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PROJECT MONITORING AND REAPPRAISAL IN THE INTERNATIONAL DRINKING WATER SUPPLY AND SANITATION DECADE

New York May 11-15, 1981

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PROJECT MONITORING AND REAPPRAISAL IN THE INTERNATIONAL DRINKING WATER SUPPLY AND SANITATION DECADE

Charles G. Gunnerson and John M. Kalbermatten
Editors

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ENVIRONMENTAL IMPACT ANALYSIS

Research Council

FOREWORD

The International Drinking Water Supply and Sanitation Decade will present major challenges to civil and sanitary engineers in both developing and industrial countries. Ready access to a minimum of twenty to fifty liters per capita per day of safe water, environmentally and socially acceptable means for waste disposal, and equitable cost recovery require assessment of conventional engineering practices during a period of increasing needs and decreasing fiscal resources. To this end, the Environmental Impact Analysis Research Council has convened an ASCE Convention Session on Project Monitoring and Reappraisal. Generic principles of service levels, willingness to pay, and economic, technological and institutional development are presented, together with case studies in water supply and sanitation from both developing and industrial countries. These are followed by guidelines for engineering design, project monitoring, and project reappraisal. The guidelines lead to policies and practices in which (1) traditional and state-of-the-art skills are used, (2) case studies precede theory, (3) individual and community hygiene are stressed, (4) existing facilities are upgraded, and (5) integrated systems for resource conservation and recovery are implemented. These are consistent with the long-term objective of EIARC: to identify and develop guidelines which will lead to greater acceptance, utilization, environmental strength and economic viability of the projects to which civil engineers contribute.

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CONTENTS

Cover illustration: Woman carrying bucket on her head,
Balikh River area, Syria.
World Bank Photo by Thomas Sennett.

Frontispiece: Rooftop reservoirs in Bogota.
World Bank Photo by Edwin G. Huffman.

REAPPRAISAL AND RESPONSE TO CHANGING SERVICE LEVELS

By Anne U. White[1] and Gilbert F. White[2]

ABSTRACT

The United Nations Drinking Water Supply and Sanitation Decade can be looked on as an attempt to enhance well being by the promotion of new attitudes towards who should benefit from improvements, what are water supply and sanitation practices and technologies that will promote health, and what actions should be considered in the design, installation and subsequent use and maintenance of facilities. The likelihood that knowledge and conviction will generate constructive behavior depends on the provision of precise information that can be used in action, consistency with other attitudes and goals, and institutional support. These considerations are particularly relevant to problems of service level and of motivation. The record of the past ten years, coupled with observations in selected places, suggests that major changes in attitude and strenuous efforts to translate these into action will be necessary to break out of prevailing situations in which improvements barely keep up with rates of population growth.

When the United Nations on November 10, 1980 inaugurated the International Drinking Water Supply and Sanitation Decade with the avowed goal that the people of all nations have access to safe water supply and hygienic waste disposal by 1990 it gave formal expression to a process which had been underway of reappraising the standards and methods used to satisfy those basic human needs. As a part of this activity developing countries are undertaking to set targets which they think they can achieve during the Decade (1). Whether the goal as it is defined nationally is complete coverage or something less, the Decade is a major effort to change for governments and large sections of the developing world's population the goals and methods inherent in providing service.

Obviously, a number of factors will affect in some degree the achievement of the agreed goals. Financial support, fiscal policy, pricing policy, construction methods, consumer participation, and training programs are a few of them. In this paper we direct attention to two sets of considerations which tend to be taken for granted or to be handled in a rather casual manner. These are the considerations relating to 1) the implied behavior changes in the variety of groups involved and 2) the values and standards associated with service levels. The key question is whether or not the broad aspirations voiced in the Decade can be translated into practical action in a fashion which recognizes that the standards are indeed changing and that the ways of planning and carrying out improvements require revision.

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INTERNATIONAL POLICY DECLARATIONS

In the mid-20th century, during a period of economic growth unparalleled in history, North America and northwestern Europe developed faith in a tradition in which all kinds of goods and services constantly improved. If it was noticed that these improvements were not shared by most of the world, it was assumed that nations newly emerging from colonial status would evolve over a hundred years or so in the pattern of the industrial countries. Recognition has come slowly, although not yet to everyone, that the options of the 18th and 19th centuries are no longer available to new nations.

Many special United Nations sessions and conferences during the 1970's dealt with a variety of technological issues faced in these new conditions (population, habitat, health, energy, food, environment and water). Drinking water and sanitation were recognized in a number of these as a basic component of human welfare. The declarations of HABITAT, the United Nations Conference on Human Settlements in 1976, the United Nations Water Conference at Mar del Plata in 1977, and the International Conference on Primary Health Care in 1978 specifically carried the message that safe drinking water supply and sanitation for all are essential ingredients in the promotion of health and development. The World Health Organization (WHO) undertook at its Thirtieth World Health Assembly in 1977 to conduct with Member governments a rapid assessment of the current situation in these fields. Meanwhile the United Nations Development Programme (UNDP) funded an increasing number of projects for improvements in water supply and sanitation as a part of development. The International Bank for Reconstruction and Development (World Bank) moved into its second mission with increasing emphasis on the poorest of the poor. Within the constraints of changing foreign policy objectives a number of bilateral agreements were directed to the same ends. Many non-governmental organizations, with their emphasis on rural and poor populations and community involvement, found themselves in the mainstream of policy. These activities culminated in the declaration of the International Drinking Water Supply and Sanitation Decade, and its formal launching on November 10, 1980, at the General Assembly of the United Nations in New York.

The ambitious goal of safe water and sanitation for all was accompanied by a reappraisal of the opportunities for achieving it and the constraining factors.

Perhaps the most pronounced and influential change was in the posture taken by the World Bank toward water supply and sanitation investments. In addition to adopting explicit policies to provide service to both urban and rural poor, it sponsored a series of studies which appraised the alternative methods of meeting those needs, and developed more sophisticated techniques for design, evaluation and construction (2), including demonstration efforts with UNDP funding.

There was a marked concern for egalitarianism and for institutional reform. The change was expressed in part by Bradley in 1978 that: "The key conceptual issue of a few years ago in water was to persuade people to think in terms of incremental improvements rather than all-or-none terms; to show that there were many steps between fetching water from a filthy pond and having multiple taps delivering chlorinated safe water. Still many people have not really accepted the need for this change of attitude. The pattern of responsibility, whereby an engineer is responsible for a project rather than for a defined population, makes the change harder. The main current conceptual issues are those of equitable distribution of water and sanitation benefits and of how to integrate water supply and excreta disposal into an overall rural development programme" (3).

SHIFTING PRIORITIES

One indication of the shift in priorities that this reappraisal brought about can be had from a look at the factors considered important by the countries participating in surveys conducted by WHO in 1970, and again as part of the rapid assessment in 1980.

When the World Health Organization sent out a questionnaire on which it based its 1970 study of community water supply and sanitation in developing countries, it listed ten constraints which could inhibit the construction of facilities, and invited the countries to rank in priority those applying to their situation. The constraints were: internal financing insufficient, external assistance insufficient, insufficient local production of material, inappropriate administrative framework, inappropriate financial framework, inadequate legal framework, lack of trained personnel and, in addition for sanitation, lack of design capability, inadequate supervision of construction, and lack of national organization responsible for programme (4). For the countries answering, the first three constraints in order of importance were insufficiency of internal finance, lack of trained personnel, and insufficiency of external assistance (5). It is unlikely that the officers of WHO at the time regarded this list of constraints as exhaustive, but it is indicative of the factors then thought to be important.

By 1980, the priorities had changed. A majority of the governments of the countries reporting to the UN in 1980 stressed four major needs: a) health education programs to accompany water supply and sanitation programs, b) wide participation by beneficiaries, c) increasing emphasis on services for rural populations, and d) higher priority to manpower development (6).

The report of the Secretary General of the United Nations on the present situation and prospects for the Drinking Water Supply and Sanitation Decade notes that from a planners point of view the consumer population of each developing country can be divided into three categories: a) those with access to facilities who can afford them, b) those not yet covered but who could afford them, and c) those with neither facilities nor the means with which to afford them. Since most of the unserved populations of the world lie in category c), the report states that there can be some cross-subsidy among different income groups, but that "a proper use of simple, easily manageable and cheap technologies produced with local materials and skills together with community participation programs can help to increase the number of people who can afford the services and reduce the numbers of people who cannot" (7). Since the total amount of money available is not expected to increase substantially, the question becomes one of its most efficient allocation in meeting stated goals. The investment requirements then depend very much on the choice of technology and mix of levels of service proposed.

The shift was from a view of the problem as almost entirely financial and technical to an emphasis on the educational and informational aspects, participation by consumers in all aspects of the programs, and recognition of the urgent needs of both the urban squatter settlers and the rural populations. There was less talk about engineering plans and more about motivation. Stress on the need for manpower training and development remained constant over the whole period.

THE INCOMPLETE RECORD FOR 1970-1980

Against the background of the global policy declarations and of the thinking and attitudes they reflect, it is sobering to examine the record of practical action in the same period. The available statistics on what happened during the past decade suggest that a simple extrapolation of those activities would leave the world's needy little better off, comparatively speaking, than at present. Those gathered by WHO in 1970 and 1975, and those resulting from the national reports obtained for the 1980 report by the Secretary General of the United Nations at the request of the Economic and Social Council, give the best available picture of trends in the drinking water and sanitation sector. However, the data are far from satisfactory.

Several difficulties arise in interpreting the available data to describe the global situation. In terms of coverage, a primary deficiency is that they do not include the People's Republic of China. In addition, numerous countries are missing for either 1970 or 1980, making the comparisons partial at best. In terms of validity, as has been noted elsewhere (8), there are at least three other deficiencies in the reporting concerning water supplies: 1) the national organizations preparing the reports are not necessarily in touch with prevailing conditions at the local level, 2) even reports from the local level may be misleading in failing to indicate whether or not a system is actually working or what proportion of the target population in fact is served, and 3) improvements by individuals or community groups not associated with a national program may go unreported.

National summaries sometimes reflect aspiration rather than accomplishment, and use handy data on expenditures and plans rather than the results of monitoring of operation. The extent to which systems reported as part of a national program have not reached the design population or are inoperative much or all of the time can be determined only by careful field checking which oftentimes is lacking. A 1977 study on one area in Kenya, for example, estimated that at the time of field visits less than 30 percent of the population which had been reported at national headquarters to be covered by completed projects was using reliably supplied water (9). At the same time, few countries have any way of keeping track of the amount of improvement such as well digging, cistern installation, and water delivery from potable sources, that is carried out by concerned individuals or groups operating without government funding.

The same sort of difficulties exist for the sanitation data. Information on the use of publically provided excreta disposal facilities is hard to come by. This is more a private than a public matter. Some improvements are made without subsidy. Moreover, as in the case of water supply, countries employ differing concepts of adequate service within the broad descriptions given.

The numbers in hand suggest that there has been a determined effort on the part of many developing countries to improve drinking water supplies over the past decade. Rapid increases in population have meant that despite these efforts, only modest gains can be shown in the proportion of the population covered by rural water supplies, and have led to a decrease in the relative water coverage in urban areas (Table 1).

In sanitation, for the countries reporting, the urban situation seems to have worsened, and the rural coverage to have increased only slightly (Table 2).

At the regional level, keeping the data difficulties in mind, comparisons can be made for water supply for those countries which were brave enough to present statistics in both 1970 and 1980 (Table 3). Sanitation data are so spotty that temporal comparisons seem unwarranted. The countries of Asia and the Pacific (ESCAP members), made the greatest strides with an increase of 11 in the percentage of their urban population served by water supply in 1980 over that in 1970, and 21 for the percentage of their rural population. It is true that this region had the furthest to go from the baseline of 1970, inasmuch as only 11 percent of the rural population was believed to be served at that time. It is likely that other regions may have already covered the more easily served populations, and that the cost and trouble of reaching the remaining needy people increases as the margins are approached.

The situation in urban areas of the three other regions appears to be holding steady or deteriorating, from a decline of 2 in the percentage of the population covered for Latin America to 8 in Western Asia. This most likely reflects the overwhelming of city services by the rapid increase in urban populations. From our scattered observations it is probable that the squatter settlements are underestimated in numerous cities. The situation was therefore less favorable than might be suggested by the figures quoted.

The reported increase in rural coverage in Africa is encouraging, but the slippage in rural coverage in Latin America indicates that those countries are not keeping up with population growth, and have not solved the problem of reaching small and scattered rural settlements.

The foregoing data suggest that what was done in most regions reporting in the decade 1970-1980 was not enough to match population growth, let alone exceed it. It is apparent that regional differences, and indeed those among countries, may be very great, and that caution should be exercised in generalizing about either world or regional trends. Aggregation of the national reports as presented to the General Assembly obscures gaps in data as well as the considerable number of countries whose records are at variance with reported global trends.

Table 1

ESTIMATED SERVICE COVERAGE FOR DRINKING WATER SUPPLY IN DEVELOPING COUNTRIES 1970-1980 a/

	1970		1975		1980	
	Population served (in millions)	Percentage of total population	Population served (in millions)	Percentage of total population	Population served (in millions)	Percentage of total population
Urban	316	67	450	77	526	75
Rural	182	14	313	22	469	29
Total	498	29	763	38	995	43

a/ Figures do not include the People's Republic of China.
Source: United Nations, General Assembly, A/35/367, p. 10.

Table 2

ESTIMATED SERVICE COVERAGE FOR SANITATION IN DEVELOPING COUNTRIES 1970-1980 a/

	1970		1975		1980	
	Population served (in millions)	Percentage of total population	Population served (in millions)	Percentage of total population	Population served (in millions)	Percentage of total population
Urban	337	71	437	75	372	53
Rural	134	11	209	15	213	13
Total	471	27	646	33	585	25

a/ Figures do not include the People's Republic of China.
Source: United Nations, General Assembly, A/35/367, p. 10.

Table 3

WATER SUPPLY COVERAGE, URBAN AND RURAL, BY REGION, FOR COUNTRIES REPORTING BOTH IN 1970 AND 1980[a]

Region	Number of countries	1970			1980			Change in percentage covered
		Total population (millions)	Water coverage (millions)	Percentage of total population	Total population (millions)	Water coverage (millions)	Percentage of total population	
Africa (ECA members)								
urban	29	62.8	51.5	82	96.2	78.9	82	0
rural	23	187.8	40.2	21	239.6	64.6	27	+6
Latin America (ECLA members)								
urban	18	153.1	115.6	76	212.6	157.8	74	-2
rural	15	110.6	25.2	24	129.1	27.8	22	-2
Western Asia (EDWA members)								
urban	9	13.9	13.3	96	22.5	19.8	88	-8
rural	7	18.0	6.1	34	18.4	6.2	34	0
Asia and the Pacific (ESCAP members)								
urban	14	220.5	130.2	59	300.3	209.5	70	+11
rural	12	737.3	77.6	11	917.3	298.6	32	+21

Footnote and source for Table 3

Source: World Health Organization, World Health Statistics Report 26 No. 11, 1973, pp. 724-731, United Nations General Assembly, "International Drinking Water Supply and Sanitation Decade Present Situation and Prospects," 18 September 1980, A/35/367, Annex V.

[a]The European (ECA members) region countries qualifying for technical assistance under UNDP procedures are not included as only one country reported in both years, and the figures listed for it for 1970 are not consistent.

One comment emerging from a review of the available statistics is that a better and different system for specifying and collecting data will have to be developed if any moderately accurate picture of the world situation is to be drawn and if useful lessons are to be derived from comparisons over time and from place to place. The data collection system tells us better what governments have attempted than what they have achieved, and it reveals little as to what goes wrong or where the promising opportunities may lie.

DIVERSITY IN NATURAL ENVIRONMENT

An important element in reappraisal and in fostering constructive action is recognition of basic differences in local situations. Any person who has observed or tried to design water supply and sanitation improvements knows that what would work in one terrain would not work in another, that a facility considered high hazard in a wet climate with poor drainage is low hazard in a very dry climate, and that what would be acceptable in one cultural setting would be rejected in another. The same national design, promotional or financial policy will have different consequences in different sections of the country or even within the same metropolitan area, depending upon those conditions. Accordingly, we note the main elements of diversity and give a few examples before discussing the problems of service level and motivation.

At least seven major classes of environment, taking into account climate, terrain, and settlement pattern, can be distinguished as shown in Table 4. A larger number of classes might readily be employed, but this suggests the principal determinants. In some cultural regions all settlements are nucleated, while in others the rural households are dispersed and even some of the commercial functions, such as markets, do not require permanent clusters of households. In those areas the conditions of climate and drainage set limits on the availability of water and the opportunities for sanitary disposal of excreta: very dry areas (D1) present special problems of obtaining water supply, and many humid, poorly drained areas (D3) offer other problems of obtaining unpolluted supplies and healthful excreta disposal.

Within areas of nucleated settlement the basic distinction is between urban clusters which enjoy the elementary forms of urban infra-

Table 4--A Classification of Natural and Social Environments for Water Supply and Sanitation

D. Dispersed settlement

- D1. Dry
- D2. Humid--well drained
- D3. Humid--poorly drained

N. Nucleated settlement

- N1. Urban infrastructure: roads, consumer services
- N2. Squatter
  - N2a. Dry
  - N2b. Humid--well drained
  - N2c. Humid--poorly drained

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structure, principally roads, water distribution systems, sewer systems, and social services such as police and fire protection (N1), and those squatter settlements where social services as well as roads, water and sewers are lacking or minimal in conditions of social instability (N2). Although the opportunities for water supply and excreta disposal may be more restricted in one combination of climate and terrain than another, those conditions are much more significant in limiting technologies and health hazards in squatter areas (N2). On a global scale the further distinction among hot, temperate and cold climates is important, but is omitted here because so much of the developing world is in tropical and sub-tropical zones.

When the opportunities and obstacles for improvement for a given area are appraised it becomes evident that the prescription and the means of formulating it may vary tremendously. For example, health hazards are bound to be lower with dispersed settlements (D) than in nucleated settlements (N), and to be highest in squatter settlements in hot, wet, poorly drained situations (N2c). Costs will be lower in flat, dry, nucleated settlements (N2a). Organization of community effort may be easy in groups that have established infrastructure (N1), and intricate in the peculiar circumstances of squatter settlement (N2) where, however, a special kind of entrepreneurial energy and ingenuity may be marshalled.

THE PROBLEM OF BEHAVIOR CHANGE

When we canvassed the available literature on water supply in developing countries in the early 1960s, almost all of it dealt with questions of technology and financing. Training was noted as related mainly to those two areas. Looking at it again in the past year we are impressed by the shifts in problem definition consistent with the policy changes noted above. The emphasis now is upon integration with other programs, community involvement, and motivation. Each of these presumes some degree of behavioral change, oftentimes radical, as does the shift noted above in attitudes toward the target population and the acceptable service levels. In a real sense the declarations and policy changes made by inter-governmental and international agencies are the easiest to achieve. Behavior change probably comes more rapidly among policy makers at the ministerial level and representatives of bilateral and multilateral funding agencies than among national operating officials, local officials and leaders, and household members. It should be remembered, however, that in many instances projects have failed because the top-level officials and design technicians were insensitive to the preferences and capacities of the householders and local officials. What may be needed to achieve goals in those instances is a change in the attitude and habitual action of the remote officials and experts rather than of the consumer.

Recent discussions of water supply and sanitation carry frequent reference to the term "motivation." For example, Wolman (10), looking at the question of why technologies have not provided the answer to disease prevention, says "In addition to demonstrated intention, what is universally lacking is manpower at all levels of expertise and managerial or institutional structure to carry out programs and projects. Curiously enough, money is not the major constraint. Real motivation at all levels of society probably is the dominant key to even partial success."

In many situations where technicians or administrators are confronted with consumers who misuse or fail to use water and sanitary improvements or who are indifferent to proposed changes regarded by the observer as better, it is common to fall back on ignorance or lack of motivation as the diagnosis and on education, or simply information, as the cure. The term "motivation" is used in a variety of connotations. It can mean recognition of a person's own interests or desire to achieve an improvement. Or it can mean forcefulness in seeking to gain what he or she knows to be good and wants. The corrective measure of education accordingly is directed at helping people to understand their needs, or to cultivate a concern to meet the needs or to see how they may act effectively.

In the context of the Decade, the question can be asked, what if everyone in top administrative and policy positions in the world were convinced that safe water supply and sanitation were essential ingredients for better health and well-being as declared at the General Assembly, would this then lead to any actual improvements? The same limiting constraints on technology, skill, resources and money would be present as before, but would the change in knowledge and feelings about articulated goal and acceptable methods lead people to better marshall their limited resources to bring about the desired results?

A good deal is known about what is involved in fostering behavior changes in a variety of situations (11). Much of that distilled experience suggests great caution in expecting that policy declarations or information programs will have a significant effect (12). There is no necessary causal relationship between what people say and what people do (13). At the same time, a few lessons can be drawn which may have relevance to the Decade effort. We point out three of them as directly and immediately pertinent to an attempt to translate the results of a general reappraisal into site-specific action. A recent review of this field (14) indicates these factors are important:

1) The degree to which information about what kinds of concrete behavior are most likely to bring about the desired goal is included in the general body of knowledge about a subject.

2) The degree to which the new knowledge is consistent with the present attitudes of the people involved and is perceived by them as useful to the attainment of a wide spectrum of other valued goals, such as better housing, health, employment, status in the community, etc.

3) The degree of institutional support for introducing and implementing the new methods and technologies.

A somewhat obvious prescription but one which commonly has been ignored in past is to start from what people in all the publics involved currently feel and do. When those sets of attitudes and behavior are known it becomes more likely that subsequent policy or design or education will have a beneficial effect. There are relatively forthright means of doing this for a community by means of six steps: 1) informal interviews with community leaders and a few knowledgeable residents to identify attitudes, present practices and preferences, 2) design and testing of a structured interview questionnaire, 3) survey of a representative sample of households, 4) discussion with the community of the results of the survey, feasible technologies and service levels in terms of the costs involved and willingness to pay, 5) training during construction, and 6) community-based continued operation, maintenance, collection of fees and involvement in monitoring (15).

These are devices that can be followed inexpensively and with benefit wherever a new program is contemplated. They lay the groundwork for genuine monitoring. From that base, attention can be directed to the three points noted above.

The synthesis of knowledge about concrete actions which may be taken with respect to water supply and sanitation may not be complete as yet, but it has come a long way since 1970, largely because of careful investigations by international organizations, including the World Bank and regional offices of WHO. These were supplemented by increasing commitment to this sector from individual developing countries, UNDP, and donors from other parts of the world, including the Canadian IDRC, the Swedish SIDA, and the WHO-Dutch International Reference Centre for Community Water Supply. Many reflect a shift towards considering health and well-being as the primary goals, rather than the provision of water supply and sanitation facilities, but there is some evidence that these goals are not completely accepted by either donor or recipient governments or by the target populations. The basic strategies to attain such goals include hygiene education, some kind of primary health care, water supply, sanitation, improved nutrition and immunization. There is agreement that water supply and sanitation are necessary to improve health, but are insufficient.

The question of relationship of water supply and sanitation to public health is directly and currently practical as well as theoretical. Its answer plays an influential role in decisions as to allocations of public expenditures and the design of public assistance programs. In the Spring of 1980, for example, the U.S. Agency for International Development went through a somewhat competitive review of the problem because program choices apparently turned on the slant of the favored solution. It appeared to outsiders that a primary justification for water supply and sanitation on the grounds of health benefits would be used in a cost effectiveness framework to show that other interventions such as vaccination or oral rehydration therapy would be preferable in the short run. The ambiguity of the evidence on the side of health benefits assures that such a choice is essentially a political judgment as to perceived gains to society as a whole.

The spelling out of the technological and social alternatives for improvements in water supply and sanitation has increased enormously in recent years. It is now possible to pick from a large number of models for safe excreta disposal, and to know how to upgrade a system over a period of time, thanks to the World Bank. Guides on how-to-do-it for community involvement and participation have begun to appear, such as that in the process of preparation by Whyte for the International Reference Centre and WHO (16).

In brief, the further supply of information on methods of making water supply and sanitation improvements now allows its packaging for particular publics and environments with the primary goals of health and well-being in view.

CONSISTENCY WITH OTHER AIMS AND METHODS

It is well demonstrated that different ethnic and economic groups have different preferences for community facilities. Regardless of the priorities set by a public health or community affairs expert, the consumers may have strong support for one kind of latrine and aversion to another or preference for a particular latrine location for reasons that are consistent with their own value systems and experience but unsuitable in the view of the expert. This is illustrated by the responses made by consumers in a number of disparate rural communities in reply to studies supported by the World Bank (17).

In that connection, it is useful to think not of one "public" but of eight different publics that may or may not share the same perceptions of environmental hazards and opportunities, and that may or may not express the same attitudes toward improvements. They are:

1) individual household consumers,
2) members of the consumer group exercising some kind of responsibility for communicating information or acting in behalf of the group,
3) officials of community government,
4) officials of provincial and state governments,
5) operating officials of national governments,
6) policy makers at the national ministerial and budgeting level,
7) consulting and contract engineers, and
8) representatives of bilateral and multilateral funding agencies.

In each class the rewards for individuals and groups that are built into the institutional system need to be examined, as each may expect to get different satisfactions and achieve different goals from participation in water supply and sanitation improvements.

The individual consumer usually receives obvious benefits from improved access to water in the form of convenience, increased free time, and perceived health benefits. Other goals may be met also, such as increased opportunity for income generation, employment opportunities through training programs, or status in the community resulting from participation in responsibility for the planning and realization of the project. Disadvantaged groups such as women and children may receive special benefits in terms of savings of time and energy.

Members of consumer groups and the groups or organizations themselves may be interested as much in their status in the community and the enhancement of their political leadership as in improvements in water supply or sanitation.

