage tank with a float valve. Once the tank is empty several hours are required for it to refill, thus householders are induced to economize in water use. Rates charged can be adjusted to the size of the storage tank required. Like the Fordilla the Skolnick is in theory a highly useful device. There has been no systematic review of experience in Argentina, however, and the device does not appear to be widely known outside the country.

Systems designed to provide house connections are more expensive than those for standpipe supply due to two main factors:

i) the cost of the additional distribution pipes, service pipes, accessories and connection devices.

ii) the costs involved in increasing the capacity of the whole system, as a result of higher water use by house connections than by standpipes.

The additional benefits of house connections as compared with standpipes are of two types:

i) health benefits as a result of eliminating the need of carrying and storing water in vessels and of the easier availability of water.

ii) increased convenience which results in time and effort savings.

Available studies and information do not clearly establish that the additional benefits to be obtained from provision of house connections necessarily justify the additional costs. A recent study in East Africa emphasizes the greater health benefits to be obtained from single-tap house connections especially in the case of connected with the use of insufficient quantities of water e.g. trachoma, scabies, and shigella dysentery.

"The policy suggested here differs from the alternative proposed by Burton and Lee[66]. in its lesser emphasis upon standpipe services. It contemplates an earlier and wider adoption of single-tap service in individual households for two major reasons. First, the capital cost of a dense network of standpipes for the same area. Second, the direct cost to individual consumers may be little more than for standpipe service, when account is taken of both the cost in carrying time and purchase and the frequent use of paid carriers at high rates".[67].

There is insufficient knowledge at this time to relate health benefits to water use in any precise fashion. It is well known and accepted that benefits increase with better quality and higher quantities of water. We can also safely hypothesize that the nature of the relationship follows something of the shape of the curve shown diagnostically in Figure 7. That is there is a certain level of service, (quality and/or quantity) that must be reached before appreciable benefits begin to accumulate. This level is shown as point A in Figure 7. Beyond that health benefits mount up to a point B and then level off. The slope of the line AB is not known. It very probably follows more of a step function in which health benefits rise sharply each time a critical level of quality or quantity is reached. This is also largely

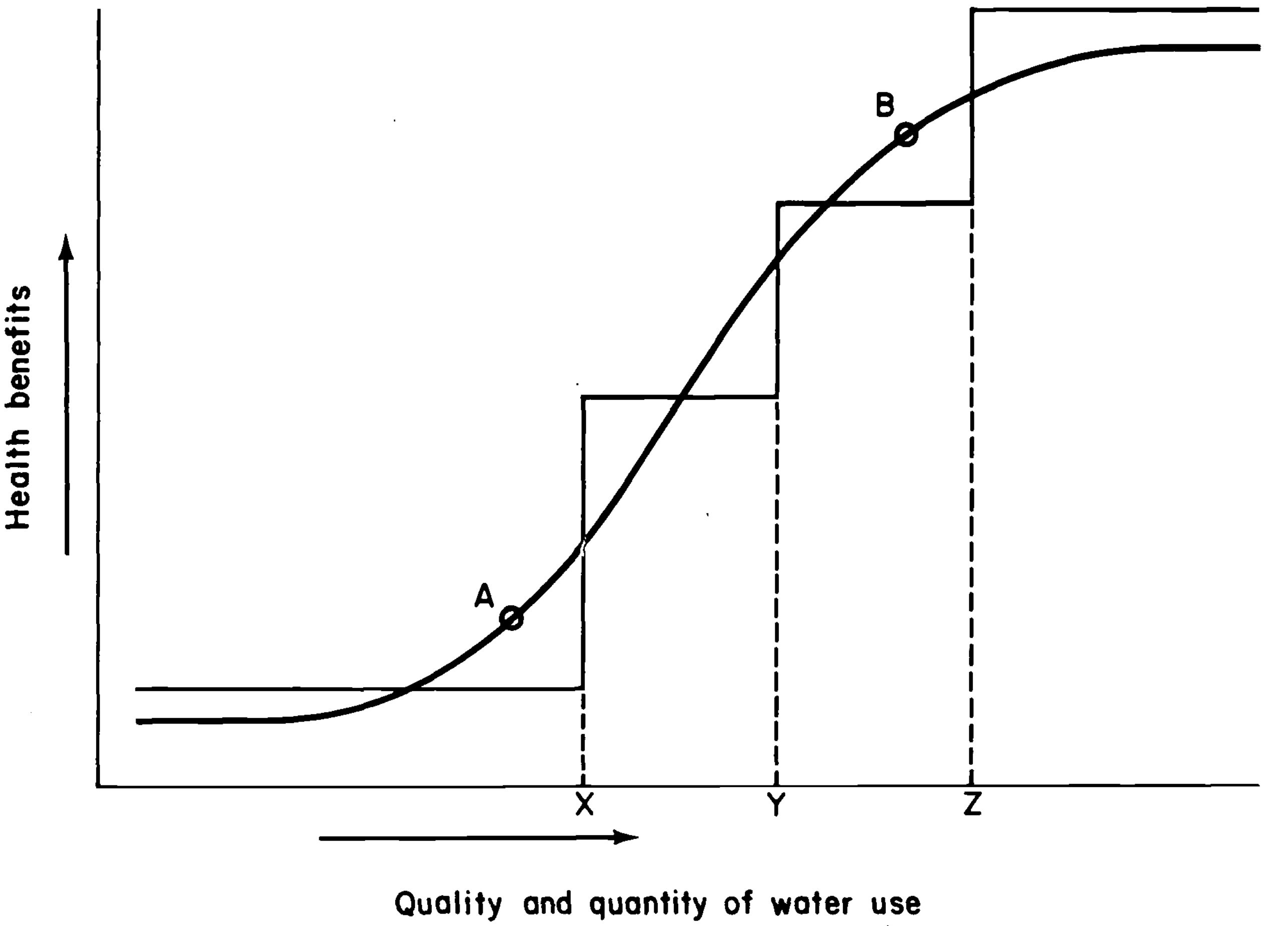

Figure 7 Hypothetical Relationship of Health Benefits to Quality and Quantity of Water Use.

conjecture, however. The steps, if such there are, would differ according to the epidemiological environment and many other factors.

Research is clearly needed to relate levels of water use and quality of water use to health benefits and other social impacts. It is remarkable that such great ignorance prevails and that few attempts have been made to remove it. One difficulty is undoubtably the complexity of the necessary research design, the costly nature of the research and the length of time required. Such research investigations as have been conducted are inconclusive or have serious weaknesses in research design.