Local officials, although gaining in local popularity from desirable community improvements, may thereby run into conflict with the national or regional authorities, and thus jeopardize their career advancement.

The officials in complementary agencies, such as health or solid waste departments, may have little to gain from cooperation with the water supply and sanitation agencies, and time spent on this may even cause them to lose some advantages in terms of career advancement.

For national government officials, there may be political gains in popularity and stability from the installation of water supply projects, less gain from concentration on operation and maintenance, and even less from the promotion of sanitation projects.

Engineers play the key role in the design and construction of most improvements in water supply and sanitation, and in many areas their stamp of approval is essential to the initiation of a project. Bearing this responsibility and reflecting training that instills caution, the engineer is more reluctant than some other professions to employ methods or points of view which are new or for which there has not been previous training. Therefore, the engineer may require information on successful cases of innovation, support from his peers and possibly re-training in order to function well in the effort.

The bilateral and international funding organizations have a special responsibility, as their requirements may divert the national governments from stated priorities. They may gain in international recognition and attain some economic benefits, but it may be at the cost of imbalance in the national programs, and a building up of large recurrent costs with no mechanism for meeting them.

Insofar as these different and sometimes conflicting aims can be recognized and reconciled, the more likely the success of a program.

Examination of the record for 1970-1980 reveals the inadequacy of much of the statistical material in revealing the successes and failures. It also suggests another reason why it is risky at this stage to draw generalizations about measures which would enhance efforts during the Decade. This is the lack of careful monitoring of improvement projects. Much of the small amount of monitoring that has been carried out is confined to data on expenditures, size of installation, revenues, and water pumpage. There is little information on actual use behavior or on the conditions affecting acceptance, maintenance and operation. Moreover, the monitored project often is a demonstration effort which is difficult to replicate, and even when representative of a larger number the results may not be shared regularly with the management in a way which affects policy.

We look forward to the development of more effective monitoring of new projects, with resulting use of the data by the planners and operators, and to the findings of post-audits of selected completed projects.

SERVICE LEVEL IMPLICATIONS

The goal of water supply and sanitation for all is being set at a time when there is intense competition for funds for other sectors, especially energy requirements. The World Bank has estimated that the total cost of reaching the goal could be a minimum of $300,000 million in 1979 dollars, and might go as high as $600,000 million unless a suitable level and mix of service levels for both the urban and rural subsection is used. The total annual investment for the period 1979-1983 is estimated at $12,000 million annually, only about 40% of the average amount needed to reach minimal level of service for all by the end of the 1980's. In the World Bank's view, the assumption that even this level of investment will be sustained may be overoptimistic (18). The level of service becomes a critical factor.

Two questions arise in the allocation of funds regarding level of service. First, what standards are to be achieved? Second, who shall be served: should those with wealth and political influence be favored with a higher and more costly level of service, or should a lower level of service be shared by all?

Water service levels can be classified on a scale of descending importance as providing for 1) basic needs, 2) amenities and 3) convenience and privilege.

The basic needs range from the 2 to 3 liters per capita daily (lcd) needed to sustain life to the 20 to 40 lcd which provide for cooking, washing and other household uses as well as drinking, and ensure most health benefits if the water is of a safe quality (19). These amounts can be provided by public water points but the fullest health benefits are obtained if the connections runs to the household site. Beyond these amounts, uses for lawn and garden watering and car washing represent added convenience and luxury. The water level service affects the sanitation technologies which can be considered. Low amounts restrict the consideration of water flushing devices, while high amounts require plans for waste and water disposal.

The provision of urban water supply and sewer facilities, like the supply of central gas and electricity, involves in most societies a process of standard setting radically different than that followed in the individual supply of food, clothing, and much shelter when the consumer decides on the tradeoffs. Public agencies in recent times have felt obliged to attempt to meet high standards for water quality in providing supplies which would reach all sectors of the community. Although the poor were known to have deficient diets, to be ill clothed and ill housed, to be deprived in transport, and often meager in educational facilities, their water was to be of as good quality as that enjoyed by other groups. The one major concession to the egalitarian view was in the degree of convenience in access to supply: the distinction among piped water in household, carrying water from a courtyard tap, and carrying water from a street hydrant. This is a distinction of major significance in looking to the Decade. While there is a strong egalitarian thrust to the pronouncements of various international bodies, the extent of the commitment to these on the part of individual countries varies enormously.

The inflexibility on the part of government authorities regarding appropriate standards is not limited to water supply and sanitation. During the 1970s there was wide and growing recognition that the standards in common use for provision of shelter in developing countries were inappropriate for the prevailing environmental, fiscal and manpower conditions. As documented by Mabogunje, Hardoy, and Misra, these standards for such parameters as enclosed space per capita and structural building materials were strongly influenced by experience in Western, industrialized countries (20). In many situations they were unsuitable for the local conditions and in most situations they were impracticable from the standpoint of cost or technical proficiency.

Arguments over the suitable service levels for housing, water supply and sanitation, and the standards to be applied to them, have not yet been settled in many parts of the world. The swelling urban populations of the developing world indicates that people are voting with their feet. They are accepting lower levels of service in order to become part of a city that offers at least the chance of employment, and possibly education for children and better medical care.

Consider a capital city in a tropical region where people are moving from the countryside at a very rapid rate, so that at present 70%

of the population is estimated to live in slums where 5 to 10 people sleep in one room or in shantytown housing of cardboard and tin. A large portion of these have no easy access to city services for water or sanitation. The government, in attempting to meet the aspirations of these people for a better life, has borrowed money from the World Bank to buy land and build sites and services projects with individual household taps and flush toilets. The influx of settlers continues. These plots are too expensive for many of them. A new project is proposed for 2,500 plots with standpipes for water and individual latrines for sanitation, a feasible alternative in this environment. The repayments on these plots would be 1/12th of that required with conventional arrangements for water and sewage. After two years of discussion, the government rejects this proposal as substandard, a second best solution. People stay in their present miserable housing with its attendant health hazards from contaminated water supplies and indescriminate excreta disposal. This example raises issues of equity in service level, the aspirations of the settlers, and the resulting costly delays to all parties.

It is useful here to ask by whom is the proposed project considered inferior? It is clear that the responsible Ministry of the Government thinks it so. It is equally clear that the prospective inhabitants would consider a move to such plots as an improvement in their lives.

In such a case an administrator may feel he or she should not accept a second best solution, or a designer may be unwilling on grounds of professional ethics to depart from a written criterion.

It is not uncommon to witness an exchange between a high government official and a consultant or design engineer running somewhat as follows:

Consultant. "The design provides for patio water taps and pit latrines."

Official. "Why don't you put taps and water closets in the houses?"

Consultant. "You can't afford it: they are far too expensive."

Official. "Are you treating all those people as second class citizens?"

Consultant. "This is the best you can do for them."

The notion of second best is inherent in most individual and collective decisions. As we all know, people and groups accept something short of the ideal because they can't afford the best and must repeatedly trade-off the losses from one action for the gains of another. So it is with water supply and sanitation improvements. Individual consumers may choose to use their limited resources for one kind of facility while deferring other facilities indefinitely. For example, they may prefer to have a new road to market their produce rather than a water system or a health clinic.

All too often the response of an official presented with second best solutions that violate his sense of propriety and his training in acceptable standards is to ignore both the solution and the situation itself. This variety of psychological denial prevails with regard to the treatment of many squatter settlements. Confronted with a shantytown that has sprung up overnight without potable water supply and excreta disposal facilities, and avoiding the temptation to bulldoze it temporarily off the landscape and seeing no way of providing the taps and sewers which would conform to approved practice for the older residential districts, the official bodies choose to act as though it did not exist. Sometimes it takes an outbreak of disease or civil disorder to trigger minimal improvements, as was the case with cholera and typhoid episodes which led to improved water supplies in Massachusetts in the 19th century (21).

A more realistic approach to standard setting, together with appropriate institutional support, would have helped the people in the example cited above to better their environment over a period of time, with health benefits from the very beginning.

Here we have a basic difference between urban and rural and between nucleated and dispersed settlement patterns. Where there is not dependence upon a centralized facility the public agencies can be more relaxed about the standards employed.

It is interesting in this regard to note that a few years ago in the People's Republic of China where there was a high degree of uniformity in provision of food, clothing and shelter the responsibility for water supply and sanitation appears to this observer to have been largely decentralized. While the primary goal of health was generally accepted there was relatively little guidance as to how to reconcile the efforts with other community goals and programs.

Where the decision is to provide a lower level of service to all, and where the rising expectations of the more well-to-do are not met, will they accept a lower level of service so that more people can achieve a minimum level? Will they accept what they may consider a second best situation?

It should not be overlooked that the level termed "convenience and privilege" may provide a strong incentive for wealthier consumers to support and disproportionately finance a scheme. A recent evaluation of rural water systems in Thailand indicates that those which provided community-wide access to water from public taps were lagging in collecting flat-fee revenues. When these systems were converted to largely private metered connections, they have proved financially viable (22). In this circumstance the wealthier groups are maintaining their superior level of service, but are supporting minimum services for all others.

There are some bits of evidence that people will if necessary, accept a lower service level, and may in practice be accepting it at present. Intermittent service is a constant and increasing problem in many of the cities of the developing world (23) and this affects the rich as well as the poor. In a rural area in Kenya the well-to-do consumers are no longer willing to join and support a system that does not function much of the time. However, this means that they may lose out on having any service at all (24).

The term "service level" is a static concept, as if once installed, a water system or sanitation facility remains as is forever. In actuality, the concept is a dynamic one, for given the state of operation and maintenance in most developing countries, the level of service may vary from day to day or house to house. What is the convenience or indeed, health benefit of a flush toilet if there is only occasional water pressure enough to flush it? Or the benefit of a deep well whose engine has run out of diesel fuel, with no money locally available for more? It may be that reliability will become a more important concept than level of service.

Another indication that people can reduce their expectation of service when convinced of the necessity comes from an unexpected quarter, one of the wealthiest areas in the United States, Marin County, California. As will be reported later in this session, the inhabitants, in response to price and public appeals, reduced their daily per capita water use from very high levels to those much nearer the amount consumed in single-tap households in developing countries (25). The necessity in the developing countries may be more financial than meteorological but is likely to exist.

CONCLUSIONS

The Drinking Water Supply and Sanitation Decade follows a period of reappraisal both of the aims and of the methods in making improvements in these areas of basic need. Building on the earlier pronouncements of the Habitat, Water and Alma Alta health conferences, it reflects changes in policy at international and national levels as to drinking water and sanitation needs and alternative ways of meeting them. But if the goals are to be met the policy changes will have to be shared more widely, and translated at policy, engineering and consumer behavior levels into consistent action.

Many changes have already taken place. International cooperation is being strengthened, some national organizations are candidates for revision, funding volumes and channels are being re-examined, methods for providing for consumer participation and responsibility are in flux, the notion of a single quality standard is being reassessed, and so on. We are cognizant that these and other initiatives will all influence in some degree the success of the Decade. In this paper we have tried to deal with only two aspects of the problem: the implications of changes in service level, and, linked to that, the question of what promotes changes in behavior. Both of these affect sound action and the avoidance of failures of the type which have been all too frequent in past efforts. To this end it is recommended that emphasis be placed on the following points:

1. The understanding that water supply and sanitation measures in many areas can only be effective when developed in conjunction with other community improvements and public health measures will have to be cultivated. The level of service accepted by a community must be

related to other choices of community improvements, and to the community's understanding of health needs and goals. Many water supply, sanitation, health education and development experts need conviction that this is practicable.

2. Stress will be needed on the diversity of ways in which the goals can be attained in specified natural and social environments.

3. Institutional support will be required to reinforce the legitimacy and feasibility of the modified goals and methods. It will not be enough to issue endorsements of citizen participation and the cultivation of motivation; the participation and motivation should be seen as actions growing out of training, information and reward systems. This support will have to come on an across-the-board basis, not as a pilot program which is isolated and usually not replicable on a broader scale.

4. Recognition is needed at all levels that the Decade is largely an egalitarian initiative in which widespread gains in health and living conditions may be accompanied by small local losses in privilege or convenience. What appears as second best in levels of service to some will turn out to be first best in satisfying health goals in many national circumstances.

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MONITORING CHANGES IN ECONOMIC DEVELOPMENT: HIGHER ENERGY PRICES AND PROJECT REAPPRAISAL

by DeAnne Julius[a]

Introduction

Probably the most significant development of the decade of the 1970s was the large and sudden increase in the world price of oil. The dramatic rise in the price of that one commodity has caused a significant slowing in the economic growth rates of both industrialized counries and the oil-importing developing countries (OIDCs) and a major redistribution of global wealth. It is now generally agreed that the energy problem of the 1970s was not a passing phenomenon but rather marked the end of an era of cheap oil and gas, and the transition to a period of high cost energy.[1]

The implications of this change are far-reaching and affect the work not only of economists and energy specialists but also of engineers and managers not directly connected with the energy sector. Whereas prior to 1974 energy was endowed with no more importance than that of any other input in production, it is now necessary for planners in every sector to reappraise past choices in light of their implications for future energy use or production.

This paper discusses the impacts of the changed energy situation on investment planning and project evaluation in the water and sanitation sector. In general, these impacts are of two types: changes in macroeconomic factors that affect the global distribution of and national demand for water and waste projects; and the microeconomic effects on project evaluation and the choice of technology.

Macroeconomic Effects

At the international level a massive shift in wealth has already taken place. The annual rate of growth per capita of the OIDCs during the 1970s was 2.7% compared with 3.1% during the 1960s. In contrast, the annual per capita growth rate of the oil exporting developing countries (OXDCs) accelerated from 2.8% during the 1960s to 3.5% in the seventies. Projections for the 1980s are essentially for a continuation of these trends (see Table 1).

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Table 1
Economic Growth, 1960-1990

	Population 1980 (millions)	Average Annual Real Growth of GNP per capita 1960-70	1970-80	1980-90[a]
Low income oil importers	1133)	3.1	0.9	1.6
Middle income oil importers	701)		3.1	2.6
Oil exporters	456	2.8	3.5	3.2
Industrialized countries	671	4.5	2.4	2.8

[a] Average of high and low growth cases.
Source: World Development Report, 1980, World Bank, August 1980.

The OIDCs

With four-fifths of the developing world's population in the OIDCs, these lower growth rates imply increased stringency in the investment criteria that will be applied to projects affecting the bulk of the world's poor. With the International Drinking Water and Sanitation Decade now underway, many countries have pledged to devote a larger proportion of their investment resources to the water and wastes sector. But with the lower growth rate in total capital available, and with inflation levels likely to remain high over the decade, the sector will probably see only a marginal increase in its real available investment resources. This implies that in order to reach the ambitious Decade goals of greatly expanded coverage,[2] the cost effectiveness of sector investment will have to be dramatically improved.

Fortunately, the technical means to do so are now at hand. Recent work, both on water supply technology[3] and on waste disposal,[4] has demonstrated the technical feasibility of providing water service and adequate sanitation at a fraction of the cost of conventional technologies used in industrialized countries. Field applications of these technologies, along with their supporting health and social infrastructure, are now underway in over a dozen countries.[5] The major remaining obstacle to the successful spread of these efforts is the politically difficult change in philosophy needed in some countries to expand sector priorities from improving the service levels and coverage of existing water and sewerage systems to include the wide-spread provision of low cost facilities to those who currently lack them. In addition, the "human infrastructure" requirements for the health and social aspects of introducing new water and sanitation technologies are very large.

The OXDCs

In some of the oil exporting developing countries the situation is surprisingly similar to that in the OIDCs. This is because OXDCs such as Ecuador, Egypt, Indonesia, Nigeria, and others are not capital surplus countries and have large populations with many unserved needs. For some, even when financial resources become available, skilled manpower and other constraints will prevent the effective construction and maintenance of conventional water and sewerage systems.

In the seven capital surplus developing countries,[6] investment capital is not a constraint. Curiously enough, however, all of these countries are very poor in water resources.[7] Since conventional technologies are extremely water-intensive, sector development in the capital surplus countries can follow one of two directions. Either conventional water resources can be supplemented with desalinization or other expensive water production technologies; or water-saving, non-conventional systems can be designed to provide the very high convenience standard that the wealthy population demands. If this latter route is followed, it could have a significant payoff for poorer countries in testing high standard, water-saving technologies that may represent the ultimate upgrading of initially simple and low-cost systems.

The Industrialized Countries

In the industrialized countries, the adjustment to higher energy prices has stimulated interest in developing alternative energy sources. Two of the most promising of these (see below) are highly water intensive and, in the U.S., would be concentrated in the western states where water is a major agricultural input and is already becoming relatively scarce. In economic terms, the impact of these new uses for water is to increase its opportunity cost and thereby signal its increased value in all uses. Only relatively high-valued uses may be able to successfully compete with energy-related water demands, and the incentive for water-conserving technologies in all uses will be increased.

The first economically promising, but water intensive, new energy source is oil shale.[8] Oil shale deposits are found throughout the world. Those in some countries (Scotland, Spain, Australia) have been the sites of small-scale industries in the past; other countries (Brazil, the U.S.S.R., the People's Republic of China) either have such industries or are building them. Large deposits are also found in the eastern and midwestern United States, but because of their richness and accessibility the deposits in the Green River formation of northwestern Colorado, southwestern Wyoming, and northeastern Utah are the ones most likely to be developed in the near future. Overall, these deposits contain the equivalent of over 8 trillion barrels (bbl) of crude shale oil, although only about 400 billion bbl could be recovered economically with existing technology.

Water is a critical resource in the oil shale region. The growing demands of towns, farms, mines, and recreation, along with the requirements for export to urban areas such as Denver, are already beginning to place a strain on the region's water supplies. There is at present enough surface water in the region to establish an oil shale industry, although new reservoirs and pipelines within the area would have to be constructed to supply water to the plants. However, the water resources are not sufficient to sustain a large industry in the longer term without diverting water from other uses.

As shown in Table 2, depending on the technology chosen, producing

50,000 bbl/day of shale oil would consume 4,900 to 12,300 acre-feet/year of water for mining, processing, waste disposal, land reclamation, municipal growth and power generation. A one million bbl/day industry using a mix of technologies might require 170,000 acre-feet/year, which would be about 30% of the amount presently used by irrigated agriculture along the White and Colorado Rivers. Depending upon the assumptions made about the growth of water demands in industrial, residential, and agricultural uses (and excluding recreational and environmental concerns), a surplus of water would be available for oil shale development for the next 25 to 35 years. However, the long lead times necessary to bring the technology up to commercial scale production, coupled with the major environmental concerns raised by large-scale syncrude developments, significantly shorten the period for unconstrained production.

Table 2
Requirements for Oil Shale Production

Resource	1990 production target, bbl/d: 100,000	400,000	1 million
	Requirements		
Institutional			
Design and construction services, % of 1978 US capacity needed each year	minimal	12	35
Plant equipment, % of 1978 US capacity needed each year	minimal	6-12	15-30
Economic and financial[a]			
Loans, $ billion	$0.9-1.35	$3.6-4.2	$9.0-13.5
Equity, $ billion	2.1-3.15	8.4-9.8	21.0-31.5
Total, $ billion	3.0-4.5	12.0-14.0	30.0-45.0
Annual, $ billion[b]	0.6-0.9	2.4-2.8	6.0-9.0
Water availability[c]			
Water, acre-feet/year	9,800-24,600	39,200-98,400	100,000-250,000
Socioeconomic[d]			
Workers	5,600	17,600-22,400	44,000-56,000
New residents requiring housing and community services	23,000	82,000-95,000	118,000-236,000

a Third-quarter 1979 dollars.
b Maximum annual requirements for a 5-year construction period.
c Assumes 4,900 to 12,300 acre-feet/year for production of 50,000 bbl/d of shale oil syncrude.
d Assumes 1,200 construction workers and 1,600 operators per 50,000 bbl/d plant. Multipliers used for total increase = 2.5 x (construction workers) + 5.5 x (operators). Ranges reflect phasing of plant construction.

SOURCE: Office of Technology Assessment.

There is evidence to suggest that once water availability does become a constraint, the oil shale industry may be well placed to compete with agriculture and other users. At the margin, the most expensive water supply option (import from other hydrological basins) could cost about $1/bbl of shale oil produced. With the benefit side of the oil shale equation tied to the price of imported oil, the industry could probably afford sufficiently high water costs to crowd out other uses.

The second energy-related technology that is likely to increase the competition for, and thus the opportunity cost of, water in the U.S. is the development of coal slurry pipelines as an alternative to rail transport.[9] A slurry pipeline involves the pumping of finely ground coal suspended in water (or potentially some other liquid medium) through a pipe over a long distance. The technology is proven and, while the economics depend critically on site-specific parameters (e.g., annual volume of coal shipped, distance traversed, mine spacing, security and location of market, etc.), under a reasonably wide range of circumstances, slurry pipelines are economically superior to rail.

The amount of water required to transport coal varies inversely with the moisture content of the coal. For 30 million tons/year of coal with a 20% (10%) moisture content, for example, about 14,000 (18,000) acre-feet/year of water would be required. It has been estimated that a pipeline carrying 125 million tons of coal per year from eastern Wyoming would use about 3% of available surplus water flows in that area. The economic and social impacts depend on the degree to which pipeline water demands infringe on alternate uses for the same water. Sufficient water is physically, although not necessarily legally, available in the three western coal-producing areas mentioned to service both existing uses at present levels and a substantial number of coal slurry pipelines. However, pipelines would compete directly with other possible future uses.

The water-related impacts of coal slurry pipelines can be mitigated if sources of water can be found which are usable for slurry but not for most other purposes. There are three promising possibilities: irrigation return flows, primary or secondary sewage effluent, and saline ground water. In each instance the water may need some purification for use as a slurry medium but this appears to be a manageable requirement. Sewage effluent will not be available in sufficient quantities in many areas to serve as more than a supplementary water source, and the sizes and locations of saline ground water sources are generally not well known. An additional means of mitigating the pressure on limited water resources is to recycle the recovered slurry water by return pipeline. The limiting factors are the high, but not necessarily prohibitive, cost of such a self-contained system and the fact that not all of the water can be readily separated from the coal.

In summary, the major impact of the changed energy situation on the water and wastes sector in industrialized countries is likely to be a positive shift in the demand function due to new uses for water in energy-related activities. In contrast, the LDCs are likely to face a tightened budget constraint. Both of these conditions, however, will have the effect of encouraging water-saving technologies and reuse possibilities in the water and wastes sector.

Microeconomic Effects

At the project level, higher energy prices may affect the choice of technology by discouraging those that are relatively energy-intensive either in their construction (e.g., excavation equipment) or in their operation (e.g., diesel powered pumps). Projects that are energy producers (e.g., biogas digesters for waste disposal) will obviously look more economically attractive.

Because domestic energy prices in many countries are significantly below opportunity costs, it is important for purposes of project evaluation that the appropriate economic cost of energy be used. There is some confusion, however, over how to determine the economic cost of resources which may be depletable (or not), tradeable (or not) and substitutable for each other. This section reviews the basic theory of economic costing as it applies to energy, and indicates the types of problems that may arise in practice.

Tradable Energy Products

The economic price of any product, including any energy product, is its opportunity cost to the country. Since most energy products are tradable, this can often be easily calculated as the highest price for which the product could be traded either within the country or with other countries. Examples of tradable energy products are crude oil and most refinery products. Here the relevant measure of opportunity cost is the FOB or CIF border price for international trade regardless of whether this is set by a cartel of major producers or by the operations of the free market. The value of an extra unit of production is the potential value of foreign exchange that is earned if the product is exported or, if that particular unit is to be consumed domestically, the value of foreign exchange that is released by reduced imports.

This principle also applies to those energy products which are not actually traded but which substitute for products that are. For example, many developing countries use natural gas as a replacement for fuel oil in generating electricity. In some advanced sewage treatment facilities natural gas is used to supplement available biogas. The production cost of the natural gas is often less than $1.00 per million BTU while the equivalent international fuel oil price is above $4.00 per million BTU. Even after appropriate adjustments are made for transport differentials (e.g., pipeline versus tanker) and conversion of the boiler, there is often a substantial differential -- sometimes called "economic rent" -- between the production cost and the opportunity cost of the gas. (Indeed it is this differential that has made indigenous energy investments so attractive in recent years.) Questions may arise about the appropriate distribution of the economic rent, but the economic price of the gas is still the adjusted border price of its tradable substitute.

In many countries, non-traded energy products such as natural gas or coal are or could be used to substitute for a variety of tradable energy products. An important question then arises about which substiture to use for economic cost purposes. For example, an alternative use for natural gas is as a feedstock for fertilizer and petrochemical plants where it might substitute for naphtha whose international price is above $7 per million BTUs.[10] For a country with limited gas resources it is important that the gas first be deployed to its highest value use, and only when that is satisfied should it be used to substitute for lower valued resources. The general rule is that the opportunity cost of the resource will be equal to its value in its marginal use as one moves down the demand curve from higher valued to lower valued uses. Thus, the economic price of gas in a country with very limited reserves will be very high to indicate that at the margin it should still be used only in relatively high value uses. In a country with more gas, where it substitutes for fuel oil as well as naphtha and other higher value fuels, its marginal value would be as a fuel oil substitute. At the extreme, for a country with gas reserves many times larger than projected demand for all its uses, the <u>marginal</u> use may be simply to leave it in the ground. For that country gas should be treated as a nontradable.[11]

Non-Tradable Energy Products

For a product that is neither traded itself nor acts as a substiture for other tradable products, the opportunity cost must be based on the economic value of the resources used in its production. This is a familiar rule to those involved in project evaluation in many sectors, from agriculture to transport to water supply. For certain energy resources, however, it contains an extra twist because an exhaustible resource possesses a scarcity value or "user cost" which must be added to its production cost to determine its economic price. Other things being equal, this user cost will be positively correlated with the current and expected demand for the product, and the expected level of prices for the substitute product which will be used to replace it once stocks run out; and it will be negatively correlated with the size of the exhaustible resource's reserves and with the social discount rate which is a measure of the extra value attached by the country to an extra unit of consumption today versus one in the future.