Assessment and Research

Water storage and distribution forms an expensive part of the supply system. If ways can be found of lowering the costs by reducing the size of the facilities required limited amounts of capital expenditure would go further.

Research should be aimed at lowering the storage component and conserving water so that smaller components can be employed. The development of such alternative technology should be accompanied by impact studies relating the design and use of systems to health effects and other social consequences. A series of comparative experiments in different climatic, social and economic conditions is needed. These should be carried out not as isolated studies but under a common design developed at the international level and repeated in a number of carefully selected places. The studies at the local level should be undertaken by national groups working as part of or in close colloboration with ongoing national programmes.

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IV SANITATION

The provision of an environment to meet the basic requirements for health include housing, community sanitary services, the protection of food and vector control. The focus here is on the means for the safe disposal of human wastes especially excretion. Where such safe disposal is lacking the contamination of food and water supplies can easily occur, and the gains in health made by the provision of improved water supplies and better diet can be lost. Sanitation is therefore the reverse side of the coin from water supply. The two necessarily go together. The design of the water supply system itself is greatly influenced by the sanitation services proposed to be used.

This is seen clearly in the practice of disposing of human bodily wastes by means of a water-borne piped collection network. Such systems are, however, only about 150 years old. Among the first were those in Hamburg (1842), London (1855) and Paris (1860). Sewerage systems became possible with the advent of abundant quantities of water supplied to the household and became fashionable with the invention of the water closet.

The beneficial effects of such systems were felt with the development of water treatment methods (filtration and chlorination) and the careful separation of water supply distribution and intake systems from sewerage outfalls. Major water borne epidemics were banished from West European and North American cities.

The dramatic successes of western sanitary engineering practice has helped to create a powerful belief in the desirability and efficiency of water borne sewerage systems and has inhibited research on alternative approaches. It is increasingly appreciated today, however, that there are other possibilities which could be developed and put into widespread use. A combination of circumstances is forcing re-evaluation of water borne systems. They are proving to be extremely expensive even in developed countries especially if the collected wastes are to be fully treated before being discharged back into the natural environment. It has been possible in the past to escape some of the costs of sewerage treatment by discharging raw or semi-treated effluent into lakes, oceans or rivers. Such practices are increasingly unacceptable. Heavy concentrations of human wastes are the cause of severe pollution problems and considerable extra expense is now being incurred in the industrial nations in pollution control and abatement measures. Although industry is a source of water pollution, the domestic wastes in municipal sewerage systems also contribute substantially.

Water borne sewerage systems have served admirably in cities with high density populations, where abundant water is cheaply available, and where the level of wealth can support the high capital costs required. They are also appropriate where the natural environment has a capacity to absorb a concentrated flow of wastes in an untreated or semi-treated state. These conditions apply in some major metropolitan areas in developing countries, but rarely do in smaller communities or rural areas.

Another source of dissatisfaction with water borne collection systems stems from the contemporary concern about man's impact upon his environment, the potential shortage of resources and the threats to the stability of the global ecosystem. This has led to a search for methods of recycling waste products. Human excreta is potentially useful as agricultural fertilizer if the health hazards can be overcome. These health hazards have led to very strict regulations to prevent the use of human wastes on food crops in many countries.

If safe and low-cost alternatives to water borne sewerage systems can be developed they will be welcome in both industrial and developing countries. In any case the task of providing water-borne sewerage to many of the world's population remains out of reach even if it were desirable to do so. The costs are prohibitive for many developing countries especially for rural areas and small communities. In areas of water shortage such as arid and semi-arid regions considerably increased costs would be entailed to provide the volumes of water required. The cost of sewerage systems (as also with piped water supplies) increases as the density of population declines, and such systems are both inappropriate and unnecessary for low density dispersed rural populations.

For the 90 developing countries surveyed in 1970 the World Health Organization estimates that 28 per cent of the urban population are served with public sewerage systems and a further 45 per cent have household systems of some sort. For rural areas it is estimated that 91 per cent of the population has "inadequate" excreta disposal facilities.[1.]

Many of those with inadequate facilities use some form of pit latrine. A hole is dug in the ground and provided with a slab or seat. The wastes accumulated ferment and decompose and infiltrate the soil. Once a pit is full it is covered and another is dug. Pit latrines are often unpleasant places, in crowded areas of dense population as in the urban peripheries they may overflow and they are difficult to protect from flies. In rural areas a more simple procedure is to "use the fields". In areas of relatively low population density this can be a relatively inoffensive method but leaves open the danger of spreading disease especially through flies, or by inadvertent contamination of water supplies.

The search for alternative methods of excreta disposal is aimed at producing a system better than the pit latrine, with the relative safety and convenience of the water borne sewerage system but without its disadvantages.

CLASSIFICATION OF WASTE DISPOSAL SYSTEMS

The most extensive report on methods of sanitation is the World Health Organization publication Excreta Disposal for Rural Areas and Small Communities by Wagner and Lanoix.[2.] This distinguishes between water-borne methods and privy methods. A classification used in Scan Plan Report No. 3 by Uno Winblad is based on the processes that occur to the waste - either it is removed manually or mechanically destroyed, allowed to infiltrate into the soil or decomposed.[3.] Infiltration refers to absorption and dispersion of liquid and solid wastes in the soil and ground water, and includes pit latrines.

Removal refers to those methods where the excreta is carried away either manually (night soil collection), by vehicle or by means of pipes, to be disposed of in sewage oxidation ponds, bodies of water or to be processed further in treatment plants. Destruction refers to those methods where the excreta are reduced by combustion. Decomposition refers to those methods where microbiological action takes place.

A listing of the alternatives is given by the Minimum Cost Housing Group of McGill University in Montreal and is reproduced here in Table 9.

DESCRIPTION OF SYSTEMS

A useful summary description of alternative waste disposal systems has been written by the Minimum Cost Housing Group and is extensively quoted.[4]

INFILTRATION

Pit Latrine

The pit latrine consists of a hole covered with a squatting plate, or a seat. The liquid wastes infiltrate into the ground, and the solid wastes accumulate in the pit, and decompose. When the pit fills up, a new one is dug nearby. This is the cheapest system for waste disposal, and quite safe as long as it is fly-proof. It uses no water. It should be located on high ground to avoid run-off water flowing through the pit. A family of six produces about 990 gallons (4455 litres) solid and liquid waste in a year. Since much of the solid waste decomposes, it may take up to ten years before the pit is full. However it can be readily seen that the pit latrine

Table No. 9

A Classification of Waste Disposal Methods

Infiltration

1. Pit Latrine
2. Aqua Privy
3. Septic Tank

Manual Removal

1. Bucket
2. Chemical Toilet
3. Freeze Toilet
4. Packing Toilet
5. Recirculating Chemical Toilet

Mechanical Removal

1. Vacuum Truck
2. Chemical Privy
3. Recirculating Fluid Toilet
4. Water-borne Network

Destruction

1. Incinerating Toilet

Decomposition

1. Compost Privy
2. Continuous Aeration
3. Algae Digester

Source: Minimum Cost Housing Group, "Stop the Five-Gallon Flush", School of Architecture, McGill University, Montreal. 1973.

is suited to heavy use. This is in fact the case in many squatter settlements, where latrines are overflowing. In addition the slow process of putrefaction and pollution of surrounding soil, makes the pit latrines unsuitable, and dangerous, for high urban densities.

Aqua Privy

The aqua privy system consists of a tank with a constant water-leval. The tank can be steel or concrete and is sometimes divided into 2 ot 3 compartments. A vertical pipe extends from the toilet seat to below the liquid surface. A quantity of water is added to the toilet each time it is used. This displaces the waste from the first anaerobic compartment, to the second, where aerobic decomposition takes place. Gases are vented to the outside. The liquids in the tank overflow into soakage, or leaching pits, to be absorbed by the soil. The solids must be removed at infrequent intervals. Some aqua privies can function on only 1 quart (1.13 litres) of water per use. This kind of system can only function where soil absorption capacity is high and where there is no danger of groundwater pollution. Initial cost is relatively high, but operating costs are low. It should be mentioned that a variation of this system, which has been tried in a number of sites in Western Canada, with little excessive smell. This may have been the design of the tank, which had only one compartment.

Septic Tank

This system is essentially an aqua privy, except that the toilet seat is not located directly on top of the tank, but some distance from it. Waste is carried to the tank by water through pipes. The advantages and disadvantages are the same as for the Aqua Privy, with a much greater use of water, about 5 gallons (22.5 litres) per use. Liquid waste is infiltrated into the soil, and solid waste settles to the bottom of the tank to be removed, usually by a vacuum truck.

MANUAL REMOVAL

Bucket

This system consists of a bucket in which the waste is deposited, and which is removed and cleaned at intervals. This traditional system, known for many years and still in use, uses no water and involves little investment. However there is a health hazard when the bucket is being handled and emptied, and the waste is accessible to flies.

Chemical Toilet

This type is essentially a bucket toilet to which are added chemicals which reduce the rate of biological decomposition and reduce odours. The bucket is sometimes in a container which is vented to the outside. Chemical toilets use none or little (1 quart, 1.13 litres) water, and must be emptied when they become full. The contents of the toilet are visible, and when the bucket is more than half full the user may get splashed. Great care must be taken with the chemicals, which usually contain lye, and should never be in the reach of children.
Though the initial low cost of this type of system makes its use very widespread, the cost of chemicals is relatively high, and their use precludes composting of the waste. Experience has shown that in sparsely populated areas the chemicals will not cause pollution of rivers or ground water, however, concentrated dumping would undoubtedly cause problems.

Freeze Toilet

This type of toilet, developed in Sweden, is a bucket toilet where the waste falls into a plastic bag which is refrigerated. Thus the health hazards of the bucket toilet are eliminated, and the waste can be composted. Though the initial cost is high, operating costs (in Sweden) are low, US$ 0.02 - 0.03 per day. Obviously electricity or gas is required, but no water.

Packing Toilet

Another Swedish refinement of the bucket toilet. The waste is sealed in a plastic bag after each use and falls into a larger sack which has to be emptied at intervals. Once again a high initial cost, no water required, and no use of potentially dangerous chemicals.

Recirculating Chemical Toilet

This is essentially a chemical toilet which has been modified by adding a pump, which recirculates the contents of the tank for flushing. The chemicals liquify the solid waste, inhibit biological decomposition, and colourize the liquid. These type of toilets are currently used in commercial passenger planes. The system uses relatively little water, requires electric power (though it could be hand-pumped), but has the same disadvantage as the chemical toilet as regards disposal of the waste. Cost is high.

MECHANICAL REMOVAL

Vacuum Truck

This type of system is also known as the Privy Vault. The toilet is located directly above a ventilated steel tank, or concrete vault. Waste falls directly into the tank, and is collected at frequent intervals by a vacuum truck, which sucks out the contents of the tank. This system is used in Japan and Taiwan. The system has the advantages that it uses neither water nor chemicals, but it does rely on a road network and specially designed trucks. There are odours when the tank is being emptied. Initial cost is low but operating costs are high.

Chemical Privy

The construction of the chemical privy, or chemical toilet, is essentially the same as the privy vault, except that chemicals are used to kill bacteria, inhibit decomposition and liquify most of the solids. For example, to an empty 150 gallon (675 litres) tank, is added 25 lb. (11 kg) of lye and 12 gallons (54 litres) of water. The contents of the tank are virtually odourless, and being liquified and noncorrosive can be pumped out with any inexpensive pump. However they must be hauled away to be disposed of, and can be hazardous to children. Same cost considerations as Vacuum truck system.

Recirculating Fluid Toilet

This system is currently being developed in the United States and is not yet in production. The system consists of flush toilets connected to a water-tight tank, which can be located inside or outside the house. However instead of using water for flushing, a fluid is substituted that does not mix with the waste. At the tank the waste and the fluid are separated and the fluid, odourless and colourless, is used again for flushing. The system thus uses neither water nor chemicals, while allowing several fixtures to be connected to one tank.

Water-borne Network

The system consists of flush toilets connected to a pipe network which transfers the waste to a point of discharge (river or lake, the sea, treatment plant). Water is used to carry the waste in the pipe network. The conventional toilet uses 5 gallons (22.5 litres) each flushing, though toilets have been developed that require only 2 gallons (9 litres) per flushing. Another type of toilet, fitted with a grinder, uses 1 gallon (4.5 litres) per flushing.

Vacuum Network

The vacuum system has been developed in Sweden in 1957. This system consists of toilets, of a special construction, connected to a pipe network, in which a vacuum is created (negative pressure 0.5 atmospheres). About 1 quart (1.13 litres) of water is needed per flushing, and the sewage can be transported up to 640 feet (192 metres) horizontally, and 16 feet (5 metres) vertically, without the use of substations. The initial cost, as with all networks, is high.