The precise calculation of the user cost for a particular case is generally impossible because of uncertainties about future demand elasticities, the size of the resource base, and future prices of substitutes. A very rough estimate is sometimes made by taking the present value of the substitute product in the year when reserves are expected to be depleted. Fortunately, however, it is very seldom that there is a need to estimate the user cost since it only becomes important for depletable products which are not tradable and which do not substitute for other products which are traded. This combination of curcumstances does not frequently arise.

Two further considerations are important in estimating the economic cost of energy resources. The first of these relates to the flexible nature of the tradable/nontradable distinction. For many energy products, this depends partly on the availability of appropriate technology and the facilities for storage and transportation and partly on the geographic, economic and political situation of the country of production and the relative product price structure. These characteristics vary considerably from country to country, and a product which is considered nontradable in one context may enjoy a healthy trade in another part of the world. Low-grade coal is an example of this type of energy product; it may only become a tradable if there are convenient transport and storage facilities and a specific, easily accessible market.

The second point relates to the technical problems that may be involved in switching from one fuel to another. It is important that appropriate conversion coefficients for calorific value and fuel utilization efficiency are used in any comparisons. A classic case is that of coal versus diesel in locomotives; theoretical calorific equivalence is about 2.5 tons of coal to one ton of diesel, but if the ash content of the coal, the additional facilities required for using it, the transport losses due to powdering and the very low operating efficiency (about 3%) of steam locomotives is considered, the real ratio is nearer 12:1.

To recap, then, the appropriate measure of the opportunity cost of an energy product is the highest price that it can be traded for either nationally or internationally except in the few instances where the product is neither tradable nor acts as a substitute for other tradables. It is only when the product cannot be traded, and cannot be used to substitute for another product which is tradable, that the opportunity cost of the product is set by its cost of production or replacement.

Conclusions

The impact of the shift from cheap energy to scarce and expensive energy is one that pervades many aspects of economic growth and investment planning. We are only beginning to understand the nature of the adaptation that will be required in the coming years until a competitive substitute is available. Experience in the seven years since the first oil price shock, however, indicates that existing institutions and financial markets are probably flexible enough to accommodate the large transfer of wealth that has taken and will take place. Further, existing methods for investment planning, project selection and choice of technology can be used to translate the higher energy prices into appropriate responses in energy-using and energy-producing sectors.

The magnitude of the changes likely to be induced in the water and sanitation sector -- both in the distribution of investments across countries and in patterns of project design -- are difficult to predict. However, the likely direction is fairly apparent. In developing countries, macroeconomic constraints caused in part by higher energy prices,[12] coupled with ambitious service targets linked to the International Drinking Water and Sanitation Decade will increase the incentive to adopt low-cost technologies. In the industrialized countries, the demand for water as an input to new energy projects will raise its opportunity cost and thus make proper water pricing policies (for <u>all</u> users) an essential concern. Water-saving technologies will become more attractive, and the potential for recycling sewage effluent -- either in coal transport or in competing non-energy uses such as irrigation -- may partially offset some of the increased water costs to residential consumers.

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10. Of course, this figure would have to be adjusted to account for differing transport and conversion costs in order to determine the opportunity cost of the gas in this use.
11. However, if a country's gas reserves are very large, export either through pipeline or liquefaction may be economic, thereby making the gas directly tradable.
12. Price increases have hurt LDCs, both directly through their increased import bills and indirectly through the effect of lower industrial country growth rates on LDC exports.

MONITORING CHANGES IN ECONOMIC DEVELOPMENT: HIGHER ENERGY PRICES AND PROJECT REAPPRAISAL

KEY WORDS: Energy, Economics, Benefit-cost analysis, Technology assessment, Conservation, Oil shale, Environment, Developing countries, Water-saving technology

ABSTRACT: The abrupt increases in the cost of energy since 1973 have had far-reaching effects, not only on global wealth distribution and world growth prospects, but also on the selection of appropriate technology in all sectors of countries' investment plans. For the water and wastes sector, the impacts of high energy prices are generally of two types: changes in the cross-country distribution and national demand for water and waste projects caused by macroeconomic changes, and the microeconomic effects on methods of project evaluation and technology choice. This paper discusses these two aspects and concludes that in both developing and industrialized countries, higher energy prices will result in a higher opportunity cost for water, thereby increasing the attractiveness of water-saving technologies.

HISTORICAL DEVELOPMENT OF WATER SUPPLY AND SEWERAGE

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Abstract

The development of water supply and sewerage services in the United Kingdom during the industrial changes and population expansion of the 19th and 20th centuries are described. The techniques of water treatment for potable purposes are outlined and the effects of a pure supply on the expectation of life is shown. The appalling sanitary conditions arising from the great concentrations of population in major cities led to the provision of effective sewerage systems discharging to natural watercourses. In turn sewage treatment techniques were developed in order to protect the rivers. Whilst the technical developments proceeded satisfactorily to meet the problems, the corresponding administrative arrangements lagged behind until a strong and comprehensive water management system was established by the Water Act of 1973. By this Act 10 Regional Water Authorities were established to cover England and Wales with other somewhat similar arrangements for Scotland and Northern Ireland. These experiences are examined in the context of the Water Decade now started with warnings against their application to developing countries unless all relevant aspects are considered.

Introduction

The ancient art of water resource management has been recorded in many countries as part of the history of civilization itself. Water supply and irrigation were fundamental to the development of the earliest civilizations, through the mediaeval era in the states of Europe and subsequently in the world wide industrial and agricultural advances of the last two hundred years.

The contribution of the great engineering and public health works will stand high in future assessments, but the importance of adequate administrative arrangements to enable the technologies to be applied on a world wide basis cannot be overstressed.

The wider aspects of water management cover not only the direct public health related activities of water supply, sewerage and sewage disposal, but also cater for agriculture, industry and transport. Similarly the prevention of disaster by either flood or drought must be an important objective.

Each country, each state or county or even hydrometic area has varying priorities and problems depending upon the particular characteristics and therefore any attempt to provide a generalized solution is doomed to failure. In order to limit the content of this paper to a particular situation we therefore propose to deal primarily with the development of water supply, sewerage and sewage treatment over the

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period of the last two hundred years and to relate this to the way such development occurred in the United Kingdom where the industrial revolution first made its impact in the North West of England in the middle of the eighteenth century.

The problems of inadequate water supply and sewerage first became a major hazard to the health and welfare of the new industrial populations in the early part of the nineteenth century. Around this period major concentrations of population became established in a very short period in an urban environment. The total population of the United Kingdom in 1750 was approximately 6.5 million and in 1870 approximately 27.5 million. The figure has increased to about 56 million at the present time. The remarkable population growth has occurred exponentially, but during recent years the rate of growth has fallen and the predictions indicate a more static population figure. This factor alone will create problems in water management due to the difficulties of confident forecasts whilst at the same time the demands for environmental improvements are increasing but are less easy to satisfy as a result of financial considerations.

Thus over the last two hundred years the United Kingdom has experienced the change from an agricultural and handcraft society through the intense period of the industrial revolution to a more orderly development and to a situation of relative administrative stability at the present time. This period was not without violence even though the United Kingdom has been fortunate enough to escape invasion. Nevertheless the stability was violently disturbed by the two World Wars of the twentieth century and by the problems which have developed as a result of the rapid change which has taken place in manufacturing processes not only in the United Kingdom but world wide.

As it would appear that the population figure in the United Kingdom is reaching some degree of stability it is possible to examine the way in which water management has progressed over the last two hundred years and to give some speculative forecast as to future trends. As the development represents a more or less complete story of change from an agricultural to an industrial society it is of great interest to try to understand how other countries are planning to pursue their activities over the next twenty to thirty years or even longer, having regard to the population changes which are taking place, the economic and financial resources available and above all the impact of the present energy situation in those countries. The knowledge of the world agencies will be of great value in extrapolating the experiences which other countries have had in the past and also in bringing together the current experiences of present day developments in the fields of water supply and sewerage as seen in the light of the situations in many different parts of the world.

Water management in society has developed from individual approaches involving family or small rural community developments to full industrial and national management systems which the individual now not only has to accept but to the regulations of which he has by law to conform.

Water Supply Development - 1800-1980

The development of public water supply was greatly accelerated after 1800 by the increasing urban development of industry and the consequent proliferation of disease.

As a consequence of the new supplies of water which became available, mostly after 1800, there was a rapid development of widespread pollution of streams and aquifers. The result, mainly because the real causes of water borne disease were not understood, was to seek increased public water resources, involving even more extensive reservoir and pipeline construction. Moreover the need to seek resources more remote from polluted streams developed accordingly. Thus, as the more lavish supplies were developed, so the pollution problems increased.

A number of engineering considerations led to an explosion of water supply development after 1840. As has frequently been the pattern, even in recent years, administrative development compelled by the industrial revolution and notably encouraged by the local government reforms, released the technical advances apparent to a notable group of already eminent engineers, to enable many works of reservoir and pipeline construction to proceed. The development of steam power, originally for the pumping machines of the mining industries in the 18th century, became later available for the construction of massive pumps driven by similarly massive beam engines of that time.

As far as possible only clean water sources could be exploited, but the need for some attempt at river water purification was called for and this need was becoming urgent in areas like London where there were no suitable upland valleys to provide unpolluted reservoir sites.

The North and West of England, Wales and to some extent Scotland, were being developed by large numbers of comparatively small impounding reservoirs each meeting the needs of local municipalities, but by the last years of 1880-90 some large cities were seeking major supplies of water for both public health and industrial supplies, which were capable of developing large reservoirs in heavy rainfall areas of Wales and the North of England. With large diameter cast iron pipelines extending for nearly 100 miles, these large cities such as Liverpool, Manchester and Glasgow took great pride in the high quality untreated water supplies obtained from the mountain catchments. These jealously guarded supplies continued with only minor extensions to meet the needs of those populations until well after 1955. Even chlorination was deemed unnecessary for Manchester and Glasgow until the problems of the 1939-45 war posed special purity risks.

However, the majority of water supply sources, particularly those depending on direct abstraction from rivers without the benefit of long period storage, were more and more dependent on treatment processes to ensure safe purity of supplies particularly where pollution upstream could not be avoided. Nearly 100 years before the medical science of bacteriological infection of water was adequately understood, the use of sand filter beds was brought into being. The first U.K. sand filter for public water supply was installed in 1791 nearly 200 years ago by John Gibb at the Paisley waterworks in Scotland.

In Crewe in U.K. the first rapid pressure filters were installed in 1900 and 10 years later the rapid gravity filters were installed for Durham County Water Board to serve the North East of England. At about the same time, it was in 1905, that Sir Alexander Houston, then medical advisor to the London Metropolitan Water Board, successfully used chloride of lime to suppress a typhoid outbreak in Lincoln. Gaseous chlorine had been suggested in 1903 by Lt. Nesfield in India. The general large scale use of the sterilization of water by chlorine was not widely used until 1917 and the general use of chlorine in one of its sterilization procedures was not adopted for wide general application until about 1930, even so, typhoid epidemics although greatly reduced continued to occur in U.K. until the last major epidemic occurred in 1937. Since that time the water pollution problem has ceased to be associated with bacterial infection and the impact of good water practice has been immense. The diagram (Fig. 1) shows the average expectation of life at birth in U.K. at selected dates in the last 150 years and the dramatic effects which occurred after the improvement of public health standards developed.

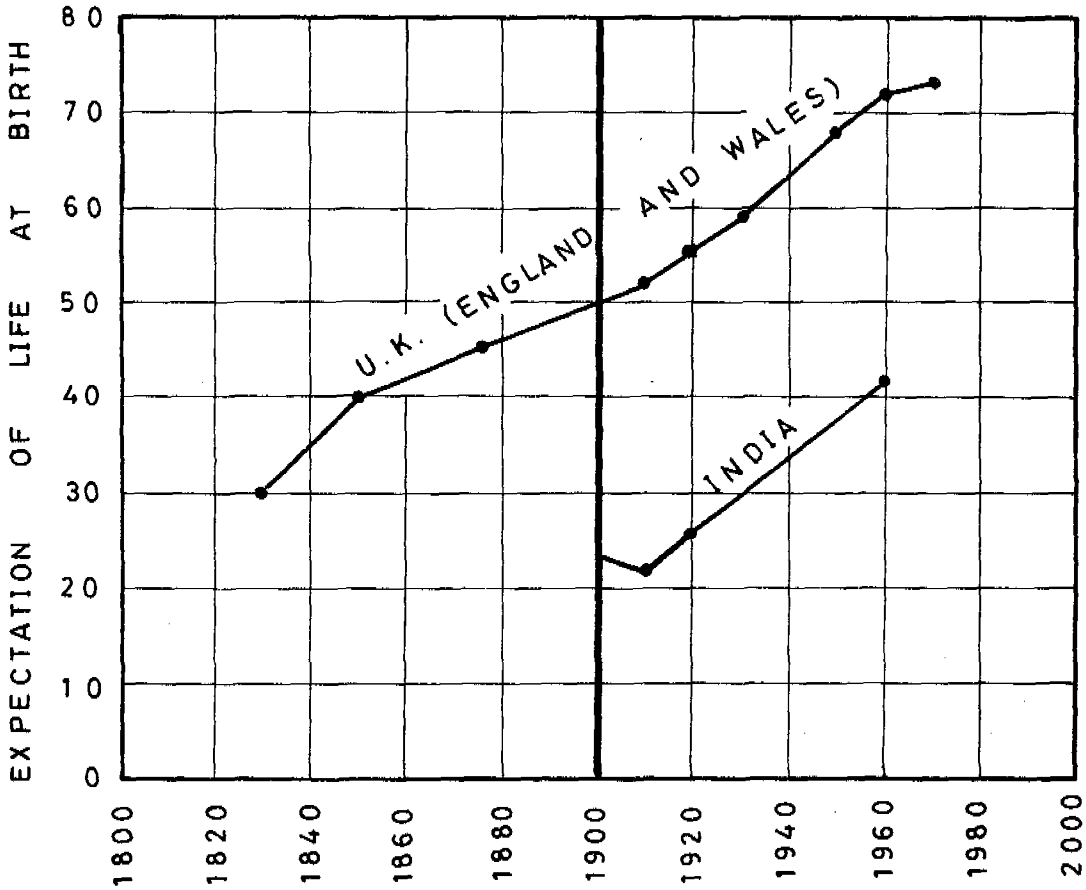

Figure 1. Comparative expectation of life at birth, 1800-2000

The start of the 20th century represented a change from the development of water resources as isolated units for the major cities into becoming widespread services operated by larger public utilities combined as the needs of the areas developed. The next 50 years, between 1900 and 1950, represented the consolidation of the water supply procedures throughout the United Kingdom and quickly made available adequate water supplies for domestic use. After 1930 the demands for industrial supplies of water were becoming important in view of the shortages of suitable quality water available to industry from the river or ground water system. Thus in the first half of the 20th century major technical changes in water supply developed. Firstly the adequate development of water resources was further implemented by a large number of surface water supplies from reservoirs or rivers and many grond water supplies from the chalk and sandstone aquifers. Gradually the purity of water supplies became essential and the discoveries of improved methods of treatment were established as general practice by 1930 and the processes of sedimentation, coagulation, rapid gravity filters followed by sterilization, usually by chlorine, were general practice.

The increasing application of hydrological studies in the early 1930's emphasized the required reliability of water resources and from the initiative of the Inland Water Survey sponsored by the Ministry of Health, the studies became the basis for the measurement of surface water resources. At the same time the geological survey was beginning to be interested in the scientific study of ground water conditions and a group of hydrologists who, so far as U.K. was concerned, had gained their experience from British Overseas Territories such as in the Middle East, Africa and India and who had returned on retirement to form an important group of expertise for the control of hydrological studies in the United Kingdom.

The great increase in the use of scientific water treatment processes led to the increased use of chemistry as a discipline for water management and the processes of coagulation, sedimentation, filtration and sterilization were rationalised to the extent that by 1950 there was little change in the methods applied to water from river systems. Obviously in the case of very clean sources such as the Lake District or the ground water resources of the South East of England, much simpler processes were applied, but in all cases the chlorination process was mandatory by 1940.

It is interesting to pause to look at the way in which energy sources for water management developed between 1900 and 1950. At the end of the 19th century most water supplies where pumping equipment was involved, required the use of steam as a source of energy and large buildings and pumping stations were required, some of which still exist to house the smaller but more powerful electrical plant. By 1920 oil and gas were already replacing steam as convenient and economical power sources. However the lifetime of the internal combustion engine in Britain was very short and from a peak in 1930 the transition of all pumping equipment to electrical energy was virtually complete by 1940. This transformation was greatly expedited by the development of the national electrical grid system, covering England, Wales and Scotland

and the considerable reliability and availability of electricity supplies that followed.

However, in 1950 it was decided to implement the River Dee control system, which originally was based on a flood management proposal for the storage of water in Bala Lake (Wales), but extended substantially to provide upstream water storage capable of regulation of the river for the towns downstream of the River Dee Catchment as far as Chester and the estuary, providing a supply of about 40 million gallons a day for these consumers.

This system, not new, but now fundamentally redesigned, became very economical and advantageous from river management points of view and was extended substantially further in respect of the River Severn involving the major cities of Bristol, Gloucester, Worcester and Birmingham involving a population of well over 2 million people.

These new supply systems involved some administrative difficulties which led to the national organisation of water resources for public supply in 1963 which included the abandonment of the water rights which had existed for a thousand years in Britain. The new system required that all abstractions of water whether from rivers or underground sources should be subject to a licencing system and require the payment of a resource licence. As a result the Water Resources Board was brought into being in 1963 to advise the 32 river authorities, with their new duties of licencing and water resource development although the actual functions of water supply and sewage disposal remained with the various undertakers, totalling over 200 local water authorities and companies and over 1,000 sewage authorities. It soon became apparent that the national system of water resources was still not adequate without bearing in mind the water quality features which had now become important. As a result, further new legislation was introduced in 1973 which led to the setting up of 10 regional water authorities covering the whole of England and Wales, and they gave the functions of water supply, sewage disposal, sewerage, flood control, land drainage and environmental management of all water sources into the control of these ten authorities (Fig. 2).

Sewerage and Sewage Developments

As already stated the Industrial Revolution started to develop rapidly at the beginning of the eighteenth century and coincided with urban concentrations and town development at a time when the disposal of excreta was indiscriminate and health hazards were in no way understood. This state of affairs was not alleviated by the inadequate and insufficient privies and earth closets. Offensive accumulations of filth and excreta in crowded courtyards and slums bred disease, not only in direct contamination of water and food, but also indirectly by flies and other means of communication. Infantile mortality was appalling and epidemics were frequent, for example the cholera outbreak of 1848-49 caused over 50,000 deaths.

Although water closets had been known in Greek and Roman cities and sporadically in some later isolated examples, it was not until the early 1800's that they began to be used and then only in better class residences. The drainage was disposed of either to such sewers as then existed or by spillage over the ground, to the side channel of a street, or to an adjacent ditch or watercourse.

However, the early sewers which had developed only for the drainage of surface water were of rudimentary construction, irregular in gradient, without self-cleansing velocities, and with flat bottoms to the inverts. They were quite unsuitable for the conveyance of water closet discharges, and in London and elsewhere Improvement Acts were obtained prohibiting their use for this purpse. Meanwhile, the provision of cesspools did not solve the problem and in 1847 the Towns Improvement Clauses Act legalised the discharge of sewage into sewers. The Public Health Act of 1848 then set up local Boards of Health empowered to construct special sewers for receiving sewage. Much of this development was influenced by the trenchant reports of Edwin Chadwick, probably the first great name in the modern history of public health reform.

A progressive change to the water carriage system then took place with the parallel development of enhanced public water supplies, although construction of major sewerage networks in some towns was not complete until the twentieth century. In some rural areas little progress was made until after the passing of the Rural Water Supplies and Sewerage Act of 1946.

However the sewers had to discharge somewhere, usually to the nearest watercourse. The resulting widespread river pollution brought a need for the treatment of sewage prior to discharge and the routing of main outfall sewers to treatment works.

Subsequently, in the last 100 years or more, the technology of sewerage design and construction has been progressive. The larger sewers were are first constructed in brickwork, but glazed earthenware pipes up to 600mm diameter were available from about 1850. In later years, concrete and cast, spun and ductile iron pipes became available in larger diameters. The principles of self-cleansing velocities were soon established, involving manholes at each change of direction and with straight runs of pipe between them. To facilitate self-cleansing velocities at low flows, the concept of "egg-shaped" sewers was first propounded as early as 1842. The work of pioneers such as Santo Crimp is due course enabled sewers to be rationally designed and led ultimately to present day computerised design.

The alternative of combined sewers with the attendant risk of pollution from storm sewage overflows, or foul sewers plus separate surface water sewers, has been a controversial question almost throughout. Modern trends have come to favour the second alternative.

Over the years the design and accuracy of storm sewage overflows have been much improved, notably by the development of stilling-ponds and syphons while pollution has been minimised by the use of holding tanks.

The re-sewering of a town and conveyance of sewage to a treatment works often involved pumping. The earliest pumping systems depended on double acting piston pumps operated by steam-driven beam engines. The steam was often generated by a refuse destructor. Pneumatic ejectors became available for smaller flows while much development of centrifugal pumps also occurred. By the 1920's this type of pump had been adapted to the pumping of unscreened sewage and the advantages of automatically controlled electrically driven installations were being exploited. The appearance in the 1960's of small mutrator-type pumps enabled small flows to be handled through relatively small bore rising mains, a particularly useful feature in many rural drainage schemes. The progressively improved facilities for pumping sewage have provided wide scope for planning sewer reticulation and drainage systems.

Maintenance of sewerage systems has been assisted by the availability of televised surveys and the development of in-situ lining of defective sewers. Chlorination has long been practised in many locations to prevent septicity in long rising mains. A recent development has been the injection of oxygen for this purpose, which also achieves some "in sewer" purification of the sewage conveyed.

The earliest sewage purification installations depended on land treatment, either broad irrigation or intermittent downward filtration. However, as schemes grew, difficulties arose, especially on clay or peat soils.

A variation of land treatment, but using different principles, was the development, mainly during the 1950's, of oxidation ponds where purification depended on oxygenation from photosynthetic activities of algae. These have found considerable employment in tropical countries where conditions in respect of temperature and solar radiation are favourable.

The earliest sedimentation tanks were simple rectangular horizontal-flow units. By modern standards generous capacities were necessary to accommodate sludge accumulated between intermittent cleanings, while desludging usually had to be assisted manually - an unpleasant task. By the 1930's circular radial-flow tanks were becoming popular for which several types of revolving scrapers had become available, enabling capacities to be reduced by one half. There has subsequently been steady improvement and development of electrically operated scrapers for both rectangular and circular tanks, including use of light alloys. Thus, apart from smaller installations, virtually all new works built in the U.K. in the last three decades have used scraped tanks from which sludge is mechanically removed under water.

Coincident with sedimentation tank development has been that of preliminary treatment prior to sedimentation. Screening of sewage has been practised for over 100 years and mechanical raking of bar screens was soon introduced to handle the arrested screenings from the bars. More recent progress has included systems to avoid the unpleasant task of handling screenings, such as automatically controlled maceration and return to the flow, or equipment for mechanised bagging and/or incineration. The development of comminutors in the U.K. around 1937 followed by barminutors introduced from the U.S.A. in the 1960's offered alternatives to screening and the disposal of screenings.

The earliest works did not have provision for the removal of grit washed from roads, but it became the practice to introduce detritus pits to intercept the grit ahead of the sedimentation tanks.

The difficulties associated with land treatment stimulated the development of "artificial" alternatives, leading by the end of the nineteenth century to the appearance of the contact bed. This was a bed of graded media, such as coke, stone or slag, a metre or more deep operated two or three times daily on a cycle of filling, standing full, discharging, and leaving empty to re-aerate. The surfaces of the media developed a biologically active film akin to that to which we are now accustomed in the percolating filter, and with double or sometimes triple contact satisfactory effluents could initially be produced. The area required was only a fraction of that needed for land treatment. As the difficulty of blockages of the interstices by a humus type sludge could only be overcome by the formidable operation of excavation, washing, and replacement of the media, the contact bed only had relatively short service.

Pioneering work operating contact beds continuously rather than intermittently demonstrated that satisfactory purification could be effected by virtue of the humus formed being voided with the effluent instead of choking the bed. This led to the emergence of the percolating filter, the refinement of which continued actively in the early 1900's aided by progress in design of machines to distribute sewage evenly over both circular and rectangular beds. The scope of the percolating filter has moreover, been enhanced by developments such as recirculation, alternating double filtration, and recognition of the importance of periodicity of dosing.

The need for post-filtration settlement to intercept the voided humus solids soon came to be accepted. The development of these final settlement tanks has similarly followed that of the primary tanks and with circular mechanical scrapers.

Earlier work attempting to purify sewage by aeration both in the U.K. and at the Lawrence Experimental Station in Massachusetts foreshadowed the activated sludge process finally developed by Arden and Lockett at Manchester, England in 1914. From a very early stage aeration was effected by compressed air introduced through porous tiles as used in 1916 in the first full scale plants at Manchester and Worcester, both in the U.K. Tanks for separation of the activated sludge were initially of the upward flow Dortmund type, but in the last three decades circular mechanically scraped units have become almost standard in the U.K. Recycling of activated sludge was usually by centrifugal pump but often by air lift where air was used for aeration. In the last twenty years Archimedean screw pumps have become increasingly popular for this duty.

The introduction of sedimentation tanks created a need for systems of sludge disposal. For the recovery of saleable manure there were attempts about 1900 to use filter presses but it was only after improved methods of sludge conditioning and better mechanical equipment that such techniques were more generally used after 1950. In certain locations and for some purposes there has been a recent trend towards tanker disposal.

As effluents become more complicated and a treatment is more carefully controlled the methods used have changed considerably during the last two centuries, but methods can still be developed and modified to provide improved and more economical service to suit the industrial and environmental problems.

Comprehensive Water Management - 1973 Water Act

Although after 1945 there were beginning to be signs that the various aspects of water use, viz. - public water supply, sewage disposal and flood management were being examined from a more integrated point of view the first real sign of any co-ordinated development commenced after the Central Advisory Water Committee reported to the Government in 1961, when many aspects of water use were considered comprehensively by various expert groups. The Government of the time did not consider it to be a matter of priority that the inter-related interests in water management should be co-ordinated. Those concerned with water use had different points of view covering various sections of water use organisations, e.g. water supply, sewerage and flood control and the different and often conflicting interests of industrial and domestic users.

However between 1963 and 1973 the philosophy of co-ordination developed and the obvious advantages having been accepted these were implemented in the 1973 Water Act. (See Fig. 2).

The ten Regional Water Authorities for England and Wales which began to operate in 1974 covered the following unified functions:

Water Supply	)	Domestic, agricultural
Sewerage	)	and industrial
Flood Management		Fisheries
Land Drainage		Water based recreation

There is a low demand for hydraulic power, irrigation and canal services in the British economy and these aspects were not specially dealt with in the 1973 Act.

In some cases parts of large countries will have varying requirements depending on geographical and other characteristics; even in the United Kingdom the requirements for Scotland were such that the provisions of the 1973 Water Act were not adopted in the same way as in England and Wales.

The ten Regional Water Authorities are co-ordinated by two Government Departments, the Department of the Environment and the Ministry of Agriculture and Fisheries. Advisory functions were provided by the National Water Council, the Water Space Amenity Commission and the Water Research Council.

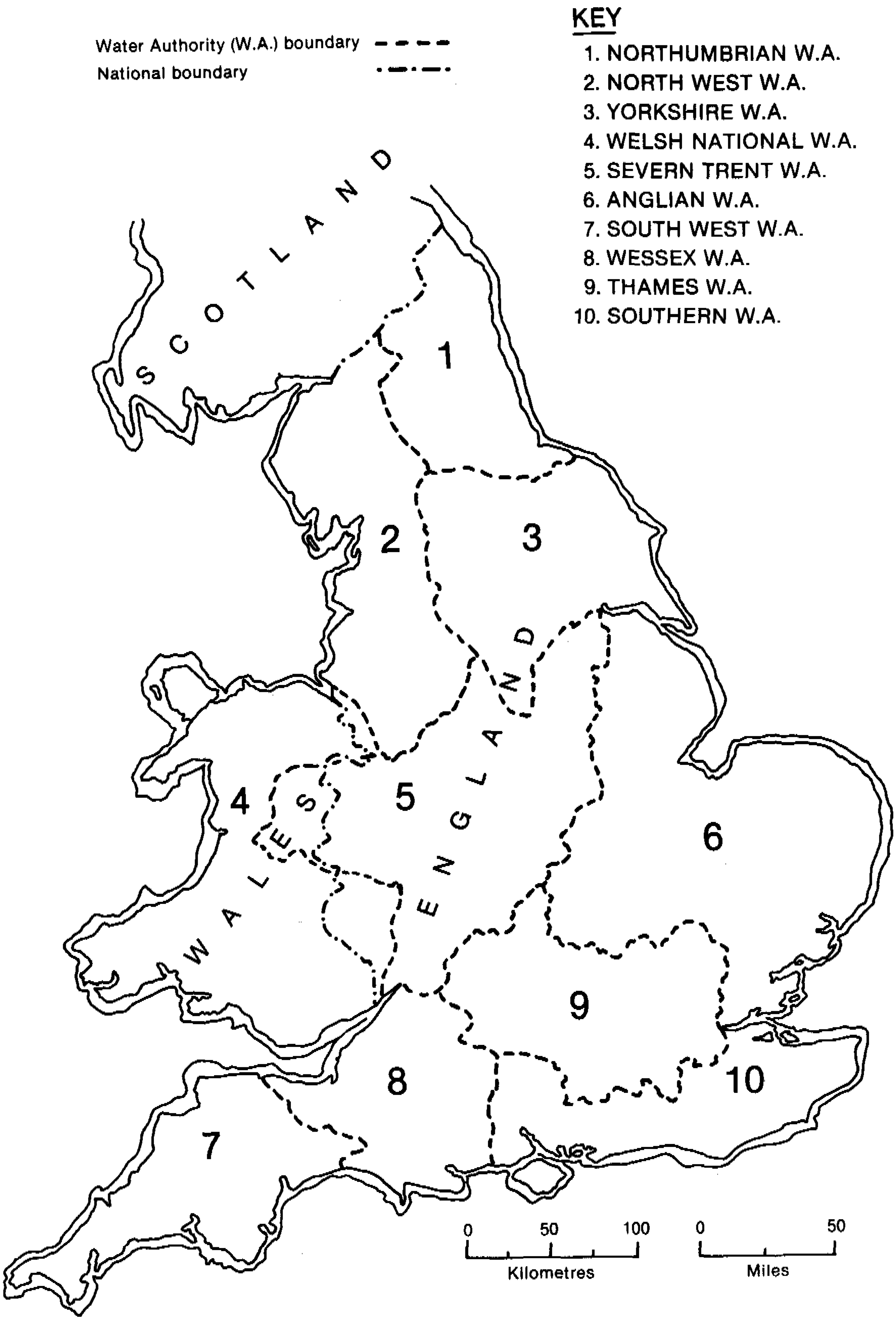

Figure 2. Comprehensive Water & Sewage Authorities
For England and Wales

Minor additions to the system include the retention of a few Water Supply Companies and the Local Authority sewer maintenance departments, both of which are delegated services under the ten Regional Water Authorities.

Unfortunately the question of how the major co-ordinated organisations were to derive their income was not fully argued. Whereas water supply had for many years been a service paid for by the public generally and by industry on the basis of the service provided, the other services notably sewerage and sewage disposal were paid for by either the Local Authority rates services or by national precepts as well as those provided by land drainage and fishery interests which were together largely financed by Central Government grant.

When the financial burdens were transferred to the Regional Water Authorities in 1974 it became apparent that there were large sections of the water industry which were previously not properly serviced and which called for large amounts of capital expenditure for replacements.

The major problem, therefore, now facing the newly co-ordinated water industry is the sudden increase in charges for water services which were previously either paid for by Local Government or Central Government rates and grants in the unco-ordinated systems prior to 1973. The sudden impact of these water charges and the abandonment of financial support by Central Government have created major administrative problems for the ten Water Authorities. These problems have been intensified by the energy crisis since 1973 which has greatly reduced Government capital expenditure and which has necessitated such expenditure being curtailed irrespective of the major demands being requested.

Undoubtedly the present situation, albeit very satisfactory from a technical and planning point of view, is facing a critical period in the difficult and formative years of the new administrative system. This is particularly so when the opportunities for development which are so obvious to the regional administrations are curtailed by the national government agencies.

Conclusions

To many of those concerned it seemed likely following 1973 that all problems facing water resource development in the United Kingdom would be satisfactorily resolved. From the point of view of technical expertise there is no doubt that in England and Wales this is largely the case. Moreover the administration which is available to 10 major Water Authorities in England and Wales coupled with a National Water Authority in Northern Ireland and in parallel with the Local Government Water Authorities in Scotland has a simplicity of application covering a wide range of water needs upon which it would be difficult to improve. Notwithstanding this, progress is never complete and there are certain aspects of water management in England and Wales which can be seen to provide opportunities for improvement as occasions develop in future years. In particular special attention will be needed to the charging system which must be developed to give the maximum balance of equity as between different users and which is at present almost entirely based on water supply criteria.

The economics of the water services will need to be rationalised and attention will have to be devoted not only to the priorities between the various services provided but also to the requirements of water for energy, transport and agriculture which are largely outside the scope of the present organisations.

Whilst the criteria, rules and procedures developed in the United Kingdom may be of interest to other countries, their value for application in most countries will depend on the special reasons which can be identified. Only those criteria capable of general application can be adopted without very careful consideration, for example, fresh water fisheries are almost entirely used in the United Kingdom only for amenity and recreation purposes. Similarly, irrigation control which is not considered to be a matter of high priority in the United Kingdom could be of considerable importance in other countries in controlling the ravages of flood and drought.

The international context of this paper must be to note the opportunities and mistakes of the last 200 years in U.K. water resource management and to expedite improvements more carefully.

Undoubtedly many countries about to embark on significant developments in water management during the Drinking Water and Sanitation Decade, which is the subject of this Session today, will need to compress into a ten year period the relevant and appropriate elements of the developments in the United Kingdom over the last two hundred years. It is hoped that this necessarily brief historical outline will be of value for comparison.

Reference

"Demographic Yearbook 1978", United Nations, New York, 1979.

The diagram (Fig. 1) is based on part of the tabulated world data.

ISTANBUL WATER SUPPLY AND SEWERAGE - A REAPPRAISAL

by

Marcial P. Cuellar and Adalbert J. Vogel 1/

ABSTRACT

During 1966-1970, United Nations Development Program/World Health Organization consultants prepared water supply and sewerage master plans for the Istanbul region, an area of about 3,500 km^2 comprising the city of Istanbul, surrounding urban area and adjacent communities.

The first-stage of the water supply master plan was constructed during the period 1970-1980, with financial support from the World Bank, at a cost of US $270 million. It more than tripled water production capacity from 123 Mm^3/ yr. in 1970 to 375 Mm^3/yr. in 1980, while the region's population increased from 3.0 to 4.8 million during the same period. However, the benefits from the improved supply have been severely reduced by increasing water losses and delays in rehabilitating and expanding the distribution system. Also, the project failed to improve the financial position and technical capabilities of the municipal water authorities.

In the sewerage, expansions of the collection system continued during the last decade, but were insufficient to cope with the demographic growth, so that the percentage of population served decreased from about 58% in 1970 to 52% in 1980. Furthermore, the increased water supply contributed, with a large industrial expansion, to a serious deterioration of the coastal oceanwaters. After numerous delays, caused mainly by institutional conflicts, the construction of the sewerage master plan is expected to get underway in late 1981.

The problems encountered in Istanbul derive mainly from the institutional approaches adopted for implementing the projects: assigning project construction to a national agency and regionalization of the operating authority.

BACKGROUND

Water Supply and Sewerage Master Plans

In 1964, the Government of Turkey (GOT) requested assistance from the United Nations Development Programme (UNDP) in the preparation of water

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1/ Respectively, Senior Sanitary Engineer, World Bank, Washington, DC and Senior Sanitary Engineer, World Health Organization, Geneva. Views and interpretations herein are those of the authors and should not be attributed to the World Bank or World Health Organization.

supply and sewerage master plans for the rapidly growing Istanbul region. This request was approved by the UNDP in June 1965 and led to the signature, in August 1966, of a Plan of Operations by GOT, UNDP and the World Health Organization (WHO), the latter being designated as Executing Agency for the project. In December 1966 WHO selected the DAMOC consortium 1/ as the technical consultant to perform the studies.

DAMOC personnel worked in close cooperation with the Turkish staff assigned to the project by the State Hydraulic Works (DSI), the Istanbul Water Administration (ISI) and the Sewerage Department of Istanbul Municipality (IB) and received additional support from the Turkish Navy and other Government institutions. The Project Manager and co-Manager were respectively provided by WHO and DSI.

Field work was started in January 1967 and was essentially completed during 1969. During June-September 1971, the project managers prepared a loan application to the World Bank covering the most urgently needed water supply facilities. Bank appraisal took place in March 1972 and brought about some significant modifications on the staging of the works recommended by DAMOC. The World Bank loan was approved in June 1972 and became effective in January 1973.

Greater Istanbul and the Istanbul Region

The Istanbul region covers some 3,500 km^2 between the Black Sea, the Sea of Marmara, the town of Buyukcekmece in European Turkey and the City of Adapazari on the Asian mainland. It includes the metropolitan urban area, or Greater Istanbul, plus 13 large and several small neighboring communities. Greater Istanbul centers in the municipality of Istanbul (1,558 km^2) and spreads over 24 adjacent municipalities, extending along the Bosphorus and along the Marmara coast from Kucukcekmece in the west (Europe) to Gebze in the east (Asia). (Figure 2)

The main topographical feature of the Istanbul region is the Bosphorus, a 31 km strait linking the Black Sea to the Sea of Marmara and dividing the region into its European and Asian parts. The urban area is hilly, with relatively narrow flat areas slightly above sea level along the shores of the Golden Horn (a 7 km long estuary) and the Sea of Marmara. Along the Bosphorus the coastline is quite steep and cut by sharp narrow valleys.

Long-term air temperatures vary from about 5^oC in winter to 25^oC in summer. Approximately 70 percent of the 726 mm. average annual precipitation falls during October through March. The region is subject to earthquakes which have caused extensive damage in the past.

1/ DAMOC, an acronym for Daniel, Mann, Johnson & Mendenhall of Los Angeles; Alyord, Burdic and Howson of Chicago; Motor-Columbus of Baden, Switzerland; and Checchi and Company of Washington, DC.

Istanbul (formerly Constantinople, and once ancient Byzantium) is the largest city and seaport of Turkey. It was formerly the capital of the Byzantine Empire, of the Ottoman Empire and briefly of the Turkish Republic. The city has a history of 26 centuries and during the reign of Justinian I (527-656) its population was an estimated 500,000. Estimated 1980 populations are 2.8 million for the municipality of Istanbul, 4.1 million for Greater Istanbul and 4.8 million for the entire Istanbul region.

Sector Institutions

In Turkey, water supply and sewerage services have been traditionally a municipal responsibility and in large urban areas a degree of regionalization often has been achieved through inter-municipal agreements establishing "union of municipalities."

In 1966, when DAMOC started the studies, the largest water supply and sewerage authorities in the Istanbul region were those of the Istanbul Municipality: ISI, a semi-autonomous municipal authority in charge of the water supply and IB, a municipal department, of the sewerage system. The water supply and sewerage systems of the remaining municipalities were operated directly by the respective municipality or through "union of municipalities" agreements as in the case of the Unions of Kartal (9 municipalities plus 10 villages) and Mahmutbey (4 municipalities plus 10 villages).

To promote sector development, in the late 1960's the GOT assigned two central government agencies to assist the municipalities with the planning, design, financing and construction of their water supply and sewerage facilities. DSI, a large technical agency (staff of 17,000) with experience in dams and irrigation but not in water supply, was assigned to construct the water production, transmission and treatment facilities for cities of over 100,000 population. Iller Bankasi (Bank of the Provinces), a medium size technical agency (staff of 2,300) was assigned to assist municipalities with populations between 4,000 and 100,000 with the design and construction of their water supply and sewerage facilities. The construction of sewerage systems for cities of over 100,000 population was not covered by these assignments and presumably remained a municipal responsibility.

Following the sector policy established by the GOT, DAMOC recommended dividing between DSI and ISI the responsibility for implementing the Istanbul water supply master plan. It also recommended strengthening and reorganizing ISI into a regional water supply authority which would provide all potable water services to the urban area and wholesale water to adjacent communities where distribution would be undertaken by local water administrations.

For implementing the sewerage master plan, DAMOC recommended the establishment of a semi-autonomous regional authority, which would be the project executing agency, would operate the sewerage facilities in the urban area and would provide disposal services to the outside communities sharing drainage basins with the city. In 1971, this recommendation was modified by the GOT by appointing Iller Bankasi as the project executing agency.

D E M O G R A P H Y

During the 1970's, the Istanbul region underwent an extraordinary demographic growth, absorbing about 20% of Turkey's total rural migration. Reflecting the socioeconomic characteristics of the new immigrants, most of the growth took place on the areas outside Istanbul municipality. At the same time, the construction of the Bosphorus bridge, linking Asia and Europe, stimulated the growth of Asian Istanbul.

The population of Istanbul municipality grew during the last decade at an average annual rate of 2.9%, from 2.1 million in 1970 to 2.8 million in 1980, while the population of the entire Istanbul region grew at an average annual rate of 4.8% from 3.0 million in 1970 to 4.8 million in 1980. At the same time, the percentage of the total population living on the European side of the region decreased from about 76% in 1970 to 71% in 1980.

This demographic growth was supported by an industrial expansion which saw the total industrial area double from 1,100 ha in 1970 to about 2,200 ha in 1980. This expansion is expected to continue, with new industries settling mainly in the Kartal area (Asian Istanbul) and bringing the total industrial area to an estimated 4,600 ha by 1995.

Population growth rates started declining in the late 1970's following a gradual displacement of the rural migration to other urban centers. Accordingly, by 1995 the population of Istanbul municipality is projected at 3.8 million and that of the Istanbul region at 7.4 million, corresponding to average annual growth rates of 2.1 and 2.9% respectively. The percentage of the total population living on the European side of the region is expected to decline further, to about 66% by 1995, a factor with important implications in the selection of future water sources. The population projections prepared by the various organizations which have participated in the Istanbul program are compared on Tables I, II and III.

W A T E R   S U P P L Y

Background

Emperors Valens (364-378) and Theodosius The Great (378-395) constructed the first major aqueducts in Istanbul, two of which are still in existence. Also, to protect the city water supply during periods of siege, a series of huge storage facilities were built in addition to many smaller cisterns for rainwater collection.

In 1453, following the conquest of Constantinople by Sultan Mehmet, a pious water foundation (Vakif Sular) was formed and became responsible for reconstruction and expansion of the city's water supply until the end of the 19th century. Between 1620 and 1838, Vakif groundwater sources provided about 6,000 m^3/d, while an additional 12,000 m^3/d came from seven masonry dams

TABLE I - Population Projections for Istanbul Municipality
(Population in Millions)

Year	DAMOC	World Bank	Camp Tek-Ser	ISI
1970	2.02	2.11	2.14	--
1975	2.31	2.51	2.44	2.65
1980	2.60	2.94	2.82	2.98
1985	2.90	3.33	3.19	3.35
1990	3.19	--	3.52	3.54
1995	3.48	--	3.79	3.75

TABLE II - Population Projections for Greater Istanbul
(Population in Millions)

Year	DAMOC	World Bank	Camp Tek-Ser
1970	2.65	2.76	2.82
1975	3.15	3.45	3.36
1980	3.69	4.20	4.10
1985	4.24	4.93	4.80
1990	4.79	--	5.50
1995	5.34	--	6.08

Note to Table II - The boundaries considered for Greater Istanbul on the above projections are not the same. However, the differences are relatively minor and should be of little significance for population purposes.

Notes to Tables I and II - Above projections were prepared by DAMOC in 1969, the World Bank in 1972, Camp Tek-Ser in 1974 and ISI in 1976.

constructed in the Belgrade Forest (14 km. north of the Golden Horn). During the late 19th century additions to the supply were made through private concessions from Terkos Lake on the European side and Elmali Reservoir on the Asian side. During the period 1932-1937, when the need for further expansions became urgent, the GOT purchased all existing facilities and established ISI as the public water supply agency of Istanbul Municipality.

Demand for water in the Istanbul region has often exceeded supply, so that physical rationing has prevailed, forcing consumers to incur sizeable costs for roof tanks. Until the mid-1970's there was an almost complete moratorium on new industrial connections so that industries had to construct their own private water systems. There was also a high incidence of water borne diseases such as typhoid and paratyphoid which began declining in the mid-1970's as the new supply became available allowing continuous service to the densely populated areas of the city.

The Situation in 1970

In 1970 average daily water produced by ISI was 283,000 m^3 and daily average water billed (including public fountains) 177,000 m^3. Of the total population of Istanbul Municipality, 1,330,000 (62%) were served by 222,000 house connections and the remaining 810,000 (38%) by about 1,700 public fountains.

1970 water production by the outer municipalities averaged 51,200 m^3/d, corresponding to a net consumption of 32,000 m^3/d, assuming the same 37.5% of unaccounted for water recorded by ISI. Of the total population of the outer municipalities, approximately 340,000 (40%) were served by 56,000 connections, 320,000 (37%) by public fountains and the remaining 200,000 (23%) lacked service. Overall consumption per capita connected was 94 lcd as compared with 133 lcd for Istanbul Municipality.

In addition to the water delivered by the municipal agencies, large consumers, especially industries, produced an estimated average 94,000 m^3/d from their own sources.

Excluding water produced by industry, DSI estimated total annual water demand in 1970 for th entire Istanbul region at 185 Mm^3 and total production capacity at 122 Mm^3 for a deficit of 63 Mm^3/year.

In 1970, ISI's distribution system amounted to about 1,600 km of pipelines ranging in diameter from 4 to 60 cm (mostly less than 15 cm) and included 28 pumping stations and 40 reservoirs with a combined capacity of 150,000 m^3. Total transmission lines amounted to about 200 km. Of the outer municipalities only those included in the Kartal and Mahmutbey unions had distribution systems with the remaining served only by a few public fountains.

The treatment plants operated by ISI were the Kagithane (European side) and the Elmali (Asian side) plants with rated capacities of 265,000 and 40,000 m^3/d, respectively. Average yields of ISI's water sources were 238,000 m^3/d in the European side and 50,000 m^3/d on the Asian side. The outer municipalities relied exclusively on groundwater but the groundwater table was falling throughout most of the region and salinity was increasing near the coast due to overpumping.

Most of the facilities described above were in poor condition. The distribution system required major rehabilitation, including the replacement of about 840 km of undersized and old pipelines, new equipment for most of the pumping stations and reservoirs and a massive program of meter replacement. Also extensive repairs and new pumping equipment were needed for the raw water transmission pipelines serving the Kagithane treatment plant.

First Construction Stage

The main water supply facilities constructed during the 1970's are shown on Figure 1 and are briefly described below:

a) Terkos Lake. Expansion of the storage capacity of Terkos Lake to 238 Mm^3 through the construciton of 3.6 km of dikes, in order to increase its average annual yield from 61 to 120 Mm^3 (maximum estimated yield). Terkos Lake has a drainage area of about 620 km^2 and an estimated annual runoff of 196 Mm^3;

b) Alibey Dam. Construction of the 28 m high, earth fill, Alibey dam. Its reservoir has a storage capacity of 67Mm^3, a drainage area of 160 km^2 and estimated average annual runoff and yield of 47 and 39 Mm^3, respectively.

c) Terkos-Alibey Aqueduct. It carries the raw waters of Terkos Lake to the Alibey reservoir. It consists of a short section on pressure pipe, a lined tunnel and an open canal. It has a total length of 14.0km and a design capacity of 3.8 m^3/s.

d) Alibey-Kagithane Pipeline. It carries the raw waters from Alibey reservoir to the Kagithane treatment plants. It has a total length of 4.5 km of 1.85 m diameter pre-stressed pipe and includes a pumping station with an installed capacity of 4.5 m^3/s.

e) Omerli Dam. Construction of the 52 m high, earth fill, Omerli dam. Its reservoir has a storage capacity of 267 Mm^3, a drainage area of 620 km^3 and estimated average annual runoff and yield of 214 and 180 Mm^3, respectively.

f) Omerli Pipeline. It carries raw waters from the Omerli reservoirs to the Omerli treatment plant. It has a total length of 1.2 km of 2.20 m diameter pre-stressed pipe and includes a pumping station with an installed capacity of 6.6 m^3/s.

TABLE III - Population Projections for Istanbul Region

(Population in Millions)

Year	DAMOC	DSI
1970	3.11	3.00
1975	3.70	3.86
1980	4.33	4.84
1985	4.99	5.77
1990	5.66	6.62
1995	6.34	7.38

TABLE IV - DSI´s Water Demand Projections Region

and Actual Water Production

(all figures in Mm^3/yr)

Water Demand Projections		Actual Water Production
Year	DSI	
1970	185	122
1975	251	200
1980	330	305
1985	417	--
1990	488	--
1995	560	--

Notes to Tables III and IV - DAMOC projections were made in 1969 and DSI´s in 1976.