DESTRUCTION

The incinerating Toilet

The incinerating toilet consists of a bowl with a combustion chamber below. Most models utilize a liner that absorbs the liquid waste and is also incinerated. Fumes are vented to the outside. The source of energy may be electricity, oil or propane gas. The destruction is rapid and total, leaving only ashes, which have to be removed periodically (and can be disposed of in the garden).

Initial cost is high, as also are the operating costs (about five cents per use in Canada), however no water is used and destruction is safe and complete. Some units may overheat if used in frequent succession.

Incinerating toilets have been developed for mainly military use (in Arctic posts) in the United States. They are used in Canadian National Railway diesel cabs. In Scandinavian countries they have been developed for the consumer market, to be used mainly in summer houses.

DECOMPOSITION

Compost Privy

Composting as a method for decomposition of animal and human waste to provide fertilizer has been in practice for a long time in India and China. Since the 1930's scientists have begun to study this phenomenon, and aerobic composting developed to the point where now in the Netherlands thousands of tons of compost are produced annually from municipal waste. Presently in India more than two million tons of compost are prepared annually. The principles of composting have also been applied to smallscale conversion of human and kitchen waste. This work has been primarily in Sweden, where a prefabricated compost privy in fibreglass is currently sold.

The compost privy consists of a tank with an air intake and a ventilation duct. The toilet is located directly above the tank, as is a garbage chute. Human waste, paper and organic kitchen refuse decompose together into a fertilized humus, whose volume is about 10 per cent of the original. At the lowest point of the tank is an access door for removing the humus. It is important that a layer of straw, sawdust or leaves be first placed in the bottom of the tank. This absorbs the liquid waste and aids decomposition. No water, fuel or chemicals are used in the process, and valuable fertilizer results, however the initial cost is high. This could be partially offset through the use of self-help, as the system is simple and contains no moving parts.

Variations of the compost privy have been developed in Sweden, using electric coils or hot air to heat the chamber and thus speed up decomposition.

Continuous Aeration

These types of toilets use the principle of aerobic decomposition and combine it with the flush toilet. The waste is carried to one or two tanks where it is continuously aerated by means of an air pump. The aerated liquid is used again for flushing. A variation of this system achieves aeration by circulating the water continuously in the system. The water must be changed once a year.

The units that have been developed thus far of the continuous aeration type have had certain operating problems. When overused the system tends to develop odours. If it is not used for a few days, the bacteria tend to die off, and flush water will smell for the first few days of use. Initial cost is high and operating is expensive.

A small unit of this type has been built at McGill but is only in its first year of operation; it runs on a 12 v. windmill operated aquarium pump, and utilizes an old gasoline drum and hand-operated pump.

Algae Digester

A closed system for handling waste disposal and producing gas and fertilizer is currently being built in London by Graham Caine of 'Street Farmer'. It combines a compost privy with a solar heated algae tank and digester. Pathogens are destroyed by the ultra-violet rays of the sun, and the algae break down the solids to produce gas (used for cooking) and fertilizer. This system is in its experimental stages, and it is too early to know its cost or operating problems. However from an ecological point of view it represents an extremely good and economic use of resources, and an important area for development.

HOUSEHOLD WASTE TREATMENT PLANTS

A North American development in sewage treatment is the individual household plant. This plant is designed to treat waste, primarily through aerobic decomposition achieved by continuous aeration, settlement and sometimes filtration. The output from such a plant is "pure" enough to be discharged into rivers, or into the soil, without danger of pollution. It could also be re-used for flushing. These type of plants are normally used where pipe networks are not economic, and where septic tanks cannot be used because of soil conditions. They require a large initial investment and continued maintenance, and are included here for the sake of completeness, and because they do represent a way of saving water by treatment and re-cycling.

ASSESSMENT AND RESEARCH

The foregoing survey carried out by the Minimum Cost Housing Group illustrates the wide range of alternatives that exist or are being developed to the water borne collection network. This work is proceeding slowly and without much official encouragement. It is also not highly popular or respected in the sanitary engineering profession. There are legitimate fears that systems other than water borne networks will not provide such high standards of health protection and disease prevention. It also has to be admitted that the simplicity of some of the alternatives means that they are somewhat lacking in glamour. Work in this area has not carried with it the prestige and status to attract imaginative engineers and scientists or substantial research funds.

The conventional water flush system is well known and has many advantages. It will doubtless continue to be used and its use further extended. Its general application in rural areas, in small communities and in the peripheral squatter settlements in the major cities is prohibited by the high cost of the initial investment.

Modifications of the water borne system are possible that would make it somewhat cheaper. The standard five gallon tank is larger than it need be for most purposes and a smaller 2½ or 3 gallon tank would substantially reduce the water requirement for toilet flushing. Also the quality of water for toilet flushing need not be up to drinking water standards as it is in most western cities. In Hong Kong sea water is used and in the older sections of Calcutta untreated river water is used in a separate system. A new concept is the use of a special fluid that does not get polluted and that can be re-cycled for repeated flushing. This is still under development and might have some limited applications.

Vacuum systems are an interesting innovation developed primarily in Japan and Sweden. The vacuum network is expensive and seems inappropriate for most conditions in developing countries. The vacuum system using truck removal is cheap for the individual household, but it requires a special fleet of trucks with road access provided and the trucks are power consuming and expensive to purchase and operate. Modifications of the vacuum truck might be investigated for peri-urban areas and intermediate size communities where population density is not high enough to support water borne systems and where the health danger of other systems is large.

The destruction of wastes by incineration eliminates the need for water and sewage treatment, but the cost is relatively high and there is need for a reliable energy supply. The use of chemical systems could also improve sanitary conditions in rural areas, but the supply and cost of chemicals can be a problem and the accumulation of chemicals with intensive use can pollute both soil and ground water. Also there can be dangers associated with the storage and handling of chemicals, especially to children.

The most promising directions for research in sanitation are in decomposition methods in which waste is reduced in volume and made suitable for use in agriculture. Several kinds of compost privy have been developed based on processes of decomposition. These include the Clivus (Sweden) the Mull-Toa (Norway) the Saniterm (Sweden) the Multrum (Denmark) and the Kern Compost Privy (U.S.A.) These units tend to be made out of relatively expensive materials or to require a power supply to circulate warm air. Research and development is needed to develop low-cost versions and to test their operation under different climatic conditions. Preliminary steps have been taken in this direction by International Development Research Centre in connection with the Multrum system. This device seems especially attractive in theory since it uses no water, no power source and no chemicals. When a power source is required the possibility of using wind power for ventilation could be explored.

NOTES TO SECTION IV

1. World Health Organization, "The World Health Organization Programme of Research and Development in Community Water Supply and Wastes Disposal", CWSS/73.1. Geneva. p.3.