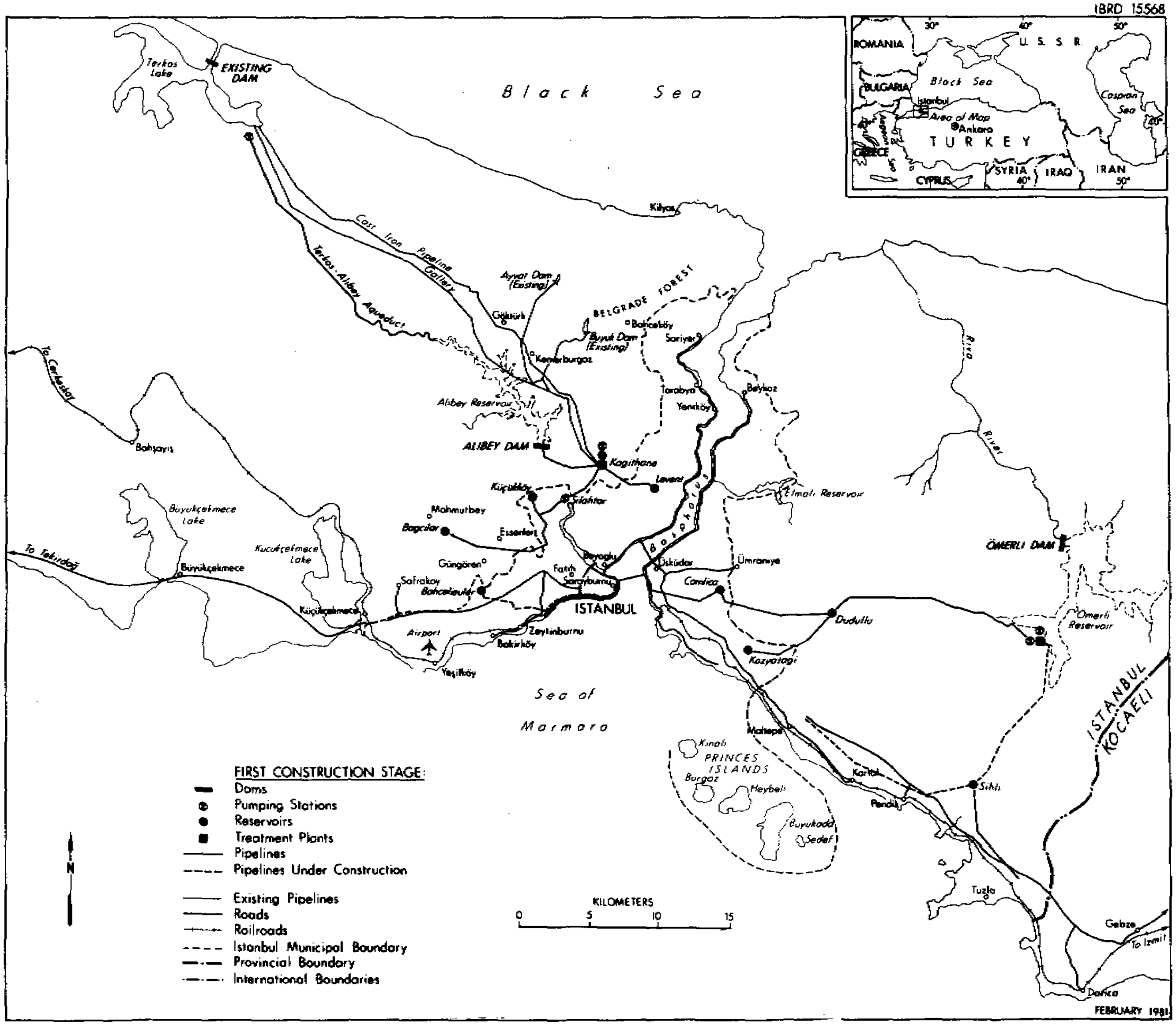

Figure 1. Istanbul Region water supply.

g) Kagithane and Omerli Treatment Plants. Two similar plants of 300,000 m^3/d capacity, treat the waters from the Alibey and Omerli reservoirs, respectively. Standard treatment process is used, consisting of coagulation, sedimentation rapid sand filtration and chlorination. To provide water to the region while the plants were under construction, two clarifiers of 100,00 m^3/d capacity each were constructed at Omerli and one of 50,000 m^3/d capacity at Kagithane. The treated water pumping stations at Kagithane and Omerli have installed capacities of 3.0 and 6.4 m^3/s, respectively.

h) Transmission Pipelines. The treated water transmission pipelines laid during the last decade amount to 31.0 km of pipe of 0.60 to 1.60 m diameter on the European side and 46.1 km of 0.80 to 2.20 m diameter on the Asian side. In addition, the Asian and European systems were linked through the Bosphorus undersea crossing, consisting of 2 pipelines of 1,016 mm diameter with a length of 1.9 km each.

i) Distribution System. The total length of the distribution system was increased during the last decade by about 900 km. Twelve new treated water reservoirs were constructed on the European side, 10 on the Asian side and 4 on Prince's Islands. New equipment was installed in most of the existing pumping stations and new stations were built. 163,000 new house connections were added within Istanbul municipality and an estimated 67,000 in the outer municipalities.

Evaluation of the First-State Project

Table IV compares the water demand projections prepared by DAMOC (1969) and DSI (1976) for the entire Istanbul Region and includes actual water production figures up to 1980.

With the completion of the first-stage project, average annual source yield which stood at 123 Mm^3 in 1970, more than trebled to 375 Mm^3 in 1980. The Buyukcekmece dam started in late 1979, as part of the second construction stage, should increase the total annual yield to 480 Mm^3 by 1983 and the Kucukcekmece dam, presently under design, should bring it up to 560 Mm^3 by 1990. Other potential sources under study are the Darlik (63 Mm^3/yr), Isakoy (160 Mm^3/yr), Sunguslu (81 Mm^3/yr) and Tarsanli dams (25 Mm^3/yr).

As shown on Table IV, annual water production also increased at a fast rate, from 122 Mm^3 in 1970 to 305 Mm^3 in 1980. Unfortunately there was also a rapid increase of the percentages of unaccounted-for-water, so that the net unsatisfied demand which was estimated at 34% in 1970, actually increased to 37% in 1975 decreasing subsequently to about 22% in 1980.

The expansion and rehabilitation of the distribution system has suffered drastic delays. About 40 km of the first-stage transmission pipelines and 105 km of feeder mains are still under construction and not expected to become operational before mid-1982. Over 80% of the 840 km pipe replacement program recommended by DAMOC for the period 1970-1980 is yet to be carried out. These delays have prevented the full utilization of the Bosphorus crossing and the Omerli treatment plant which were completed in 1979. They have also affected the provision of water to the peripheral urban area, the uniform distribution of water within the city and the effective control of water leakage. These defficiencies are compounded by intermittent service in the higher elevation areas caused by frequent interruptions of electric power due to wide-spread energy shortages.

The number of house connections and the yearly water production and sales by ISI during the last decade are tabulated on Table V. Even though the number of connections has increased from 222,000 in 1970 to 395,000 in 1980 and practically 100% of the connections (including public fountains) are metered, since 1973 the percentage of unaccounted-for water has remained above 40%. Unaccounted for water figures are, however, unreliable because the production meters are not operational and water production is estimated from the number of hours of pump operation.

Almost 95% of the secondary distribution system (pipes 30 cm diameter and smaller) is composed of locally manufactured, bell and spigot, cast iron pipe with lead joints. While even the older pipe (40-50 years old) appears in good condition, there is extensive leakage through the joints due in part to poor pipe bedding and caulking practices, but basically to the inability of the lead joints to withstand seismic and vibration stresses.

ISI's records show that during 1978 a total of 906 leaks were repaired, of which 413 corresponded to leaking pipe joints, 354 to broken pipes and 139 to leaking valves. Most were surface leaks reported by the population and only in a few cases were invisible leaks detected by ISI's leak survey teams. The large volumes of infiltration observed in the sewers even during dry weather and in the high areas of the city suggests that a large amount of leaks may have found their way into the sewer system without surfacing. Also, in the coastal areas, which are only slightly above sea level, leaks may not always surface.

In 1977, ISI established a leak detection departmant which is still very poorly equipped, relying mostly on primitive devices such as copper rod aquaphones. One pilot for measuring flows and a few leak detectors of the acoustic type have been purchased, but are rarely used because of shortage of trained personnel. Attempts by the World Bank to implement a program for training ISI personnel on leak detection procedures have so far been unsuccessful.

ISI believes that part of the high percentage of unaccounted-for water is due to under-recording by consumption meters although this was not corroborated by data from some areas where extensive meter replacement was

TABLE V - ISI's Water Production, Sales and Number of House Connections During the 1970's

Year	Water Production Mm^3/yr	Water Sales (billed) Mm^3/yr	Unaccounted for Water %	Number of House Connections (000)
1970	103.3	64.6	37	222
1971	104.8	69.3	34	242
1972	120.4	74.1	38	260
1973	136.5	78.1	43	287
1974	149.8	83.0	45	306
1975	182.6	101.3	45	335
1976	209.7	116.7	44	347
1977	227.8	129.3	43	360
1978	247.1	146.0	41	374
1979	272.2	158.2	42	388

TABLE VI - Wastewater Testing by Camp Tek-Ser

Location	Period Gaged hr	Average BOD_5 mg/l
Atakoy	72	152
Unkapani	48	176
Besiktas	48	66
Uskudar	48	195
Levent	24	140
Kasimpasa	24 1/	150

1/ Eight readings taken over 24-hour period undertaken. Indeed, a preliminary survey carried out by The Pitometer Associates (USA) in 1968 and brief studies of some small residential areas conducted in 1976 by Binnie and Partners (England) suggest that the bulk of the unaccounted for water is due to physical leaks, with illegal connections and inaccurate production metering being secondary but important contributory causes.

While regular leak detection and improved production metering should reduce the percentage of unaccounted-for-water, it is most unlikely that they could bring it down to the 20-25% range assumed in most of the studies. Part of the physical losses result from a large number of minor leaks through the pipe joints and will disappear only with the replacement of the older pipelines. It is essential, however, to prevent further leakage by improving pipelaying practices and using flexible jointed pipe which is better suited to the soil and seismic characteristics of the city.

Within Istanbul municipality practically the entire population is served by the ISI system. Population served by house connections increased from 1.3 million in 1970 to about 2.3 million in 1980, while the population served by public fountains decreased from about 0.81 million in 1970 to an estimated 0.53 million in 1980. Net average per capita consumption for the population served by house connections also increased from about 83 lpcd in 1970 to an estimated 94 lpcd in 1980. While water supplied by ISI to industry increased considerably during the last decade, over 60% of the industrial waters currently are extracted from private wells.

The service records kept by the outer municipalities are incomplete and don't allow an accurate estimate of changes in service levels during the last decade. Rough estimates indicate that of the 2.0 million people living in the outer municipalities in 1980, about 0.7 million (35%) were served by house connections, 0.8 million (40%) by public standpipes and the remaining 0.5 million (25%) lacked service. Net average per capita consumption from house connections seems to have declined during the last decade as demand outstriped supply.

Clearly, the outer municipalities have been drastically affected by the delays in expanding the distribution system and the high water losses. The amounts of water to be sold by ISI to the outer municipalities were expected to increase gradually, reaching 54 Mm^3 by 1980. Instead, they amounted only to about 24 Mm^3 even though the population of these small municipalities has increased faster than anticipated.

ISI has tried to fulfill its responsibility for regional planning and in 1977 completed a distribution system master plan based on a computer model supplied by Binnie and Partners. Unfortunately, this master plan is flawed because its preparation did not include the measurements of flow and pressures which Binnie and Partners considered essential for an accurate design.

Institutional Considerations

Following DAMOC recommendations, the loan agreement between the GOT and the World Bank established that DSI would act as consulting engineer and contractor for ISI in the construction of all water production, transmission and treatment facilities. ISI would concentrate on rehabilitation and expansion of the distribution system. It was expected that because of its better experience in water supply, ISI would be able to direct and supervise DSI's work. The conversion of ISI into a regional authority would be achieved by gradual expansions of its service area throughout the project period. It was expected that the larger water sales would strengthen ISI's financial position, allowing ISI to finance at least the routine expansions of the distribution system.

This institutional approach did not produce the results sought by the GOT and the international organizations. DSI rapidly recruited experienced staff and established a well managed construction office in Istanbul as well as a water supply unit at its Ankara headquarters. ISI, constrained by low salaries, was unable to upgrade its staff and quickly lost control of the construction program. By 1980, DSI water supply units had become highly competent in construction management, while ISI had been unable to undergo a technical and institutional development compatible with the construction program. While the upgrading of DSI should be of considerable benefit to the country, since DSI is undertaking construction of water supply systems for several of Turkey's larger cities; the lack of development of ISI jeopardizes not only the adequate maintenance of the new facilities but also the timely implementation of subsequent construction stages. Furthermore, by relying on the eventual conversion of ISI into a regional authority, this institutional approach prevented the development of the water authorities of the smaller municipalities and unions.

Attempts to implement the reorganization of ISI recommended by DAMOC and the World Bank or subsequently by the Instanbul Institute of Business Administration have been unsuccessful.

ISI's most glaring weakness lies in the shortage of experienced technical personnel. While low salaries and inadequate career opportunities have deterred many capable candidates, there has been also little interest from management in fully utilizing the training opportunities provided throughout the implementation of the project. Funds designated in the World Bank loan for overseas training were hardly touched and the on-site training provided by the manufacturer of the treatment plant equipment was attended almost exclusively by DSI staff.

ISI's annual water sales increased for 64.6 Mm^3/yr in 1970 to 158.2 Mm^3/yr in 1979, but tariff adjustments often below the inflation rate produced a further erosion of ISI's financial situation, forcing the GOT to subsidize not only the ongoing construction program but also part of ISI's operating expenses.

The *financial situation* of the water supply organizations in the smaller municipalities is not any better, as the monies from water sales are normally used to supplement the meager municipal budgets. These small municipalities fail consistently to pay for the water they buy wholesale from ISI and usually their debts are paid to ISI directly by the GOT.

S E W E R A G E

Background

In contrast to the availability of old records of water supply, records of early sewerage systems do not exist. During the Byzantine and Ottoman times approximately 40 km. of so-called "black channels" were constructed of rectangular or square masonry sections covered by stone or concrete slabs. They are still in use and their size varies from about 30 by 40 centimeters to large conduits measuring 2 meters square. Approximately 35 km. are located in European Istanbul and 15 km. in Asian Istanbul. Except for poor hydraulic characteristics, they were well-constructed and are still in relatively good condition even though they quickly fill with grit during storms and require frequent cleaning. It is theorized that they were constructed as part of an old water system and later converted to sewers.

Additional sanitary and combined sewers were constructed according to a plan prepared around 1920, to serve a population of about 500,000 within the then existing boundaries of the city. In the late 1950's another plan provided for retention of much of the combined system and for separate sewers in new areas; only a small portion of this was executed. By the late 1960's an estimated total of 400 km. of sewers existed in Istanbul serving approximately 25 per cent of the city's area. Most of the population used cesspools, holding tanks or open channels and ditches.

Present Situation

An estimated 1.75 million within Istanbul municipality plus 0.35 million in the 21 surrounding smaller municipalities are served by sewers. This corresponds to 62% and 27% of their total populations, respectively. Higher service levels prevail on the European side of Greater Istanbul where about 59% of the population is sewered, as compared with 31% for the Asian side.

New cesspool construction is not permitted. Instead, the city requires the construction of holding tanks from which vacuum trucks (vidanjors) remove the contents for disposal into existing sewers, water courses or open fields. Many multi-storied apartment buildings served by holding tanks have been constructed in recent years, but the vidanjor service has not been proportionately expanded so that building owners have often constructed illegal surface overflows for their holding tanks or have provided bottom or wall openings to induce seepage from the tanks. Although construction of local sanitary sewers in streets of newly developed areas has been mandated, often they are not connected to trunk or interceptor sewers. In general, soil conditions are not conducive to sewage disposal so that use of vidanjor service is essential.

Sewer construction proceeded at a rather fast rate during the 1970's and presently the total length of sewers in Greater Istanbul is estimated to exceed 1,200 km of which about 900 km are within Istanbul municipality. Over 50% of the sewers are of recent construction and were designed as sanitary sewers even though they also receive storm water. There are also about 80 km of recently constructed storm sewers, which are increasingly becoming combined sewers due to illegal connections, particularly from holding tank overflows.

With few exceptions, all sewers are cast in-situ or hand-made concrete pipes. Poor construction and deficient aggregates, especially sand with a high sodium chloride content extracted from the Marmara, make these pipes so pervious as to be unsuitable for coastal areas. A case in point is the recently constructed Florya coastal interceptor which could not be placed in service because of excessive infiltration. This and similar problems are being solved with the installation by the municipality of Istanbul of a concrete pipe factory which produces precast pipes with flexible watertight joints.

Until recently, sewer maintenance was limited to manual cleaning of the largest interceptors and black channels, which became often clogged by large amounts of granular material and street rubbish carried into the sewers by runoff and by domestic garbage dumped into the manholes. Since 1978, it has improved considerably, with the purchase by IB of rodding equipment and tank trucks for flushing work and with the establishment of a program of sewer inspection and repair.

Average dry weather flow (excluding infiltration) from sewered premises in greater Instanbul is estimated at 333,000 m^3/d, of which about 146,000 m^3/d (44%) correspond to industrial effluents. Total BOD_5 loading is estimated at 122 ton/d, indicating rather strong wastewaters with an average BOD_5 concentration of 366 mg/l. Testing of composite sewage samples conducted by Camp Tek-Ser in 1974 (Table VI) showed, however, actual BOD_5 concentrations between 66 and 195 mg/l, with a weighted average of about 125 mg/l. These concentrations are much lower than would be expected from the low per capita water consumption and seem to be due to the dilution caused by excessive infiltration.

While a complete industrial wastewater survey is yet to be undertaken, testing of ocean bottom sediments indicate high concentrations of metals of industrial origin at 2 sites;

a) heavy metals, particularly lead, on the upper reaches of the Golden Horn; and

b) chromium in the Marmara Sea off Yenikapi, caused probably by the tanneries located in that area.

Trunk sewers ran usually perpendicular to the coast line and discharge into the coastal waters. This system of multiple discharges into the well oxygenated waters of the surf zone produce excellent dispersions of the wastewaters so that with few exceptions, sleeks and floatables are the only visible sign of pollution. Coliform levels are high throughout the coast line and affect all the bathing beaches.

Institutional Outlook

Following the appointment of Iller Bankasi as the project executing agency, in 1972 the World Bank granted a loan to Iller Bankasi for reviewing the DAMOC sewerage master plan and preparing the designs for a first construction stage. Iller Bankasi selected the Camp. Tek-Ser consortium 1/ as their technical consultants and the studies were completed in early 1974. From the start of the studies, there were jurisdictional disagreements between Iller Bankasi and Istanbul Municipality which led Iller Bankasi to grant priority to the outer municipalities with populations less than 100,000 where its right to design and construct sewerage facilities was clearly established by law. Istanbul MHnicipality, with a population in excess of two million insisted on its right to act as its own construction agency. Thus, Camp Tek-Ser studies concluded by recommending first priority for the sewerage of some of the outer municipalities while postponing the construction of the urgently needed facilities for the densely populated areas within the city of Istanbul.

The inadequacy of the staging recommended by Camp Tek-Ser together with the experience being provided by the water supply project, gradually convinced the GOT that there were significant advantages in placing full responsibility for both construction and operation of the project into a single agency. Thus, in mid-1978, the GOT assigned the Municipality of Istanbul to undertake the construction project. Since then, IB and its consultant (Nedeco of the Netherlands) has updated the DAMOC master plan and prepared a sensible staging of the construction program. At the same time, all the municipalities within the project area have signed a union of municipalties agreement which should serve as the basis for the conversion of IB into a regional sewerage authority. It is expected that construction of the sewerage master plan will get underway in late 1981, probably with partial financing from the World Bank.

Sewerage Master Plan

The sewerage master plan is basically the one devised by DAMOC and consists of a series of independent sewer systems discharging raw sewage into the Sea of Marmara and the Bosphorus through ocean outfalls. Pretreatent is included in all the outfalls for degritting and floatable removal. With the modifications introduced by Camp Tek-Ser and Nedeco, the master plan now

1/ Composed of Camp Dresser and McKee Ltd. (USA) and TEK-SER Teknik Servis A.S. (Turkey).

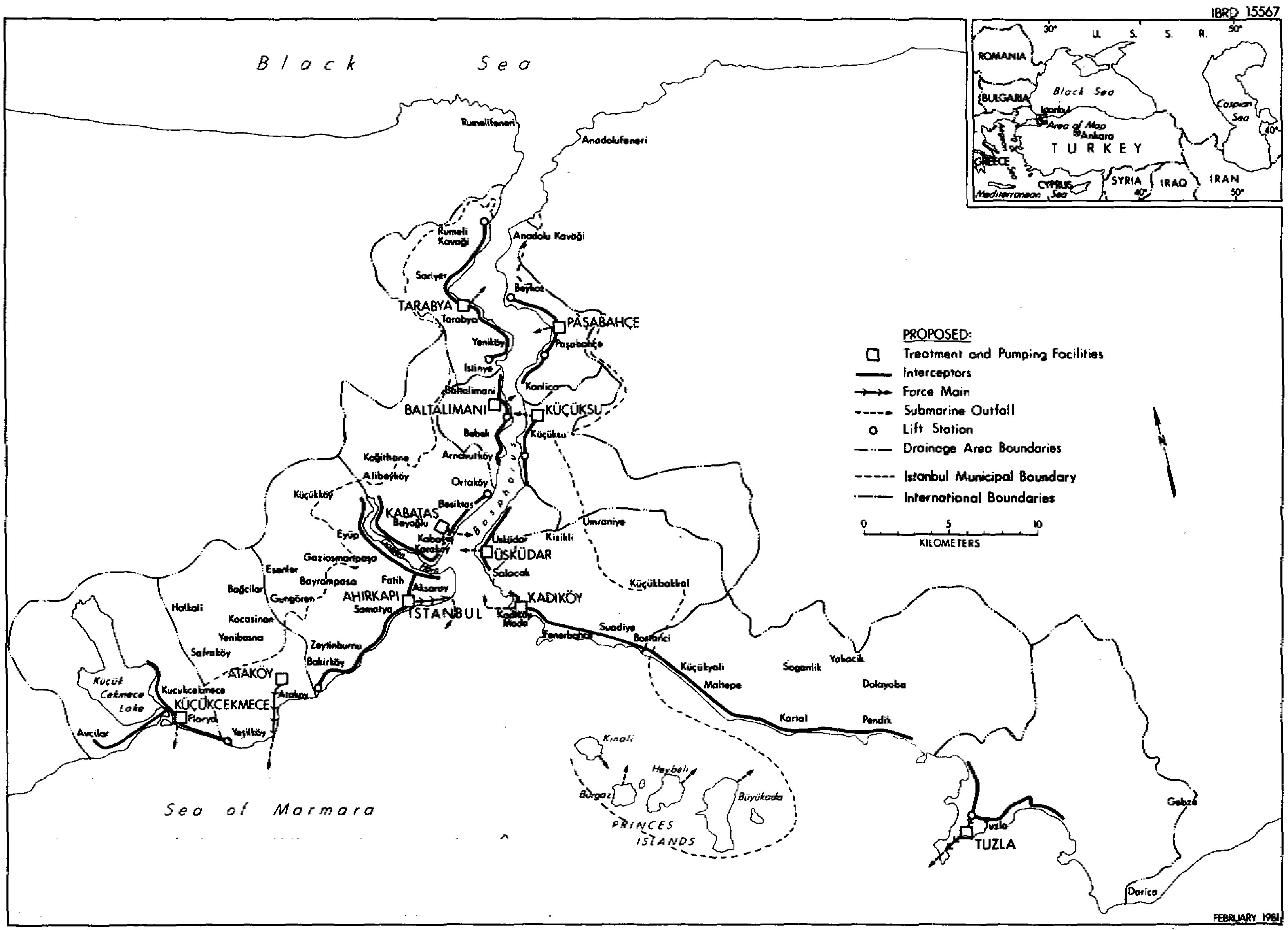

Figure 2. Istanbul sewerage project: interceptor, treatment, and outfall sewers.

includes 12 sewer systems, 4 of which discharge in the Marmara and the remainder in the Bosphorus (Figure 2). Projections of population served, wastewater flows and BOD_5 loadings for each one of those systems are tabulated on Table VII.

The hilly topography of the city allows good flow velocities and turbulence within the sewers, thereby minimizing solids deposition and sulfide generation. It permits also extensive use of small diameter sewers and a minimum of pumping, thus allowing the design of a relatively low construction and maintenance cost collection system. It limits, however, the location of the main interceptors to the densely built coastal areas. This is particularly important along the congested historical shores of the Golden Horn, where interceptor construction requires extensive housing demolition and could be seriously delayed by archaeological finds. The possibility of installing the interceptors along the shores, on new grounds to be gained from the sea, appears therefore advisable and is presently under study. Another solution, construction of tunnel interceptors, was proposed by Camp Tek-Ser but implies structural risks because of the high seismicity of the region.

The disposal procedure is the most outstanding technical feature of the master plan and because of the sui-generis oceanographic characteristics of the Instanbul area, it has been the subject of numerous articles and studies. The Bosphorus Strait and the Sea of Marmara have a stable two-layer density system, with the lower layer of denser more saline waters from the Mediterranean moving north to the Black Sea and the upper layer of less saline Black Sea waters moving south to the Mediterranean. Estimated average flows are 6,100 m^3/s in the lower layer and 12,600 m^3/s in the upper one. The boundary between the two layers is at a depth of about 10-15m in the north-eastern Sea of Marmara, 25m at the mouth of the Golden Horn and 50m at the northern portion of the Bosphorus. All the outfalls have been designed to discharge into the lower layer, at sufficient depths to produce minimum initial dilutions of 1/100 in the Marmara and 1/50 in the Bosphorus. The depth of the outfalls ensure that most of the wastewaters would remain in the lower layer where they would mix with the Mediterranean waters flowing into the anaerobic lower portion of the Black Sea.

Ocean currents are very swift in the lower layer of the Bosphorus, increasing from about 10 cm/s (0.2 knots) at the southerly entrance to an estimated 50 cm/s (1.2 knots) at one-third the distance to the Black Sea and 60 cm/s (1.4 knots) at two-thirds the distance, so that the wastewaters discharged by the Bosphorus outfalls will reach the Black Sea in less than 24 hours. Currents are much slower in the lower layer of the Marmara and are due mostly to regional weather and sea level patterns. They range along the coast of European Istanbul from 9 cm/s off Atakoy to 4 cm/s off Kucukckmece, diminishing to 2-3 cm/s on the coast of Asian Istanbul offshore from Kartal.

The waters of the upper layer are well oxygenated everywhere but in the upper reaches of the Golden Horn. In the lower layer of the Marmara, dissolved oxygen levels average about 5 mg/l but values as low as 2.5 mg/l have been often recorded, particularly during the summer. Higher dissolved oxygen values prevail in the lower layer of the Bosphorus.