2. E.C. Wagner and J.N. Lanoix, Excreta Disposal for Rural Areas and Small Communities. World Health Organization Monograph. Geneva. 1958.

3. Uno Winblad, Evolution of Waste Disposal Systems for Urban Low Income Communities in Africa. Scan Plan Report No. 3. Copenhagen. 1972.

4. Minimum Cost Housing Group, Stop the 5 Gallon Flush: A Survey of Alternative Waste Disposal Systems. School of Architecture, McGill University. Montreal. 1973.

V TOWARDS A HIGHER LEVEL OF ASPIRATION

A number of possible directions for research and development in the technology of water supply and sanitation have been suggested. Criteria have been developed that can be applied to the choice of existing technology and the evaluation of proposed research and development. What possibility is there that such work can be effectively and successfully carried out? If this is done will the choices made available be acceptable to engineers and water users? Will any new ideas that are produced be adopted and what potential is there that the prevailing unhappy situation can be radically transformed?

The water supply and sanitation problem is not highly complex in technical terms, but the intimacy of the intentions between technology, society and environment do make the questions both complicated and delicate. It is hard to find any firm ground on which to base a realistic assessment. In some perspectives the difficulties seem so frustrating and intractible that it is hard to summon much optimism. Clearly it could be as wrong to fall victim to a despondent pessimism as it would to get carried away with naive and/or ill-placed optimism. Our best judgment is that there are grounds for hope that more can be achieved if our aspiration levels are set somewhat higher. We also believe that a little rashness is called for. A calculated risk should be taken to put a substantial increment of research and development funds into the development of appropriate technology for water supply and sanitation. We have in mind especially the sorts of technology needed in villages and in the village-like communities that are growing rapidly around and within major metropolitan areas. Such a gamble may fail. If the risk is not taken, however, all the gains that might be made in availability of skilled manpower, better administration and management will be of little avail, and all the manuals, guidelines, and standards that are produced, will be a great deal less effective. Moreover, there will be little incentive to allocate more funds from national budgets if the benefits are seen to fall on the small number of people that can be served with high-cost technology.

To take such a calculated risk would be to count on the creative imaginations of scientists and engineers to develop some new and improved alternatives. The modest suggestions made here are not an exhaustive list and as more work is put in hand it may be confidently predicted that new research opportunities will be opened up. The present proposals are a beginning only; no more than a way of getting into the problem.

There is, however, no panacea in technology. The research and development suggested should go hand-in-hand with a number of other activities needed to strengthen the effort. These include steps to expand the supply of trained manpower, develop the local manufacture of needed materials, improve administration and management, and supply information in a comprehensible form to those that can use it.

The proposed technology research and development should be conducted in close colloboration with on-going programmes, and with social, health and economic studies designed to evaluate the impact of improvements, and to contribute to the shaping of future technology. It is also highly desirable to review recent successful experience and to make it widely known. This might best be accomplished in a series of internationally organized and sponsored studies, carried out in conjunction with national programmes largely by local personnel. The studies would attempt to follow a common design so that maximum opportunity could be given to transfer experience and benefit from results.

THE UNDERLYING ORIENTATION[1].

As the priority needs in water supply and sanitation shift away from the major metropolitan areas towards villages, smaller towns and the "temporary" urban peripheral settlements some changes in orientation are required. The technologies and the means whereby it is made available that have been so successful are often inappropriate, and the strengths of the work accomplished so far threaten to become its future weaknesses. These include reliance on a western developed costly technology that is highly demanding in skills for operation and maintenance, an orientation towards higher and relatively rigid standards of risk, dependence on professional engineering skills and cash repayment by the consumers. The organization of administration and management, the content of training schemes, the pattern of international financial and technical assistance, and research priorities have all been oriented towards these characteristics.

The orientation that emerges from this study is different in several respects. It imphasizes the development of low-cost technology with lower requirements for operation and maintenance. It implies the provision of manpower with sufficient skills to provide such operation and maintenance at a sub-professional level. It also strongly calls into play local community or user-participation in project design and selection, in construction and in operation and maintenance. It also recognizes the need for a flexible approach in rural communities which would involve finding out local perceptions, preferences, and value systems, providing education on the health consequences of improvements and offering technical assistance to help in a series of incremental improvements to meet the aims of the users.

The adoption of such an underlying orientation can only be gradual. It requires a shift in perspective and attitude by those who now deliver water supply and sanitation systems towards one focussed much more on users' choice.[2.] It also requires changes in methods of administration and management, and financing programmes. Alternative methods are not immediately available for adoption. They have to be developed and worked out in considerable detail and tested. It is unreasonable to expect accepted ways backed by professional experience to change overnight. Even if this were possible it would not be desirable, until the implications and methods have been more fully developed.

Two points at which the orientation proposed here may be at variance with the professional views seem crucial and should be faced. These are the matters of health standards and economic benefits.

HEALTH STANDARDS

The orientation towards gradual or incremental improvements in water supply and sanitation suggested here arises from a recognition that the changes involve some cost to the community and impose demands. If the changes are out of line with the capacities of the community then newly created systems are likely to be poorly maintained, ineffectively operated and eventually abandoned.

The adoption of an incremental improvement may be difficult for a water supply agency to accept. Once an external agency intervenes in a village water supply situation it may feel a heavy responsibility for what ensues, and may be embarrassed by the inference that it shares in the responsibility for any disease and death that may occur as a result of the continued presence of less than perfect water supplies and sanitation methods. The fears of a doctor that he may make the patient ill by his treatment - the so-called iatrogenic diseases - find a close parallel here. Although there is no word in English for an engineer-created-disease, the fear is a profound one. A reaction to this fear is the creation of standards for drinking water and the vigorous efforts of the profession to meet those standards.[3.]

No one would doubt or dispute the desirability of developing and holding such standards as a goal. If they are interpreted as an inflexible rule, however, they can serve to delay or prevent what is possible because it does not constitute what is most desirable. In practice such delay or prevention may not occur very frequently. Certainly it is widely recognized that it is not possible to attain high standards everywhere and immediately. Every time a decision on an improvement is delayed or an alternative rejected on the grounds of a universal health standard, whether explicitly stated or not, the responsible official is, in effect, judging that he would prefer to maintain the high health risk for the population a while longer, rather than see it marginally reduced, and risk his reputation as a purveyor of the near perfect. How widespread such a professional stance is and how common such a paternalistic attitude may be we cannot judge. Insofar as it may block improvements to incremental improvements to water supply and sanitation the situation could be alleviated by setting quality goals for individual communities in terms of a benefit-risk appraisal in which the community concerned should have an opportunity to decide how much benefit to aim for at what cost and how much risk should continue to be borne.

More research is needed to elucidate this problem. In particular the relationship between water quality and quantity and health as depicted in Figure 7 needs to be more fully explored. Lack of this knowledge should not be allowed, however, to delay the provision of those steps towards safer water that are now possible.

ECONOMIC BENEFITS

The second area where the underlying orientation may be at variance with professional views is economic. It is held by would-be national allocators of limited financial resources, that to achieve the goals of economic development, money should not be invested where it does not yield a good rate of return or when it can contribute more effectively to raising the natural income by being invested elsewhere in other activities. This has often led in the past to a preference for investment in directly productive activities over infrastructure and services. Thus a strictly financial criterion is applied to water supply investments--"if they can pay for it, they can have it". In rural areas and urban peripheries where ability to pay is often severely limited a broader economic view may be adopted--"they don't have to pay cash but we have to be convinced that the social benefits are worth it". This has led to proposals for research to attempt to assess in monetary terms the benefits to health that may be expected to accrue from water supply and sanitation improvements. Twenty-six empirical studies have been reviewed by Saunders[4] which provide "a significant amount of evidence that more and better water is associated with better health". This is an encouraging if not very novel conclusion. It is also found that the amount of improvement in health for a similar water supply improvement can differ in two villages according to "previous level of health, cultural habits, educational level, and the general physical environment including adequate means of waste disposal and income level". Significantly, none of the twenty-six studies are without serious design and conceptual problems and not one such study has been carried out "which allows an accurate prediction of health (and economic) improvements under a variety of circumstances". The view is expressed that "there is no possibility of designing and carrying out a one-time-only water supply-health-economic development study which from the point of view of the epidemiologist, economist and engineer, yields conclusions that are without drawbacks or major problems".[5.] More precise knowledge of the relationship between type and degree of water supply and sanitation improvements is needed as discussed above in the section on distribution and as illustrated in Figure 7. Such knowledge would aid considerably in the design of schemes, as for example, in making the judgement between standpipes and single-tap house connections. Lack of such knowledge should not be allowed to delay improvements that are now possible.

Recognition of access to improved water supply and sanitation as a basic human right would undermine much current sophistry. Improvements beyond a certain level might well continue to be regarded as an economic good to be purchased like any other. To deny access to a basic right when its attainment is within the bounds of the possible, is to throw up roadblocks in the interests of rational allocation of resources, presumably in favour of other more basic and essential requirements than drinking water and sanitation.

It does not necessarily follow, however, that the allocation of limited funds in the direction of achieving greater social equity is detrimental to the development effort. Conventional economic wisdom has tended to assert that this is the case. Under this view a policy of "trickle down" has been widely followed in which investments have been concentrated in the major cities in the expectation that the effects would eventually filter out into the rest of the economy. This has not happened and an alternative view is now gaining wider support. "Contrary to the assumptions of the 1960's, the development record of these (sic) countries indicates that policies which enhance social equity need not deter, and may accelerate, over-all economic growth. We are learning that if small rural and urban producers and underemployed workers are given a chance to participate in the development process and access to education, credit, technology and health services, then they too can become highly productive....".[6.] The changing views of economic development strategies are compatible with the sorts of policies that seem most desirable in the water supply and sanitation field. They also emphazize the use of appropriate technology and the involvement of the population in the development process. "Fortunately there is growing evidence that policies which are carefully designed to raise the income of the poorest half of the population, by increasing their ability to participate in the development process can actually accelerate not hinder, economic growth. These policies require not only favoring use of plentiful labour over scarce land and equipment, but also providing incentives to encourage savings, establishing or supporting institutions which give small farmers and entrepreneurs ready access to capital and technology, and ensuring the availability of rudimentary but meaningful education and health services to virtually all their citizens. Through such policies, these countries (sic) have made social justice a major ally of growth by putting idle labor and resources to effective work, and making more efficient use of capital and foreign exchange."[7.]

A PRACTICABLE PROGRAMME

A programme of research and development in the technology of water supply and sanitation would have as its aim a much faster rate of progress than has hitherto been thought possible in rural areas, small communities and the urban peripheries. A goal might be set as the provision of improved water supply (and corresponding improvements in sanitation) to 95 per cent of the population by 2000. The goal is stated as 5 per cent short of complete coverage to allow for those people who live in such rigorous and remote habitats that improvements will be infeasible for a very long time to come. No absolute standard of service to be reached is specified on the assumption that what can be attained will depend on the aims of the population to be served as well as on the standards that are set as universal goals. The nature of the task is suggested by superimposing this goal on the linear extrapolations, (shown in Figure 2 above) of past performance and current programmes. As Figure 8 indicates major new efforts will be needed if the proposed goal is to be attained. Extrapolation of the trends of the past decade would suggest that the goal is beyond reach. We are convinced that it is attainable if the kinds of technical research and development suggested here can be vigorously pursued and supported with corresponding improvements in administration and management and the expansion of training and education as part of an international initiative based on an underlying orientation of the sort suggested.

INSTITUTE OR TASK FORCE?

We have given some attention to the shape that an international initiative might take and alternative proposals have been canvassed and widely discussed. One obvious suggestion is that a new institute for water supply and sanitation research might be established.