TABLE VII - Istanbul Sewerage Master Plan

Projections of Population Served, Wastewater Flows and BOD_5 Loadings

Sewer System	Year 1990 Population served (000)	Year 1990 Avge. Flow 1/ $m^3/d \times 10^3$	Year 1990 BOD Loading ton /d	Year 2020 Population Served (000)	Year 2020 Avge flow 1/ $m^3/d \times 10^3$	Year 2020 BOD Loading ton /d
European Istanbul						
Kucukcekmece (M)	200.0	70.0	20.0	413.0	136.7	41.5
Atakoy (M)	293.0	95.7	22.7	600.0	200.1	53.5
Ahirkapi (B)	1,395.0	364.0	101.1	2,015.0	634.0	192.5
Kabatas (B)	950.0	255.0	70.8	1,190.0	390.0	106.4
Baltalimani (B)	100.0	33.5	5.0	145.0	48.6	10.9
Tarabya (B)	69.0	18.5	4.7	108.0	35.9	9.9
Asian Istanbul						
Pasabahce (B)	80.9	22.9	8.2	129.0	44.1	13.9
Kucuksu (B)	111.3	30.9	6.6	243.0	78.8	19.4
Uskudar (B)	143.5	32.0	7.2	244.0	72.7	18.3
Kadikoy-Kartal (B)	950.3	303.3	65.2	1,831.0	609.9	157.4
Tuzla (M)	84.9	67.8	11.5	172.0	102.9	22.3
Prince's Islands (M)	32.0	8.6	1.6	72.0	20.9	5.4
TOTALS	4,409.9	1,302.2	324.6	7,162.0	2,374.6	651.4

1/ Average dry weather flow including infiltration

(M) Marmara Sea outfall
(B) Bosphorus outfall

It is evident from the above that raw wastewater disposal into the lower layer of the Bosphorus is an excellent solution for protecting surface waters and bathing beaches from bacterial pollution. On the other hand, effluents discharged into the lower layer of the Marmara may remain in the vicinity for several weeks, further reducing dissolved oxygen levels. Because of this uncertainty and its potential effect on fish, the outfall proposed by DAMOC at Kartal has been eliminated and consideration is being given to providing primary treatment at other Marmara outfalls (Atakoy and Kucukcekmece) or to intercepting and relocating their discharge points to the southerly entrance of the Bosphorphus.

Because of poor practices of street cleaning and solid waste collection, large amounts of garbage and debris accumulate on the streets and are washed by the rains into the coastal waters. The eventual elimination of this problem lies, of course, on improved practices of street cleaning and paving. Meanwhile, the combined system serving the older part of European Istanbul is to be maintained and improved. To do this, Camp Tek-Ser recommended designing the new Marmara and Golden Horn coastal interceptors for capacities of 2 and 4 times the average dry weather flow, respectively, so that the more heavily contaminated initial volumes of runoff could be discharged through the submarine outfalls. Camp Tek-Ser computations indicate that this solution would produce a better protection of the surf zone than a separate storm sewer system discharging at the shore line, though under present conditions this protection would not be sufficient to allow bathing or other water contact sports. The situation should improve in the future as streets are paved and solid wastes are better managed and may allow a reduction of the ratios of capacity to dry weather flows during subsequent construction stages.

First-Stage Project

The sewerage project being considered for immediate construction represents the first-stage of the master plan and includes the Ahirkapi, Kabatas and Uskudar sewer systems, all of them discharging into the Bosphorus. The project would include also an industrial wastewater survey of Greater Instanbul, additional oceanographic studies, acquisition of sewer maintenance equipment, expansion of the Istanbul municipality concrete pipe factory and staff training programs. Construction time for this project is estimated at 6 years and base cost (excluding price and physical contingencies) at US $232 million (1980 dollars).

The project would cover about 90% of the higher density residential areas of Greater Istanbul and serve an additional 1.2 million people. The project has been devised as a vehicle to create a competent sewerage organization which could be replicated in other urban areas of Turkey; to develop local expertise on wastewater engineering and sewer operation and maintenance; and, to establish regulations for the disposal and monitoring of industrial effluents. The latter is of particular importance in Istanbul, since wastewaters will be discharged into the ocean without prior treatment and, therefore, industrial toxicants must be removed at the source.

To improve sanitary conditions within the city and achieve a cleaning of the coastal waters, the project would be supplemented by a solid waste project which is presently under preparation by UNDP/WHO and for which World Bank financing is also being sought.

Capital costs for the forthcoming sewerage project would be covered by central and municipal governments grants, borrowing from international financing organizations and direct contributions by the property owners benefitting from the project. Operation and maintenance would be financed through a surcharge on water consumption. Beginning in January 1980, a surcharge of T.L. 1.00 per m^3 of water has been collected from sewered premises within Istanbul Municipality. Although it is not enough to cover even the operation and maintenance costs, it represents the first sewer service charge ever established in Turkey. This surcharge is expected to be increased and extended to the entire Istanbul urban area once the sewerage project gets underway.

CONCLUSIONS

The first construction stage of the Istanbul water supply master plan was completed in 1980 but failed to provide the institutional development needed by the local water supply authorities for managing the new facilities and undertaking subsequent construction stages. Institutional conflicts were also responsible for delaying the implementation of the sewerage water plan. These problems derived mainly from two institutional approaches often favored by the international development organizations: assignment of project construction to national agencies and regionalization of the operating agency.

The international organizations often recommend assigning to national agencies the construction of municipally operated projects in order to speed up project implementation, facilitate central planning and attain country-wide dissemination of new technologies. This approach is usually supplemented with institutional studies and staff training programs aimed at developing the expertise that the usually weak local agencies will need for operating the new facilities. Close liaison between the executing and operating agencies is stressed and ample cooperation among all sector institutions is assumed.

This institutional approach is usually a good short-term solution because it facilitates the implementation of the construction program and the obtainment of central government funds. As shown by the Istanbul experience, it can also develop the expertise of the national agency. However, it turns out often to be a poor long-range solution because it further weakens the local agencies, placing in jeopardy the operation and maintenance of the new facilities. In the absence of strong municipal organizations it may lead also to distortion of priorities and premature standardization of technical solutions.

Direct and continuous involvement with the planning, design and construction phases of the project is probably the only way for the management and staff of the municipal agencies to acquire the sense of responsibility and the familiarity with the new facilities needed for their operation. This experience can be enhanced, but not replaced, by institutional studies and training programs. A close liaison between the national and local agencies which could alleviate the negative aspects of this approach is, unfortunately, difficult to achieve - the tradition and institutional discipline it requires being rarely found in the developing countries.

Within the DAMOC concept of limited regionalization, the outer municipalities were expected to continue operating their water distribution systems. No steps were taken, however, to develop and strengthen their water supply agencies, even though this may have been achieved easily through the traditional Turkish "union of municipalities" approach. Indeed, the entire DAMOC concept was replaced by a new policy aimed at converting ISI into a full regional authority. In retrospect, it is evident that some of the most serious shortcomings of the water supply project could have been obviated had the water supply authorities of the outer municipalities been properly developed.

Regionalization is another aspect of project work which is often overemphasized. In its pursuit, local agencies are neglected and too often replaced by large and ineffective bureaucracies. Economies of scale are seldom attained and responsiveness to the population is generally lost. Full regionalization should nobe imposed but should evolve from inter-municipal agreements and should wait until adequate institutional development has been achieved. In the meantime, a partial regionalization along the lines proposed for Istanbul by DAMOC appears advisable.

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INUVIK - SANITATION IN AN EXTREME ENVIRONMENT

by James B. Kirch[1], MEIC, and Dick Hill[2]

ABSTRACT

Twenty-five years ago, the Federal Government created the community of Inuvik to serve its needs in the remote western Arctic Region of northern Canada. For the first time in the far north, government personnel were to be provided with the type of fully-serviced community to which southern Canadians were accustomed. Since then, as a result of oil and gas exploration in the Mackenzie Delta area, the town's facilities have been extended to the limit on several occasions to meet an unexpected level of growth.

In general, the practices applied at Inuvik were appropriate and do meet southern standards of quality service but the development also provided a stimulus for Government to tackle the serious health problems then prevalent in northern settlements which were principally due to unsatisfactory sanitation. Over the last five years, acceptable and realistic water supply and sanitation policies have been defined and great strides have been made in meeting the basic sanitary requirements for good health in many of the 60 or so organized communities in this vast region of over 1.3 million square miles. It is planned that, within the Water Supply and Sanitation Decade, practically all northern residents will have access to a sufficient quantity of safe, potable water and will benefit from waste disposal practices that are compatible with good health.

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INTRODUCTION

Inuvik, an Inuit (Eskimo) word meaning "Place-of-Man", is a town of about 3,000 inhabitants situated at Latitude 68°22'N on the East Channel of the Mackenzie Delta. (See Map - Figure 1). It is the administrative centre for government in the Western Arctic and an important distribution point for frontier oil and gas exploration activities now centred in the Beaufort Sea some 60 miles (100 km) to the north.

Inuvik is not yet 25 years old. Prior to its development, Aklavik had been the principal Delta community but its location was not suitable as a base for expansion to meet the growing need for government presence in the area. The site selection process was completed by the Government in 1954 and construction of the permanent facilities commenced in 1958. The town was formally opened in 1961 by the Prime Minister of Canada, the Hon. John G. Diefenbaker, with words that are now engraved on a monument in Mackenzie Square, viz:

> "This was the first community north of the Arctic Circle built to provide the normal facilities of a Canadian town. It was designed not only as a base for development and administration but as a centre to bring education, medical care and new opportunity to the people of the Western Arctic. 21 June 1961."

Perhaps in those words the Prime Minister, who had his own rather special visions for the future of Canada, had a more farseeing premonition of things to come than the original planners and designers. Certainly Inuvik was conceived as a modest community, principally consisting of civil servants who would concern themselves with the problems of administration, social welfare, health, law and order, education and particularly Arctic research and national defence. The Prime Minister's reference to Inuvik being designed as a base for development was clearly not reflected in the original planning, at least in the heavy industrial sense. A significant commercial/industrial component was never anticipated and as a result the community facilities were laid out to meet quite limited demands.

Accordingly, Inuvik has had to struggle harder than most places of its size and characteristics to meet the problems of unforeseen rapid growth. In view of the very extreme climate, perhaps the most difficult aspect of coping with that growth has been in the area of water supply and sanitation. The demand for water has outstripped the supply capability on several occasions, creating urgencies for the facilities to be expanded. The manner in which growth has been accommodated is described in this paper. Thereafter, some of the lessons learned from the Inuvik experience and the development of appropriate water supply and sanitation policies for the future are discussed. Initially, a brief description of the extreme environment is presented, a little history is introduced, and the original development concepts are explained to provide some background to what follows.

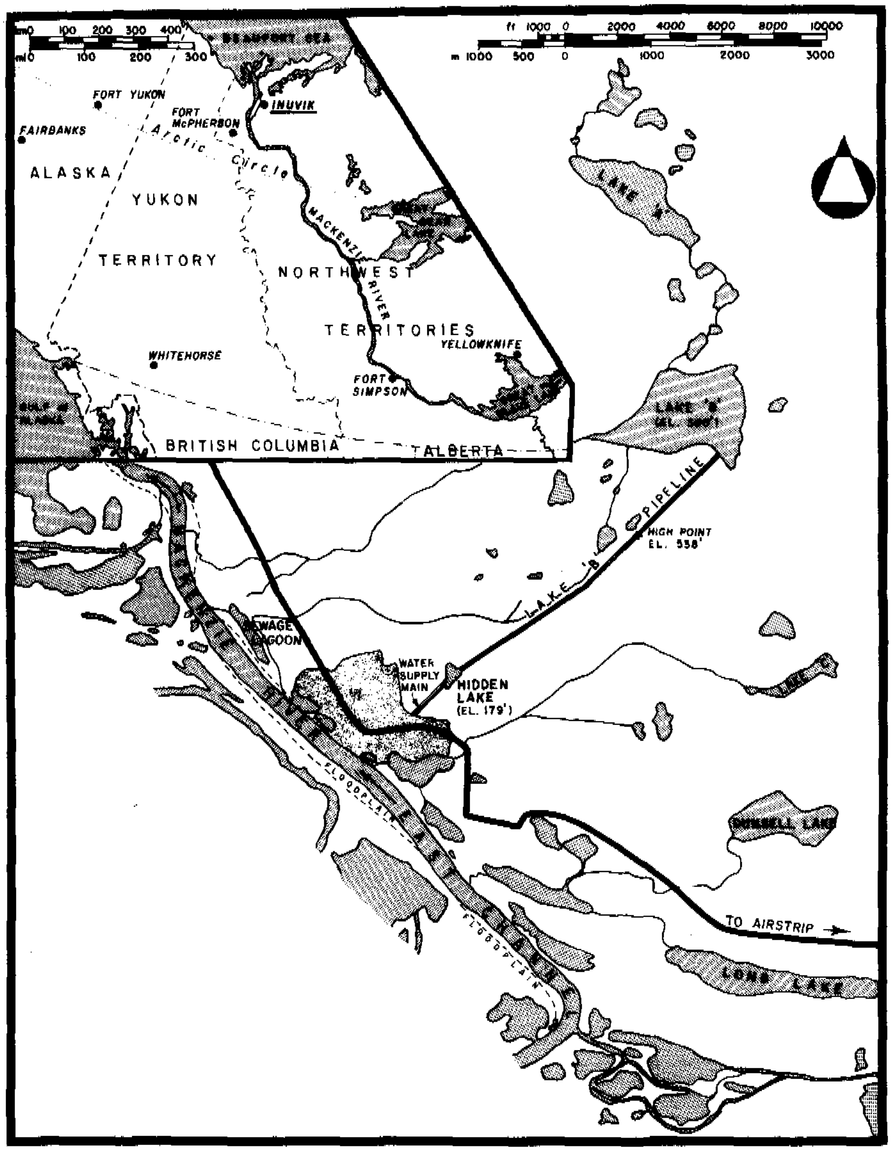

Figure 1: INUVIK & IMMEDIATE AREA with GENERAL LOCATION MAP

CLIMATE, GEOLOGY & VEGETATION

The mean annual air temperature at Inuvik is 15°F (-9°C). Normal daily maximum temperatures exceed the freezing point only during the period from late May through early September. In July, the residents experience the midnight sun and enjoy mean high and low temperatures of 67°F and 47°F (19.7°C and 8.2°C). An extreme of 90°F (32°C) has been recorded at the Inuvik airport.

In mid-winter, however, the sun does not show its face for about six weeks and there is only a twilight period at midday. Mean high and low January temperatures are -15°F and -32°F (-26.1°C and -35.7°C). An extreme minimum of -70°F (-59°C) has been recorded.

Precipitation is low, averaging less than 11" (276 mm) annually. Of this total, only 4.3 inches (110 mm) appears as rainfall and the remainder, 65.4 inches (166 mm) as snowfall. The prevailing winds are easterly at 5.2 knots.

Certainly Inuvik has an exteme climate. But the air is clear and dry and the winds light at sub-zero temperatures. Although long, the winters are not unpleasant. Cross-country skiing is a popular pastime.

The Mackenzie Delta lies between the Richardson Mountains, of Cretaceous age, in the west and the Caribou hills, perhaps of Tertiary age, on the east. The valley has been eroded by the river and modified by glacial movements. To the northeast, one or more post-glacial deltas are evident. The origin of the soils at Inuvik is not certain, but they are thought to consist of either a kame terrace or a pre-glacial lake.

A thin surface cover of living moss exists wherever it has not been disturbed. This layer is important to preserve because it provides excellent insulation for the underlying permafrost. Below the moss is generally a layer of peat containing occasional blocks of almost pure ice. Beneath the peat lie gravels of varying size distributions but frequently containing high percentages of fine sands, silts and sometimes clays. (15)

HISTORY

Alexander Mackenzie, fur trader and explorer extraordinary, may have paddled past the site of Inuvik with his party of French-Canadian voyageurs and Indians during his epic dash from Fort Chipewyan on Lake Athabasca to the Arctic Ocean and back between early June and mid-September in 1789, but he was not followed thereafter for many years by others seeking their fortunes. Mackenzie's motives for this incredible voyage were largely economic, not geographical. As a most successful partner in the Northwest Company of fur traders, he was concerned about the long, arduous and expensive overland transportation route from his western outpost to Montreal from where the furs were shipped to Britain and Europe to satisfy the insatiable demand for beaver hats - then the status symbol of success in the Old World. He believed ardently that an alternate, shorter route to the Pacific Ocean existed and both his northern river excursion and his trans-mountain exploration to the west coast five years later were dedicated to that end. While he did not succeed in finding an easier transportation route, his northern voyage opened up the river system that was later named after him, and provided new sources of supply for the lucrative fur trade (19). Since that era and until very recently, trapping has been the mainstay of the region's economy and is still the major industry in terms of the numbers of people engaged in it. A majority of the indigenous inhabitants depend upon it to some degree, at least as an income supplement, but to many it remains a way of life they are reluctant to give up completely.

During the 18th and 19th centuries, the principal area of trapping interest in the Mackenzie Region was somewhat further west and the early trading posts were located accordingly. Fort McPherson was established in 1840 and has occupied its present location on the Peel River since 1852. Both Indian and Eskimo trappers traded at this fort for many years but the latter preferred the territory beyond the treeline further north and sought more contact with the whaling ships in the Arctic Ocean. To accommodate this trend, a second trading post was established at Pokiak Point in the delta in 1912 but it also was moved a few years later to provide an improved facility for docking river steamers on the Peel or Western Channel of the Delta.

Thus the settlement of Aklavik, meaning "place of the barrenland grizzly bear", was established in 1921 as the principal trading and administration centre for the Delta. Gradually, the Royal Canadian Mounted Police, the churches with their schools and mission accommodation for children, the Hudson's Bay and other traders, Canadian Pacific Airlines, the military and the Federal Government moved in to create a frontier settlement. As work opportunities expanded, members of the native population began to exchange their traditional nomadic way of life for a more-settled existence in an organized community, and Aklavik became a multi-racial centre for Eskimo, Indian, white and Metis (mixed-blood) peoples. The demand for proper housing and better municipal services accelerated.

As people from many parts of the world will attest, the middle of a delta is not a good location in which to develop a modern community. The normal delta problems of limited availability of suitable land, lack of construction materials and the difficulties of providing adequate sanitation services were greatly magnified at Aklavik by the presence of underlying permafrost, perennially frozen ground, to great depth. The fine silty soils contain as much as 60 percent of ice by volume in their frozen state. Thus burial of pipes conveying water and sewage was considered out of the question. Heat transmitted from warm buildings had led to severe subsidence. Attempts to cut drainage ditches had resulted in bank sloughing and impossible muddy conditions during the summer as still more permafrost melting took place. Contact with the outside was limited to small planes that could land either on the water or the ice and was consequently not possible for two periods of several weeks annually during the spring break-up and fall freeze-up. Clearly further development of Aklavik as an important administration and commercial centre was severely restricted and by the early 1950's, the Canadian Government had decided to relocate the town.

SELECTING THE NEW TOWNSITE

The search for the new townsite was guided by five essential factors and three highly desirable features (15). These included the importance of having a location within the Mackenzie Delta Region that was socially and economically acceptable, with close access to both a good navigation channel and a site for a permanent first-class airfield. A good supply of gravel and sand for construction materials was considered to be highly desirable as were wharf facilities for trans-shipment of goods from river steamers to sea-going vessels to service points further north.

Of more important concern herein, however, were three essential factors related to sanitation, i.e.

- that the site should be within economic distance of a suitable public water supply,

- that the site should be suitable for the installation of permanent sewer and water systems, and

- that the site should provide for the economic and convenient disposal of sewage.

Clearly, good sanitation was considered of critical importance to the development of a model Arctic community.

Initially twelve sites were selected from an inspection of aerial photographs and four were chosen for more careful evaluation. During the summer of 1954, field surveys were carried out involving both government personnel and local people from Aklavik. By August, a provisional selection had been made and more-intensive investigations were centred on the preferred site, then known as East Three. Suitable maps and field data were prepared for town planning purposes.

In November of 1954, the Federal Government approved the choice and officially declared that Aklavik should be moved to its new site. This last point is worthy of particular note. There is no doubt that the Government intended that the entire town should be physically relocated to a new home and that government facilities and services would no longer be available at the old site.

It is interesting to observe 25 years later that Aklavik is now a hamlet of about 760 people that has certainly not died as a result of the move. Possibly it has persisted because many of the native inhabitants had established traplines in the western delta and did not wish to move some 45 river miles (75 km) further east. Nevertheless, it does appear that many of the people in Aklavik 25 years ago did not fully appreciate either the intent or the ramifications of the planned relocation. Since then, the economy of the hamlet has also been strengthened as a result of oil and gas exploration activities and more recently reinforced by opportunities for the manufacture of handicrafts and fur garments. Its population is approximately half Dene (Indian) and half Inuit.

However, permanent water supply facilities still do not exist in Aklavik, although steps are being taken to remedy this situation. An above-ground piped system supplies water free to residents in the summer and tank trucks are used to deliver water in winter for a fee to those homes that have storage facilities. A few still cut ice in winter and store it for drinking water during the summer. Sewage is disposed of in plastic 'honey' bags together with the household garbage at the dump and causes much concern because landfill operations are not practical in that location. Sullage is disposed of on the ground outside of each house and in winter forms masses of dirty grey ice that constitute a severe health hazard in the spring (12).

PLANNING THE NEW TOWN

With the decision taken and the field surveys complete, the task of planning the new town was entrusted to a consortium of engineers and town planning architects. A committee representing the concerned federal agencies of Public Works, Northern Affairs and National Resources, and Health and Welfare, as well as local interests was formed to guide the work. The Consultant's recommendations were made to Public Works in August 1955 and set the standards for most of the development thereafter (7,8).

a) Population forecasts

Table 1 illustrates the population and land requirements that were developed for initial planning purposes. The data show the extent to which it was anticipated government and service activities would dominate. Schooling and hostel accommodation was to be provided for children from other Delta settlements. On a percentage basis, the population concerned with the commercial needs of the town was expected to grow the most in reaching the ultimate level of development but it was also forecast that this component would remain substantially smaller than either the government or church-affiliated personnel.

In practice, the population has grown much faster than was expected and in a direction not originally foreseen. The experience has been as noted in Table 2 (21). For its first few years, Inuvik's population growth reflected a rather normal pattern for a large construction activity with new employment opportunities. However,

TABLE 1 Inuvik - Population and Land Requirement Forecasts (Ref. 7)

UNIT	POPULATION		LAND REQUIREMENTS (acres)	
	Initial	Ultimate	Initial	Ultimate
Government Services	971	1855	116*	262*
Church Missions & Hostels	629	1207	13	17
Commercial	249	746	7	10
Industrial	Nil	Nil	19	55
SUB-TOTAL	1849	3808	155	344

* including schools, recreation, parks, etc.

TABLE 2 Inuvik - Actual Population Growth (Ref. 21)

Year	Population	Data Source
1961	1248	Canada Census
1966	2050	Canada Census
1970	3078	Municipal Census
1971	2669	Canada Census
1976	3115	Canada Census
1978	2938	Census by Government of the N.W. Territories (G.N.W.T.)
1980	2865	Estimate by G.N.W.T.

this trend did not reverse itself, as could have been expected, because the town became host to first seismic survey teams and later drilling operators intent on locating and proving the underground natural resources. Interest grew in the potential for a natural gas pipeline along the Mackenzie Valley.

As soon as resource explorations in the area began to show a potential for future exploitation, concern over the potential social, environmental and economic impacts of a natural gas pipeline traversing this area were expressed. In March, 1974, the Canadian Government commissioned Mr. Justice Thomas R. Berger to investigate upon the terms and conditions that should be imposed in respect of any right-of-way across Crown Lands that might be granted to a pipeline proponent. Justice Berger conducted his Inquiry with a deep sense of concern over the welfare of Canada's northern native peoples. He carried out hearings in every city, town, village and settlement in the Mackenzie River Valley and the Western Arctic and made an exhaustive analysis of the many related issues of native culture, social well-being, land claims, environmental aspects, economic stability and future opportunities. He came to the conclusions that oil and gas developments in the Mackenzie Delta-Beaufort Sea region were inevitable and that, in due course, an energy corridor along the Mackenzie river to northern Alberta would be needed. He recommended, however, that no action be taken for a period of ten years to allow sufficient time to settle native claims and to establish new programs and institutions so that orderly development could take place.

The impact of Justice Berger's recommendation on the growth of Inuvik was significant. There are signs, even today, of construction that was terminated abruptly and the rapid population growth of the previous five years was again reversed.

The centre of exploration activity has now moved north to the Beaufort Sea where the small community of Tuktoyaktuk, meaning "looks like a caribou", is now receiving its share of the boom activity and is incidentally experiencing its share of sanitation problems due mainly to a limited availability of potable water. The standard service in 'Tuk' consists of water delivery by truck to a tank in each house and sewage pump-out into a tanker for ocean disposal.

The partial withdrawal of industrial activity is providing Inuvik with an opportunity to consolidate and plan for what is acknowledged to be an uncertain future. How the community plans for that future depends very much on the planner's viewpoint. If oil and gas exploration in the Beaufort Sea proves to be commercially viable, the estimate of 15,000 population by the year 1990 suggested by one of the oil company executives (21) is perhaps conceivable. At the other end of the scale, the Government of the Northwest Territories is planning for a continued modest growth rate of 1.3 percent annually to less than 4,000 by the end of the century, which it acknowledges does not reflect any resource development projections. Several intermediate forecasts have been made, thus rendering the town planner's job a difficult one under the circumstances.

b) Residential Housing

The original town plan anticipated the need for three levels of residential housing (8).

> Group A housing, to include both single family units and higher density single quarters, would be constructed to government standards and provided with electricity, water supply, sewers and central heating. This housing was to be designated for government personnel on a subsidized rental basis, although a few lots were to be set aside for private sale.
>
> Group B housing would be provided with electricity, water and sewer services and offered for sale to non-government residents. To keep the cost of services down, a higher density layout was to be adopted but even then it was expected that some form of government-sponsored mortgage loans would be required. Owners were to be provided with central heating if they wished at their own expense. Standards were to be somewhat lower than for Group A housing and efforts were to be made to encourage the native population to settle in the Group B areas.
>
> Group C housing would be unserviced, except possibly for electricity, and no minimum standards were to be established for size and type of construction. The area set aside for this housing was remote from the town centre and was to be 'screened' from the remainder of the town by a government-owned camp area that could be re-zoned if necessary. Residents would be provided with water by truck but would be required to deposit night soil at designated service centres as "collections from houses cannot be justified financially". Each service centre would have cold water on tap and be equipped with toilets but for "efficiency and economy, hot water, shower and laundry facilities would be concentrated at one centrally-located service centre only" (1).