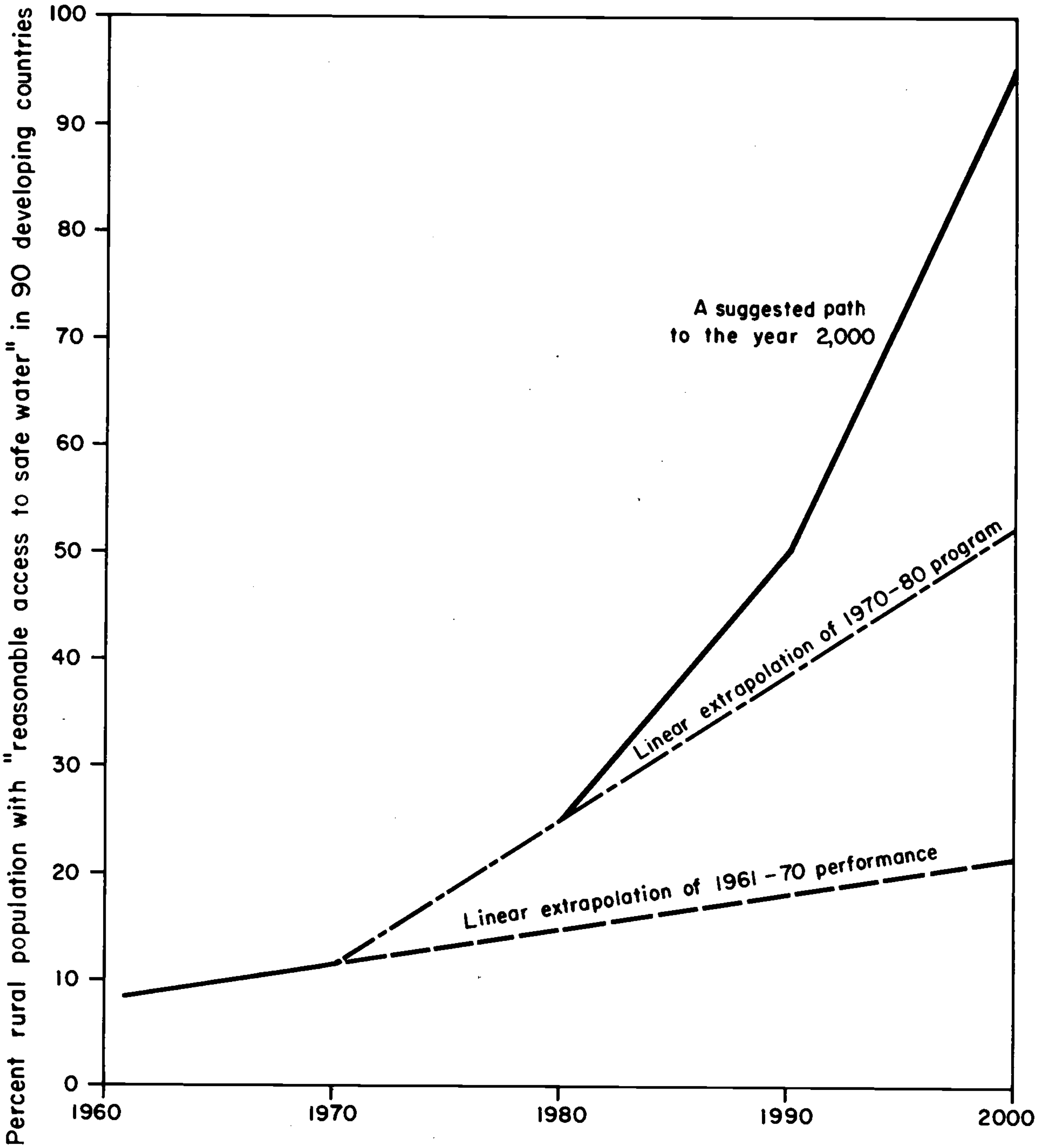

Figure 8 Water Supply for Rural Populations: A Possible Path to a Goal for the Year 2000.

By a new institute we have in mind the sort of bricks-and mortar establishment where teams of scientists and technologists could be assembled together with social, economic and health experts to carry out a long-term research programme. The breadth of the field, however, and the diverse needs in different regions, and for different settlement patterns and climatic zones, suggest that it would be unwise to contemplate only one such center. Furthermore, a number of institutions where useful work has been done, already exist. On the whole it seems better therefore to strengthen and coordinate the efforts of existing institutions and to discuss the redirection of research priorities along the lines proposed. Also a considerable part of the needed research should be done in field conditions. It would be wrong to create too heavy an emphasis on laboratory and workshop research. One exception to this is that Africa is not well served at the present time with research establishments in this area. There might be a case for establishing an institute in Africa, therefore, not to be the world center for research in water supply and sanitation but to be one among a number of such centers. The function of strengthening and coordinating the research of existing centers is an important one and is being helped by the work of the World Health Organization International Reference Centres.[8]

Another alternative form that a new international initiative might take is in the creation of a Task Force to organize and coordinate a research effort. This seems to have much to recommend it and it is an idea that we favour. The Task Force would be given a limited life of about five years in which to lay the basis for a global

20 year programme. The function of the Task Force would thus be to guide and coordinate a programme of research and development which would include the following:

1. Technical research and development designed to create new alternatives and to improve existing technology by making it more appropriate to the needs of developing countries.

2. Description and popularization of technological choices for particular habitats in terms and languages siitable for use by sub-professionals and community leaders.

3. Appraisals of recent successes and failures in providing improvements in urban peripheries and rural areas.

4. Impact studies designed to strengthen knowledge of critical areas of design.

5. The development of techniques for assessing user perceptions and involving the community in the improvement process.

6. Supporting the development of national training and educational programmes and the provision of the sorts of technical information required.

The Task Force would also have a vital role to play in cultivating an awareness among responsible national leaders of the opportunities and problems presented by accelerated programmes. The five-year research programme proposed would also help to refine the underlying orientation suggested above, and to indicate how the ensuing 20 year action programme would take shape. Basic to the attainment of these aims would be the fundamental changes in approach described with an emphasis on incremental improvements and comnunity participation.

In adopting a view of water supply and sanitation services as a right to which all are entitled rather than an economic good to be marketed where the consumer can afford it, national governments would make some important commitments. They would publicly accept an obligation to help consumers achieve adequate supplies within some target period, recognizing that rights are to be claimed and merited not given. They would provide trained personnel to assist local groups and communities to make technically sound choices, and they would also allocate sufficient funds to pay for environmental health components in education, for continuing technical assistance and in-service training. They would also have the opportunity to participate in a programme of collaborative international research and information dissemination directed towards the support of their efforts.

A role for external financial and technical assistance would remain, but chiefly directed at the major metropolitan areas. Massive transfers of capital for construction of projects could neither be necessary or desirable. International assistance would be focussed upon research on key technological problems and in establishing institutional competence to carry out educational and technical assistance activities. An important component would also be the establishment of local industries to manufacture the sorts of equipment required. The major international financial agencies would take the lead in institution building, but a key role would be open to non-governmental organizations.

The Task Force might be composed of representatives of all the relevant organizations from the United Nations family; some of the major donors of research and development funds; certain external aid agencies; a substantial proportion of members from the developing countries, and a few individuals selected for their knowledge and experience. Such a large body might expect to have an inner group that would meet more frequently and a small secretariat to carry out day to day activities. The Task Force would necessarily work in close cooperation with the World Health Organization and other bodies.

To embark upon this course of action would not provide any guarantee that the present unhappy situation could be radically altered. As far as we can soberly judge, however, it appears to offer a fighting chance of bringing a real prospect of improvement to those hundreds of millions of people who would otherwise be left with little hope. To set a goal for the provision of such basic requirements 25 years into the future is as long as a major world effort can be expected to accept. Setting out to reach the goal in significantly less time would be wholly visionary.