Initially, the development emphasis was placed upon the public and mission/school buildings and the Group A housing. Within a short time thereafter, the demand for serviced housing matched the population growth and government-assisted mortgages were required to facilitate this development. While the amount of unserviced housing in the west end of town grew rapidly to meet the early demands for accommodation, the concept of permanent low-quality, unserviced housing soon became untenable.

It is interesting to reflect upon the planning philosophy that led to the designation of an area for unserviced housing in a new community that was designed to be a showplace for northern development, particularly in view of the known relationship between poor sanitation and ill-health. Certainly a number of northern residents cherish an isolated existence and prefer not to be dependent upon public sanitation services. Such people would not wish to move into a large community like Inuvik. Some native people coming from small family-type settlements have suffered a culture shock in larger organized communities even within their own northern environment. Perhaps the unserviced area was intended to provide a transition zone so that the inhabitants could gradually become acclimatized to their new surroundings. In any event, Inuvik has not attracted any significant numbers of such people and may indeed be viewed by many traditional northerners as an artificial aberration in terms of appropriate living conditions.

c) Water supply and sewerage

The big advantage to the site of Inuvik was that it was located at the edge of the Delta, on gently sloping, well-drained land above spring flood levels. An initial soil survey was carried out within the planned boundaries of the new townsite so that the principal buildings and residential areas could be placed on the better soils.

Nevertheless, the entire area is underlain by permafrost, as at Aklavik, and it was considered impracticable to bury the water and sewer mains. A design based upon enclosing these pipes in insulated boxes above ground level, called utilidors, was developed. Since it was also considered important to avoid the need for storing sewage in heated enclosures at intermediate pumping stations, the town layout was dictated primarily by the locating of utilidors to facilitate gravity flows (Figure 2). Dead-end streets and extra roads were used to avoid costly utilidor crossings wherever possible.

d) Central Heating

The extreme climate necessitated special measures to ensure that the water and sewer mains did not freeze. Heat tracing and continuous circulation alternatives were considered but it was decided that, for a small compact community of the type envisaged, the use of central heating had much merit and would, in addition, provide within the utilidor the necessary heat to prevent freezing of the water and sewer mains. Comparative studies indicated that if all principal buildings and the fully-serviced housing were heated from a central plant, overall economies could be achieved, there would be a reduced fire hazard, fuel requirements and maintenance costs overall would be lower and the opportunity would be available to combine the heating and electrical generation into one main plant burning residual oil transported from the Norman Wells refinery, some 450 miles (725 km) to the south on the MacKenzie River, instead of the more-costly fuel oil needed for small individual building units.

For technical reasons beyond the scope of this paper (see Ref. 6) high pressure, high temperature water rather than steam was selected for the heating system. The hot water is pumped through a flow and return pipe network within the utilidors. Heat exchangers are used in each building.

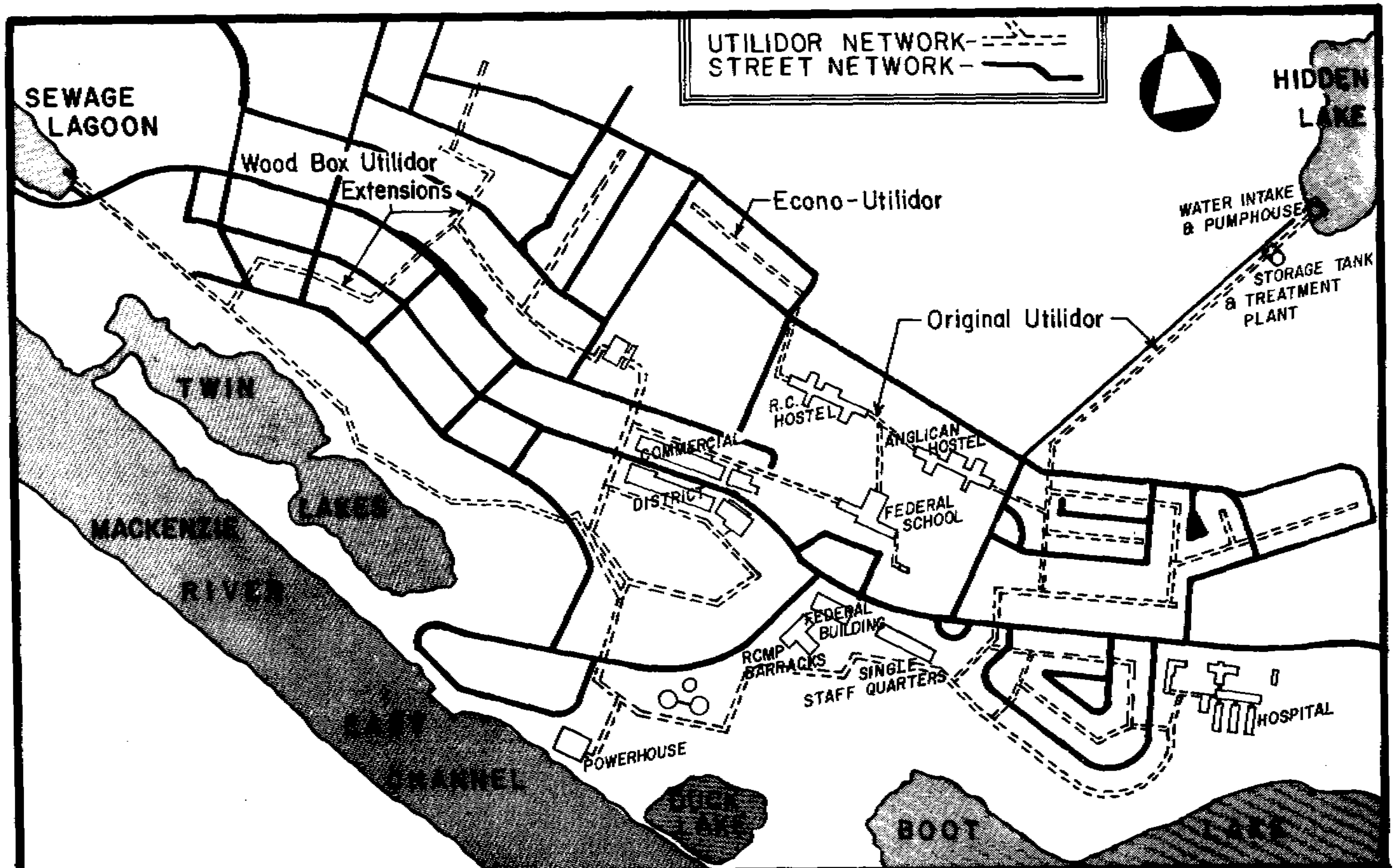

Figure 2: LAYOUT OF UTILIDOR SYSTEM FOR INUVIK

WATER SUPPLY & SANITATION SERVICES

Following the decision to entrust the Northwest Territories Power Commission with responsibility for all utilities at the new townsite, consulting engineers[3] were retained in June 1956 to carry out all initial studies, prepare detailed designs and contract documents and supervise construction of the facilities. The work commenced immediately and was timed to provide for heat and power to be available to a small number of buildings by the fall of 1958.

The initial specifications called for a treated water supply to be taken from the Mackenzie River. Sewage was to be discharged to the river but the need for prior treatment was left open for further study. In June 1957, the Northern Canada Power Commission (the successor to the NWT Power Commission) advised that "the ultimate population of that portion of the town that will be supplied with water and sewer services should be taken as 2,500 people ... it is not intended that water and sewer lines will ever be extended to service the so-called unserviced area" (16).

The water supply system and distribution network was designed in accordance with the Dominion Fire Commissioner's requirements. Because of the relatively small size of the community to be served, this requirement largely determined the amount of storage to be provided and the pipe sizes for the distribution network. Since the pipe sizes in turn determined the design of the entire utilidor system, this decision was most fortuitous in view of the increased demands that were placed on the network as the population increased to unexpected levels.

The Utilidor System

The original utilidor was designed to carry flow and return hot water central heating pipes, a water main and a sewer (Figure 3). Because of the range of temperatures that would be experienced in the central heating system, it was decided that provision had to be made for expansion and contraction. The cost and above-ground location of the utilidor eliminated options for providing sufficient flexibility in the lines to absorb thermally-induced movement and hence the alternative of using flexible expansion joints was adopted. They were placed at intervals between anchors on all long straight sections of utilidor and at each change of direction. Since the water in the heating pipes was pressurized at 150 psig (1034 kPa) to maintain the required normal operating temperature of 350°F (177°C), the out-of-balance forces created by these expansion joints were considerable and necessitated the use of steel piles and supporting

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3 Montreal Engineering Co. Ltd., Montreal, in association with Stanley, Grimble and Roblin Ltd., Edmonton.

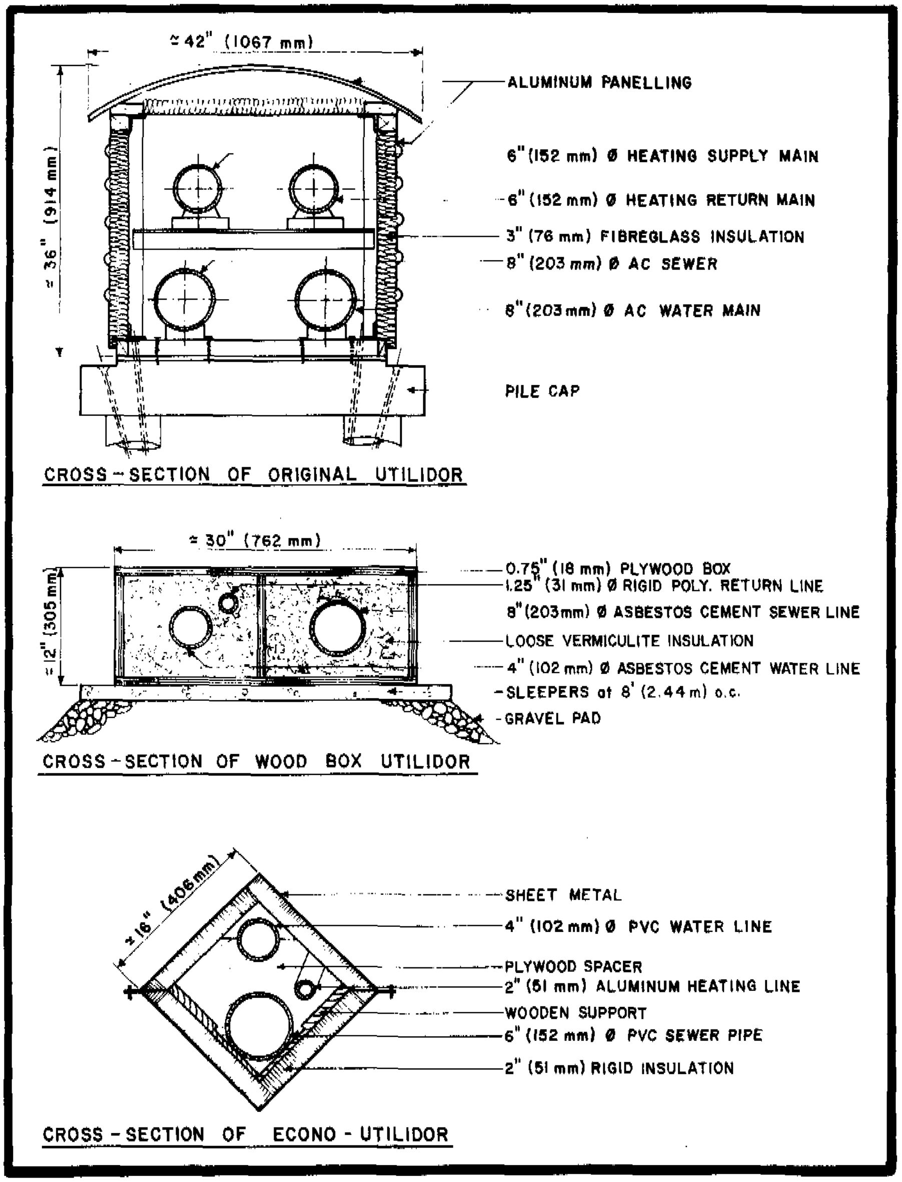

Figure 3: EVOLVING TYPES OF INUVIK UTILIDORS

structures that were much more elaborate and costly than the wooden piles used not only elsewhere for the utilidor but also to support the principal buildings.

Following consultation with selected suppliers, and in recognition of the magnitude of the shipping problem, it was decided to have the insulated utilidor panels fabricated at the factory in ten-foot lengths. Since the side panels had to be removable for repair and maintenance purposes, their weight was also a design consideration. To achieve lightness compatible with durability and safety requirements, aluminum-clad sandwich panels containing three inches (76 mm) of fibreglass insulation and a curved corrugated aluminum roof were used in making up the utilidor section.

The panels were bolted to steel angle frames supported on timber pile caps. These in turn were pinned to timber piles at ten-foot spacings wherever the steel-piled anchor supports were not necessary. For improved stability, alternate pile caps were supported upon one or two piles. Since the length of utilidor originally installed was about 6,000 feet (1,830 m), it can be observed that a very large number of timber pilings were needed. Fortunately, after initial testing, it was concluded that these could be cut from local sources of spruce (8). They were normally about 20 feet in length with average diameters of 9" (23 cm) at the tip and 13" (33 cm) at the butt. In general, they were sunk to a depth of 12 feet (3.7 m) so as to have at least two-thirds of the pile held in the permafrost below the "active-layer" that melts during the summer. The adfreezing strength of the ice against the pile, rather than end-bearing, was considered as providing the necessary load capability.

The original piles were set in place by steamjetting a hole in the permafrost to the desired depth using a portable oil-fired boiler and a 3/4" (19 mm) diameter steel pipe. After about one-half to one hour, depending upon the soil conditions, the jetting was stopped and the pile driven into place. Once re-freezing was complete, its load capability was found to be ample - tests gave acceptable loadings of 15 to 18 tons (13.6 to 16.3 tonnes) each (8). The major concern for the utilidors however, was over heaving because of the very light loadings imposed on most of the piles.

In practice, experience has been excellent. While a few piles have heaved, generally where summer ponding in areas of poor drainage has caused excessive melting of the permafrost, the great majority are still in first-class condition after nearly 25 years.

During the early planning period it was concluded that, even at Inuvik where soil conditions were superior to those found at Aklavik, none of the soils in the townsite area were suitable for foundations unless they were maintained in a frozen state (8). For most small buildings, this condition has been achieved by placing several feet of granular fill on top of the natural organic cover of tundra moss. Larger structures, such as oil tanks, are placed on granular pads in which conduits have been laid to ensure air circulation and hence heat dissipation. Unfortunately, although an adequate availability of granular fill was one of the townsite selection criteria, excessive demand has depleted many of the sources originally located. Thus, the town still has to use timber pilings for structural purposes wherever ground subsidence would not be acceptable. Nowadays the piles are generally placed butt-end downwards in an 18" (46 cm) diameter drilledhole which is then backfilled. The obverse direction of the tapered surface helps to counteract any heaving tendency.

All utilidor sections were laid out with at least 18" (45 cm) clearance under the structure so as to minimize the possibility of heat transfer to the soil. Generally the gently-sloping terrain on which the town is built facilitated the use of minimum clearances but in a few locations, particularly along the shoreline of the East Channel, the utilidor sits as much as ten feet (3 m) in the air to retain a grade that permits gravity flow to the sewage outflow point north of the town. While not aesthetically pleasing, this option was deemed operationally preferable to the use of a sewage pumping station above ground.

The original utilidor system cost about \$ 230 per foot (\$ 750/m) length. At that stage in the development of northern communities experience with utilidors was limited and generally not good so that for Inuvik, quality and low maintenance cost requirements were placed ahead of initial cost in order of importance. Apart from some physical damage to the cladding, because the top of the utilidor was used as an access walkway, the structure has stood up extremely well and is not difficult to maintain.

Nevertheless, as the demand for services grew, unlimited funds for expansion were not available and the original plant was inadequate to support the increased use of central heating. New techniques were needed to permit future expansion of the utilidor system.

The first extension was a double wooden-box utilidor (Figure 3) constructed of 3/4" (about 16 mm) plywood placed upon sleepers at 8-foot (2.5 m) intervals laid within a continuous gravel embankment. Access is from the top only through removable cover plates. The 8" (25 cm) sewer, 4" (12.5 cm) water main and 1 1/4" (30 mm) water return line are packed tightly within loose vermiculite insulation.

Another extension, of an experimental nature, was installed in 1968 to service a new area in the north-eastern part of the town. The design of this Econo-utilidor is also illustrated in Figure 3. Shortly after it was installed it was vandalized but has since been returned to service and has been found to function satisfactorily.

The above discussion is a brief review of the history of utilidor development at Inuvik. One Master's thesis and several comprehensive papers have been published on the subject and would provide much more-detailed information on design and operating details for those interested (4, 12, 14).

a) Water Supply

The original water supply facilities were designed to meet the needs of a population of 2,500 people at a usage rate of 70 gallons/day per person (265 litres). Thus the total daily demand for the community was not expected to exceed 175,000 gallons (660 m^3). No attention was paid to means by which this supply could be expanded to serve a larger population in the future.

Groundwater was considered as a possible source of supply but experience with underground abstractions in permafrost was very limited and it was decided not to pursue this approach in view of the availability of an acceptable surface water source.

Several small lakes near the town were also considered but their drainage areas are all very small and it was concluded that replenishment would not be adequate. Thus the East Channel was selected as the town's source of water supply. Samples taken from the East Channel in the summer of 1954 indicated a water of good quality for potable purposes (Table 3) but it was recognized that turbidity would vary widely with the seasonal variations in river discharge. Treatment for the removal of turbidity was considered essential, but information on the range to be expected was not available.

The location of Hidden Lake less than a mile (1.6 km) from the river at an elevation of about 180 feet (55 m) presented an acceptable solution. A permanent pumping station with a capacity of 180 gpm (11.4l/s) was constructed on a good foundation near the shoreline of the East Channel and used to pump river water through 5,200 feet (1600 m) of 4" (10 cm) pipe into Hidden Lake from where the town's supply was abstracted. The water was not treated but a connection to the distribution system and a chlorinator were supplied for emergency use in the event that the Hidden Lake supply and treatment plant was out-of-service.

Water was supplied to the permanent pumphouse by means of a portable pumping unit that was housed on the ice of the East Channel. The sizing of the pumps was based on supplying the full annual water demand during the winter thereby allowing for the portable pumping station to be dismantled before the ice went out in the spring and replaced when the ice formed in the fall. It was expected that, as the demand gradually increased, some pumping in the summer using a small unit on floats might be needed to top up the Hidden Lake reservoir but that it should be possible to avoid taking water from the river during the spring flood period and immediately thereafter when high natural turbidity levels could be anticipated.

Soundings showed that Hidden Lake had sufficient retention capacity to allow much of the river water turbidity to settle out before the water was used as well as to meet the needs of the community during the period when pumping from the river was not desirable. Under these conditions the only treatment needed would be filtration of the finest particles and probably some algae during the

TABLE 3 Inuvik - Water Quality Data

Location	pH	Iron (Fe)	Alkalinity ppm.	Total Hardness ppm.	Color
East Channel (1954)	7.3	0.1	110	130	c5
Hidden Lake (1954)	7.1		46	52	c50
Hidden Lake (1959)	7.3		32	46	22
Boot Lake (1959)	6.8		21	29	54
Twin Lakes (1959)	7.5		44	73	66
Lake "B" (1959)	7.0		22	31	57

TABLE 4 Inuvik - Sewage Lagoon - Performance Data (1972)

Parameter	Median Values (mg/e) Influent	Effluent Summer	Effluent Winter	% Reduction Summer	% Reduction Winter
B.O.D (5-day)	195	40	51	80	71
C.O.D.	335	n.a.	135	--	60
Total Solids	520	175	500	66	Nil
Suspended Solids	135	20	20	85	85
Total Coliforms	$3.5x10^7$	$6.8x10^3$	$1.0x10^5$	49*	34*

* Logarithmic reductions

summer. Filterability tests were done during the summer of 1957 and, on the basis of these results, a Glenfield and Kennedy Microstrainer was purchased from Britain for water treatment. The strainer was fitted with fabric having an aperture size of approximately 23 microns. The treated water was stored in a 108,000 gallon wood-stave storage tank enclosed in the heated treatment building from where it was fed by gravity to the town's distribution network. Chlorination and later flouridation were carried out.

To meet the Dominion Fire Commissioner's requirements, the Hidden Lake intake was also equipped with twin electric 900 gpm (57 l/s) firepumps and a 1,800 gpm (115 l/s) gasoline-driven standby pump. Water for fire-fighting purposes would not be filtered but a booster pump was provided on the chlorinator system to facilitate disinfection. A master flowmeter was installed to measure total water usage but because most of the accommodation was planned for use on a rental basis by government staff, individual meters were considered to be unnecessary.

Precise information on the number of people being served from time-to-time is not available but by 1970, when the total population had already exceeded 3,000 (according to the Municipal Census - Table 2), it was estimated that about 1,750 were connected to the utilidor system and the other 1,300 were being supplied by tank truck at an average daily usage rate of only 5.3 gallons per capita (20 l) (7). By that time the pumps on the delivery system from the East Channel to Hidden Lake had already been enlarged to provide 320 gpm (20 l/s). This increase had necessitated the addition of a booster station at the base of the hill on the line to Hidden Lake, so as to keep operating pressures in the network within the pipe's rated capability. A hotwater backwashing system had been installed to increase the filtration capability of the Microstrainer.

The total mean annual use of water had, by 1970, reached 375,000 pd (1,420 m^3). Allowing for the amount of trucked water (about 7,000 gpd) this corresponds to a mean daily usage rate by the serviced population of over 200 gallons (750 litres) per capita, an incredibly high consumption rate for a northern town.

While the average demand rate has apparently decreased somewhat since that time, excessive usage continues to be a problem in Inuvik. Current rates are in the order of 150 gpcd (570 lcd). Leakage from the water mains within the utilidor can be stated from observation to be negligible. Some water is certainly wasted trying to run taps until the water becomes cool and some is no doubt run to waste in the winter by a number of users fearful that their lines will freeze if they do not keep the water flowing. Six test meters were installed to obtain consumption data. They confirmed the high use rate but no action has been taken to reduce demand. Since consumers in Inuvik either do not pay for water themselves or are invoiced only a flat rate regardless of use, conservation is not considered to be important.

By the late 1960's, the basic problem was a shortage of water. The river pump and piping system was not able to replenish the drawdown on the Hidden Lake reservoir. During the spring break-up the situation was partially ameliorated because the melting snow around Hidden Lake provided some extra water when the river pumps were out of service. In the fall, however, no such replenishment was available and, with the pumps out of service for up to six weeks, the total demand volume was approaching 15 million gallons (57,000 m^3). The total usable storage in the top 1.5 m of the Hidden Lake reservoir, with minimum ice cover in the fall, was estimated to be about 22.5 million gallons (85,000 m^3) but the summer is the heaviest demand time and it was becoming more difficult to approach the freeze-up period with the Lake full.

It was also observed that, because of heavy drawdown annually on the Hidden Lake reservoir and the need to continue pumping for as long as possible from the East Channel, lower quality water with high turbidity was being delivered to the upper reservoir on a routine basis. Tests showed that the quality of water in Hidden Lake was deteriorating and could be expected to reach a level within a few years when filtration alone would not provide sufficient treatment. In addition, the chances of introducing oil and human wastes pollution from the Mackenzie River was becoming greater as use of the wharf and shoreline area increased.

Another factor leading to deterioration of the water quality in Hidden Lake was the forest fire of 1968. A large part of the catchment area was burned in that year and, since then, there has been a much greater rate of sediment addition to the reservoir from local runoff during the spring melt period.

Several studies have been carried out since 1969 to investigate methods for meeting increased demands. Consideration was given to augmenting the seasonal supply to Hidden Lake by installing an 8" (20 cm) pipeline from the East Channel to be used instead of the original 4" (10 cm) line. Since there was not sufficient space in the utilidor, it was recommended instead that it be well-insulated and supported on the pilings outside the utilidor (13). However, this short-term solution was not favoured since it failed to cope with the basic problem of the limited storage capacity and water quality in Hidden Lake.

Investigation showed that Lake 'B', about three miles distant from Hidden Lake, had sufficient capacity and was of acceptable quality to meet the summer needs of the town. An uninsulated steel pipeline, 5 km long, was installed, together with an intake and pumphouse at Lake 'B', in 1973 to provide up to 800,000 gpd (35 l/s) summer replenishment to Hidden Lake. In the fall, the line had to be taken out of service and emptied. More recently, additional improvements have been made. In 1975/76 a 600,000 gallon (2,270 m^3) insulated steel storage tank was added to the Hidden Lake complex and in 1979/80 the first stage of a new treatment plant beside the East Channel was completed. It provides a filtration capacity of about 1.4 mgd (5,230 m^3), sufficient to meet the needs of a population of about 8,000. Water from this plant can be pumped either to Hidden Lake, or after heating, filtration, chlorination and flouridation, directly into the distribution system (21). After a difficult decade of trying to cope with rapid changes, the water supply problems have been solved for the foreseeable future and logical growth to a population of even 15,000 can be accommodated.

b) Sanitation

According to the original plans, those living in the unserviced area of town would be supplied with water by tank truck (probably by a contractor who would charge for the service) but would not benefit from any other services. It was anticipated that "honey bag" toilets would be used but no pick-up arrangements were planned. Service centres were to be provided for individual disposal of sanitary wastes but residents were to be able to use the toilet and water supply facilities at these centres as an alternative to having water in their residences.

These plans were put into effect but were not satisfactory. Little respect was felt for the communal services and it was almost impossible to keep them clean. The showers provided at the central laundry building were not widely used and the service centres were quickly phased out. Bagged sewage and random disposal of greywater was the only alternative.