If this programme or something similar were to be launched as a major international effort, more effective tactics and operating methods would very likely be devised than those suggested here. Even so it might fall short of its objectives. Amid considerable uncertainty it remains clear that technical skills, administrative decisions and political motivation can be harmoniously developed together in recognition of the simple principle of a healthy environment as a basic human right. If the diagnosis offered here is substantially accurate, and if the opportunities described are rightly conceived then there are grounds for hope that a significant advance can be made in the provision of better water supply and sanitation for the well being of rural people.

NOTES TO SECTION V

1. Many of those ideas expressed in this discussion have grown out of the two International Development Research Centre Seminars held in Ottawa and Lausanne. They are also expressed in a paper by Gilbert F. White, "Domestic Water Supply: Right or Good?" in the CIBA Foundation symposium volume, Human Rights in Health. London. Forthcoming.

2. The concept of user's choice and the requirements for its development and application are more fully described in Anne V. Kirkby, "The Development of User-Choice Systems in Rural Water Supply Projects", Working Paper No.17. Lausanne Seminar. May-June, 1973.

3. World Health Organization, International Standards for Drinking Water. Third Edition. Geneva. 1971.

4. R.J. Saunders, "Village Water Supply in Developing Countries: Problems and Policies", Unpublished report prepared for the International Bank for Reconstruction and Development. Preliminary Draft. Washington, D.C. March, 1973.

5. Saunders, "Village Water Supply".

6. James P. Grant, "Development: The End of Trickle-Down?", Foreign Policy No. 12. Fall, 1973. pp.43-65.

7. Grant, "Tricle-Down". pp.47-48.

8. Annual Reports of the World Health Organization International Reference Centres.

APPENDIX I INTERNATIONAL DEVELOPMENT RESEARCH CENTRE SEMINARS

OTTAWA SEMINAR AUGUST 17-18 1972

List of Participants

Dr. Mary Barker	Department of Geography, Simon Fraser University, Burnaby 2, B.C. Canada.
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Dr. Donald Ferguson	Population and Health Sciences, International Development Research Centre, P.O. Box 8500, Ottawa, Ontario K1G 3H9, Canada.
Prof. Robert W. Kates	Graduate School of Geography Clark University, Worcester, Mass. 01610 U.S.A.
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Prof. Gilbert F. White	Institute of Behavioral Science, University of Colorado, Boulder, Colorado, 80302 U.S.A.
Prof. Abel Wolman	209 Ames Hall, Johns Hopkins University, Baltimore, Maryland, 21218 U.S.A.

List of Background Papers

No. 1. List of Background Papers

No. 2. "Preliminary Notes Towards the Specification of System Components and Criteria" - Mary Barker.

No. 3. Questionnaire: "Water Supply and Sanitation: Conditions and Appraisal" - Mary Barker.

No. 4. "Review of East African Experience" - Leonard Berry.

No. 5. "Rural Water Supply and Sanitation in Tropical Areas: Technology Assessment and Research Review" - International Development Research Centre, Rural Water No. 2.

List of Background Papers continued

No. 6. "Technology, Social Organization and Water Supply: A Need for New Ideas" - Robert W. Kates.

No. 7. "Rural Water Supply and Sanitation - Survey of Needs" Charles S. Pineo.

No. 8. "Annotated Bibliography" - Anne U. White.

No. 9. E.K.G. Borjesson and C. M. Bobeda, "New Concept in Water Service for Developing Countries", Journal of the American Water Works Association. Vol. 56, No.7. (July 1964), pp. 853-862.

No. 10. H.F. Ludwig and A.W. Jorgensen, "Package Approach for Development of Village Water Supply Systems", Proceedings. International Conference on Water for Peace. United States Papers, Washington, D.D. 1967.

No. 11. World Health Organization, Water Supply, Sewage and Waste Disposal. WHO/EH/71.2. Basic Paper prepared for the United Nations Conference on the Human Environment. Stockholm. 1972.

No. 12. List of participants.

No. 13. "Essential Ingredients in an Effective Program to Improve Rural Water Supply" - Gilbert F. White.

LAUSANNE SEMINAR MAY 29 - JUNE 1ST 1973

List of Participants

David Bradley	Sir Wm. Dunn School of Pathology, South Parks Road, Oxford OX13RE
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Jeremy Warford	International Bank for Reconstruction and Development, 1818 H. Street NW Washington, D.C. 20433, U.S.A.
Simon Watt	Research Engineer, Water Unit, National College of Agricultural Engineering, Silsoe, Bedfordshire, England.
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Gilbert White	Institute of Behavioral Science, University of Colorado Boulder, Colorado 80302 U.S.A.
Uno Winblad	Scan Plan, Sankt Kjelds Gade 3, DK 2100, Copenhagen, Denmark.

List of Background Papers

1. Water for the Well-being of Rural Peoples - Ian Burton.
2. Selected Annotated Bibliography on Rural Water Supply and Sanitation in Developing Countries - Anne U. White and Chris Sevior.

List of Background Papers continued

3. Aims and Achievements of the Intermediate Technology Development Group in Rural Water Supplies - Peter Stern.

4. Notes on Research Recommendations - various sources.

5. Experience in User-Choice from Kenya and Tanzania - Robert Kates.

6. The Technological Frontier - A State-of-the-Art Review - E. Idelovitch.

7. Notes on a Field Mission to Ethiopia, Kenya and Ghana E. Idelovitch.

8. A Comment on Working Paper No.1. - Robert Kates.

9. Progress in the Rural Water Programs of Latin America (1961-71) - David Donaldson.

10. Evaluation of Waste Disposal Systems for Urban Low Income Communities in Africa - Uno Winblad.

11. Series Filtration Using Local Filter Media - Richard J. Frankel.

12. A System Approach to Assessment of Rural Water Supply Program Effectiveness - Richard J. Frankel.

13. Report of the meeting of Directors of Institutions Collaborating with the World Health Organization International Reference Centre for Community Water Supply, Bilthoven, April 1973.

14. Functioning of the International Network for Community Water Supply - Hans van Damme.

15. Interdisciplinary Training of National Engineers and Technicians for the Implementation of Rural Water Supply Programmes.- E. Idelovitch.

16. An Essay on a Logical Model for Rural Water Supply and Sanitation Investigations - Yves Maystre.

17. The development of user-choice systems in rural water supply projects - Anne Kirkby.