Conditions were not considered acceptable by those residents that did not benefit from piped services and action for improved facilities was initiated. In 1969, the Council of the Village of Inuvik prepared a statement of request to the Government which stated in part (22),

> "The Inuvik Council insists that equal utility services be available to all residents at equal rates ... as forty percent of the Inuvik residents now lack piped water and sewer services, the Inuvik Council proposes a 1970-71 utilidor extension program to correct this situation ... The utilidor extension program will primarily serve homes in the West End and will assist in bringing all homes in the present Inuvik townsite up to a suitable standard."

The Government responded favourably to this request and embarked upon the series of utilidor extensions already described (Figure 2). The town of Inuvik now has a By-Law requiring all new construction to be connected to the utilidor system for water and sewer services. There are, however, a small number of houses receiving trucked water where the owners do not wish to connect to the system and several commercial operations, as well as the naval base to the north of the town, that are outside of the serviced area.

About 20 to 30 buildings still depend upon bagged sewage. The bags are picked up about four times a week and deposited at a dump clear of the town. Most solid wastes are burned in drums provided for the purpose to each residence. Other solid wastes are also deposited at the dump, preferably separate from the bagged sewage. To the extent conditions allow, the wastes are covered during the summer but landfill operations are difficult to manage effectively.

c) Waste Treatment and Disposal

Ultimately, the East Channel of the Mackenzie River had to be the receiving water for all waste effluents from the town. Since, at least throughout the winter, this same Channel was to be the source of water supply, it was important to ensure that re-cycling could not occur.

In view of the inadvisability of dumping fresh raw sewage into the river, even with good dilution, at times of minimum flows and the considerable technical problems of achieving satisfactory sewage treatment by conventional means under extreme climatic conditions, early attention was given to the possible use of a sewage lagoon. This treatment procedure had not been widely practiced in such cold climates at that time, but it appeared that use of a lagoon for storage in the winter, followed by release of the supernatant to the river each spring just after break-up when the flow in the river was at a maximum, would prove satisfactory. During the few warm months of summer, it was expected that algae would bloom thereby generating plentiful oxygen during the very long days to achieve an acceptable breakdown of sewage sludges. Some odour problems in the early spring, immediately after break-up, could be expected, but isolation from the community by at least 1000 feet (300 m) would help to reduce the nuisance value to an acceptable level.

During the winter of 1956/57, attempts were made to measure the flow velocity in the East Channel. When no flow could be detected it was decided that any discharge of sewage to the Channel during winter,even from a primary settling unit, would be undesirable. Subsequent, more careful flow measurements have indicated a very small winter discharge with estimated minimum velocities as low as 0.07 ft/s (0.02 m/s). However, rock may be seen outcropping on both sides of the East Channel about 35 miles (55 km) upstream of Inuvik at a location known as Big Rock and it is possible that, in low flow years, the river freezes to the bottom there in late winter.

Ongoing studies focussed on a system whereby complete or primary treatment only would be provided and the effluent stored until it was safe to discharge it to the river after spring break-up. Since the 1955 preparatory studies had anticipated that direct discharge to the river would be satisfactory[4], little site information had been gathered to facilitate an assessment of the suitability of natural ground depressions for winter storage. Preliminary estimates indicated that if a lagoon could be considered acceptable, the cost could be expected to be considerably less than for any alternative scheme involving either primary treatment plus temporary storage and chlorination or complete treatment.

During a visit to the site in August 1957, it was noted that a long, narrow, low-lying area downstream of Twin Lakes was suitable for a sewage lagoon and further that existing low dykes in the area built on permafrost were standing up well. Plans were formulated to construct a protective dyke along the east side of the East Channel to contain a sewage lagoon within this depression. It was felt that no dyke would be needed on the landward side which sloped gently upwards from the depression.

Residents remained uncertain about the suitability of a lagoon so near the town and requested consideration of an under-channel crossing that would permit disposal on the west side of the East Channel. This alternative was considered briefly but much concern was expressed from a technical viewpoint about the maintenance of an inverted siphon for a sewer in such an extreme environment.

Eventually, the use of a lagoon, located as shown on Fig. 2, was approved. An area of about 43 acres (17.5 ha) was enclosed by dykes on three sides to create a pond varying from zero to about 8 feet (2.5 m) in depth. Because of the difficulties of working on permafrost, no clearing of the lagoon area was carried out before it was put into use. The original intention of providing a comminutor at the influent end was dropped because it was considered desirable to reduce the use of mechanical equipment to a minimum.

The effluent is discharged over a stop-log weir at the northern end into a small creek that empties into the East Channel. After break-up each year, the stop-logs are removed and the lagoon is drained to the river. The logs are then replaced and the lagoon is allowed to fill during the summer. It is drained again before freeze-up and used as a holding pond over the winter.

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[4] Generally speaking, it was the policy of the Department of National Health and Welfare that sewage could be discharged to a natural watercourse as long as there was sufficient assimilative capacity to obviate nuisance conditions downstream. In the case of Inuvik, the Department preferred complete treatment with effluent chlorination firstly because of the proximity of the water intake and secondly because of the frequent use made by native people of the river water downstream for all purposes, including drinking.

In 1971/72, after nearly 15 years of use, students of the University of Toronto carried out a year-long monitoring of the Inuvik lagoon to assess its efficiency and more generally to determine the suitability of lagoons for use under Arctic conditions. The report onthose studies provides much useful information for readers that are interested in detailed loading rates, efficiency parameters and designfeatures (11). Selected results from their studies are presented in Table 4.

At the time of the field investigations, the researchers estimated that about 2,500 persons out of a total community population of some 3,500, were connected to the utilidor sewer system. Thus the lagoon was receiving its nominal design loading. In fact, the volume of sewage was about twice that originally expected because per capita water consumption was estimated at 145 gpd (550 l/day) by comparison with the design value of 70 gpd (265 l/day).

A number of operating problems had arisen, partly because of the original construction procedures and partly because of the rapid unexpected growth of the community.

- Failure to clear the lagoon area and level the bed had resulted in an inability to drain the lagoon completely each spring. In addition, snowmelt drainage on the landward side, where no enclosing berm exists, had caused overbank flooding and swampy conditions that constituted a health hazard.

- Excessive sludge build-up at the influent end left exposed sludge banks after drainage causing serious odour, fly-breeding and aesthetically displeasing conditions. (Perhaps if the comminutor, as orginally intended, had been installed this problem would not have been so severe).

- The nearest housing had encroached to within 600 feet (180 m) of the lagoon under the pressure of development. This represented a severe health hazard as the lagoon itself was not protected from access and children regularly played along the banks.

- The winter ice thickness reached 5 feet (1.5 m) and this left insufficient volume for winter storage.

Perhaps the lagoon would have performed adequately from the nuisance and health hazard viewpoints, if the volume of sewage to be stored and subsequently drained each year had remained close to the design value. Experience has now shown that sludge build-up in lagoons in northern areas is substantially greater than in warmer climates, thus provision would have to have been made to deposit the influent in the deepest portion of the pond. In retrospect, clearing of the area and minimal grading of the bed would have been desirable in spite of the difficulty of working in permafrost conditions. However, rapid growth has overtaken the usefulness of the facility and it is clearly not satisfactory for sewage disposal in its present form and location.

The existing unsatisfactory situation was presented to a firm of Consulting Engineers for review and recommendations in 1978. Their study commenced with an analysis of the assimilative capacity of the receiving stream in accordance with the policy of the Government of the N.W.T., and led to a provisional conclusion that only nominal treatment was necessary as long as it was operated effectively (3).

Dissolved oxygen levels in the East Channel occur at the time of minimum flow at the end of winter. Scattered measurements indicate that the D.O. level falls to about 5.0 mg/l at that time. Based on measurements in ice-covered rivers in Alaska, it was estimated that if all of the raw sewage from Inuvik were discharged to the river after initial comminution, the D.O. would fall to about 3.0 mg/l for a population of 3000 and to nearly zero (0.3 mg/l) for a future population of 7000. It was further estimated that for a population of 7000 the minimum D.O. level could be held at 3.0 mg/l if a short period retention lagoon (about 19 days allowing for ice cover) were constructed at the downstream end of the existing lagoon area to hold the effluent before discharging it to the river.

At the time of writing, four alternatives were under consideration:

- comminution and raw sewage disposal to the East Channel;

- clean-up of the existing lagoon area and construction of an improved, smaller cell within the present limits to provide about 45 days retention with the current rate of inflow;

- construction of a sewage treatment plant; or

- pumping of all effluent across the East Channel (as originally rejected) to the Delta Lakes.

The second alternative appears to be favoured but no decision has been taken.

MEETING FUTURE NEEDS

Thus far, this paper has concentrated upon a historical perspective of the development of water supply and sanitation facilities for a model community in an extreme environment. The authors conclude that, in spite of a number of inconveniences experienced by the residents, the system is a success and is not unduly expensive to operate and maintain. As a tax-based municipality (one of only seven in the Northwest Territories) Inuvik is not eligible for government grants to support operation and maintenance costs. The current rate for residential water and sewer service is Can. $ 29.34 per month. High rate users, when metered, are charged $ 2.95 per 1,000 gallons (Imperial) (4.55 m^3). No doubt metering would reduce consumption but since there are only 20 privately owned residences on the entire system, there is little incentive to spend money on metering by the Public Utilities Board, at least until shortages are again being experienced. All capital expenses, with the exception of house-connections, are to the account of the Territorial Government who may, in the longer term, have to decide whether to tackle excessive usage rates as part of a program to meet future needs as the population increases.

In a number of areas, residents find that with the central heating system built into the utilidor only warm to hot potable water is available in all seasons and their heating systems cannot be turned down to an acceptable comfort level. A number have chosen to pay for their own oil-fired furnace so that they can have personal control. The newer utilidor extensions have not provided for expansion of the central heating system and therefore depend on electrical heat tracing to cope with frozen lines when necessary. This arrangement has proved to be satisfactory and it appears probable that, except for very special compact settlement arrangements, future utilidor developments in northern communities will not incorporate central heating facilities.

For the larger communities in the Northwest Territories, complete piped systems for water supply and sanitation still represent the most economic solution and it is now the policy of the Territorial Government to install such systems for all major municipalities. The majority of the nearly 30,000 inhabitants living in 13 designated principal cities, towns and villages, are being served in this manner. For the remainder of the 60 or so communities in the Territory, complete piped systems are neither economic nor practical.

Policy Development

The first formal statement of water supply and sanitation policy was presented in 1962 and affected only unorganized communities. It was promulgated upon the realization that health conditions were extremely unsatisfactory and that Government assistance was essential if improvements were to be made in the many small settlements widely scattered across this vast area.

In the past, most northern communities have been served with extremely rudimentary sanitation systems and, as a result, hepatitis, gastroenteritis, typhoid, dysentery and other diseases have been difficult or impossible to control. Infant mortality rates have been high by comparison with the rest of Canada. The practice of discharging sullage, or grey-water, on the ground, just as much as the handling of bagged sewage, contributes to the recurrence of disease epidemics and is of great concern to the health authorities.

Progress under the 1962 Policy was very limited, mainly because of jurisdictional problems, but also because it was realized that the great majority of northern residents were unable to pay even a nominal portion of the costs of improved service. The 1967 Policy review provided for Government to make available, at no cost to the population, access to a potable water source and collection and disposal of bagged or bucket sewage. Those persons who wished to receive a better level of service were able to pay for trucked water and personal waste collection. This policy also was not satisfactory. There were still a large number of consumers who were either unwilling or unable to pay for these services and even where piped services were found to be economically preferable, many who could not afford their own house connection or who would not pay the assessed cost for serviced properties (5). The 1973 policy review and program document prepared by the Government of the Northwest Territories noted that almost all of the 60 organized communities required substantial upgrading of facilities to provide a satisfactory level of service (9). The proposed program anticipated capital expenditures of nearly $ 75 million (expressed in 1973 dollars) over the following decade to serve a total population expected to increase to about 50,000 by 1981. This program provided for government to pay virtually the entire capital cost of all improvements even in the larger tax-based municipalities and to absorb, for all non-tax based communities more than 75 percent of all annual operating and maintenance costs. The proposed program was approved by the Treasury Board in 1974.

In 1976, the Government of the Northwest Territories established its own Water and Sanitation group and another review of the implications of the 1973 program document was carried out. As a result it was decided that the fully-piped, Inuvik-type, utilidor service was not essential to achieve satisfactory health standards and was usually not an economic solution in communities with under about 700 persons. The 1973 policy had established four groups of communities, generally according to size:

- 7 settlements of less than 50 residents;

- 6 settlements with between 50 and 150 residents;

- 34 settlements with between 151 and 700 residents; and

- 13 towns and villages with over 700 residents.

The $ 75 million program assumed that Group 4 communities would have fully-piped systems, Group 3 communities would have partially-piped systems with trucked services to the less-dense portions of the village and Group 2 communities would have only trucked facilities. The 1976 review concluded that piped services were generally not economical for the Group 3 communities. The capital requirements were reduced by about two-thirds and it was decided that each situation should be looked at on its own merits.

Current policy for water supply in Northwest Territory communities is that wherever wells are not practical, a minimum basic potable domestic supply of about 12 gallons (45 l) per person per day shall be trucked to each residence which will be equipped with a storage tank [usually 300 gallons (1.13 m^3)] for the purpose. The policy for sewerage is that a holding tank [usually 480 gallons (1.82 m^3)] shall be provided in each house to store all sewage and waste water and this tank shall be pumped out at least weekly. Piped systems will only be installed where they are clearly economic in capital and operating costs. In very small, Group 2, settlements if trucking is impractical, a potable water source will be provided for personal access by residents.

Bagged sewage is considered to be incompatible with good health standards and will be phased out as a matter of policy wherever practical. Disposal of pump-out tank contents presents special problems in northern communities as does the handling of solid wastes. Controlled dumping at a contained site remote from the community, preferably where landfill can be practised if possible, is desirable. Ocean disposal of liquid wastes is considered satisfactory subject to acceptable disposal site conditions.

In the great majority of communities, which do not yet raise their own tax and service revenues, the Territorial Government will guarantee 100 percent of all capital and operating costs for water supply, sewage and waste collection and wastes disposal and will, as conditions permit, raise revenues from the beneficiaries to cover partially the cost of services provided. Much of the collection and delivery service will be contracted to private operators. The large communities will handle the operation and maintenance activities themselves. Costs for household tanks and other personal facilities will be charged against the respective house owner, unless the serviced land belongs to the Government (Territorial or Federal).

SUMMARY AND CONCLUSIONS

The town of Inuvik was developed 25 years ago to standards hitherto unknown in the North. It was conceived as a basically government centre of limited size to provide accommodation of a quality that would attract southern Canadians to northern service and improve the availability of education, health care, and social welfare to the native peoples. These objectives have been met.

At the time the town was developed, oil and gas explorations in the area had not indicated the possibility of resource exploitation. As geophysical and later drilling activities increased, Inuvik was exposed to growth pressures never originally foreseen. Difficulties have been experienced from an early date with water supply and sanitation services. They have been solved effectively and at least the foreseeable future growth potential of the town is now assured. A new period of rapid expansion may be forthcoming if it is decided that frontier gas and maybe oil reserves should be exploited.

Originally the Inuvik town plan allowed for fully-serviced, mainly Government housing and lower-quality or unserviced facilities for others in accordance with their anticipated preferences. Experience has shown that such disparate standards in a single community are not acceptable for long. Within ten years, the Council had sought and achieved equality for all in the availability of basic sanitation and other community services.

In the days when Inuvik was conceived and constructed, sanitation in the north was generally poor and many waterborne and filth diseases were endemic. While Inuvik itself was built to meet a specific need for a new community, it was about that time that the relevant governments and local authorities began to realize that northern living conditions had to be improved and that such benefits could only come from massive Government support. Over the 20 years since then, a series of policy formulations have been tested and in very recent times, major inroads have been made in solving the unsatisfactory situation.

Since the mid-1970's, spending levels have been increased signficantly and the Territorial Government is now past the peak of its capital investment program. Some 70 percent of northern communities now have access to a satisfactory supply of potable water and efforts are continuing to meet the residual needs. Sewerage and wastewater disposal programs lag somewhat behind the water supply program but about 40 percent of communities now have adequate service. The Government hopes to maintain its current level of capital investment at about $ 8 million annually (down from a peak of $ 14 million in 1979/80) for two or three years and complete its program of providing an acceptable quality of service in all towns, villages, hamlets and organized settlements within 6 to 8 years.

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ACCRA - UPDATING A FEASIBILITY STUDY

by

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Abstract

The paper reviews recent attempts to develop a conventional sewerage system to solve the sanitary problems of a city in a developing country that grew up without such a system. After 25 years of the combined effort of reputable international consultants, national engineers, review panels of international experts as well as support from international organisations and institutions, the sanitary problems of Accra are far from being solved and are rather deteriorating to a desperate situation calling for urgent remedial action. The new approach being followed is described. Based on the upshot of a two-year research project of the World Bank, it involves a multi-disciplinary approach and consideration of a range of technological options, including the possibility of the simultaneous application of different levels of sanitation service to different areas of a community. It is advocated that the choice of technology should be dictated by relevance, technical soundness, acceptability, affordability and, above all, attainability in the shortest possible time. It should work and last under local conditions, and it should be capable of being upgraded to meet rising aspirations.

INTRODUCTION

The acquisition of public sewerage systems in towns and cities that grew up without them remains one of the unsatisfied aspirations in the developing countries. Efforts made towards this end have so far proved futile, ineffectual and disappointing. In Nigeria, for instance, it is reported (Ref. 1) that for some 50 years succeeding governments had been commissioning consultants to look into the problem of sanitation in Lagos. Each time the consultants made proposals for water-borne sanitation. But each time the proposals have had to be shelved. In Ghana, between 1951 and 1974 four reports on a sewerage system for the city of Kumasi were prepared by consultants. But Kumasi remains without a public sewerage system. The experience is probably similar in other developing countries. In some situations the best that has been achieved has been partial implementation of proposed sewarage schemes; in other places recourse has had to be taken to private septic tank systems or isolated institutional sewerage systems. But for developing countries, the successful implementation of a public sewerage system

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for a city that grew up without one still remains an unachieveable dream. Why?

Whatever the constraints may be, are they surmountable? Or are these the appropriate questions to ask? One may very well ask what problems conventional public sewerage systems are designed to solve in the first place; what technological alternative solutions exist or can be developed; what are the likely constraints in the application of such alternatives and what prospects there are for overcoming such constraints.

The objective of this paper is to review the recent experience in Accra where an effort is now being made to find answers to such questions.

ACCRA

Geography

Accra is the capital of Ghana. It is a coastal city located on the Gulf of Guinea at latitude 5° north of the Equator just west of the Greenwich Meridian. Its 1980 population is estimated to be 997,000 and it occupies an area of about 22,273 ha. The main topographical feature is a ridge which starts from sea level in the south-west section of the city near James Town and runs in a north-easterly direction to an elevation of 70m above sea level in the vicinity of the Accra international airport. Beyond the airport the ground rises to a small plateau of about 76m elevation crowned at the University of Ghana by a knoll known as Legon Hill (about 148m). North and north-west of the city lie the Akwapim-Togo Ranges from the top of which one can see a panoramic view of Accra lying within the southern savannah zone of the country. The James Town-Airport ridge and a second ridge located further east between the suburbs of Teshi and Nungua divide Accra into three major natural drainage basins shown in Fig 1. These three topographic areas are located in the West Accra area, the East Accra area and the Teshi-Nungua area.

Accra lies in the driest area of the country. It has an annual rainfall of 73.7cm compared with 147.3cm in Kumasi located north of Accra in a semi-deciduous forest zone, and with 109.2cm in Tamale which is located further north in the Northern Savannah zone of the country. It has two rainy seasons separated by two dry seasons which run from November to February and from mid-July to September. The mean temperature ranges from 76°F in August to 82°F in March. The average relative humidity at mid-day ranges from 60% in January to 75% in June/July.

The geological conditions in the Accra Plains do not favour the creation of useful aquifers which could serve as an important source of ground water supply for the city. Consequently its water supply is obtained from two surface sources, the Densu River to the west and the Volta River to the east. The first major water supply for Accra was built in 1914 at Weija based on the Densu River; the second was built in 1954 at Kpong based on the Volta River. The total output from these two waterworks is now 243,000 m^3d^{-1} (53.5 mgd) out of which Accra receives 136,000 m^3d^{-1} (30 mgd).

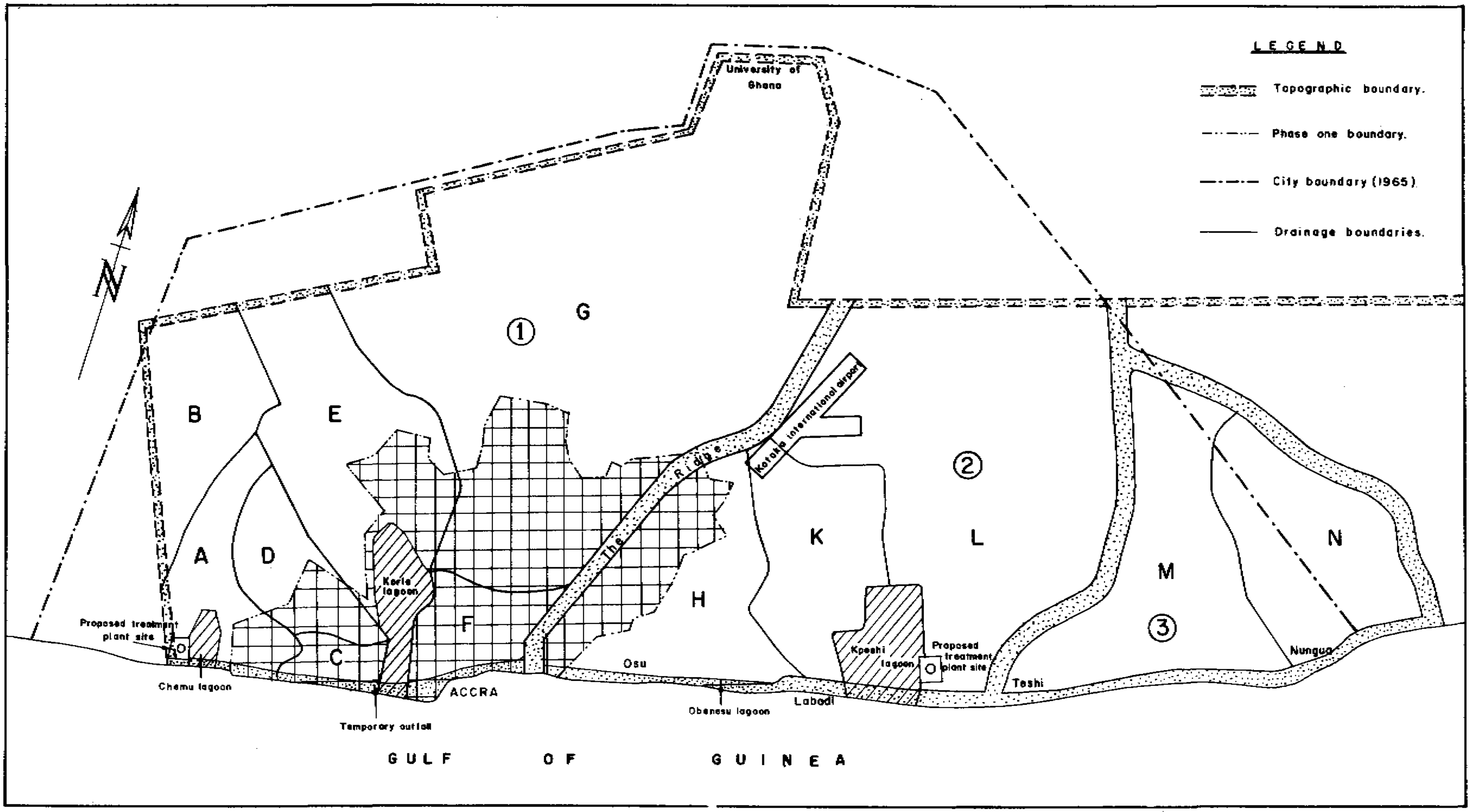

Figure 1. Accra Sewerage Scheme: topographic divisions (numerals and drainage areas (letters) for 1965 master plan.

History

Accra is the most cosmopolitan town in Ghana to-day. But in the 16th century it existed only as a small fishing village inhabited by the Ga people. During the 17th century a number of European trading companies built in the vicinity of the village a number of trading posts and forts. Those remaining up to the present are James Fort, Ussher Fort and Christiansborg Castle. The forts are now used as prisons whilst the castle is used as the official residence and office of the Head of State.

In 1877 the capital of Ghana (then the Gold Coast) was transferred from Cape Coast to Accra; Following this a new settlement known as Victoriaborg was established for the construction of government offices, colonial residential buildings, and recreational ground for colonial civil servants. Meanwhile the areas near the forts had developed into indigenous residential areas known as James Town and Ussher Town separated from Victoriaborg by an area which developed into the first commercial area of Accra. Between 1920 and 1940 most of the other residential areas for the indigenous people were established in places like Adabraka, Korle Gonno and Korle Bu.

During the second world war Accra became a supply base for the conduct of operations in Africa. Military camps and installations were built, the airport was extended and modernised and the town took on the additional function of a military centre and a main international airport.

Following independence in 1957 the growth of industry, commerce and administration together with the establishment of financial institutions and foreign embassies created an influx of large numbers of skilled and unskilled job-seekers from other parts of Ghana and from neighbouring African countries. Soon new middle and upper classes of indigenous people emerged and started moving away from the traditional indigenous residential areas to build medium and high grade houses in other parts of Accra. Neglect of the houses in the older parts of the city and the creation of squatter areas outside the statutory planning areas of the city also led to the creation of low grade and sub-standard housing in different parts of the city. These developments have resulted in the creation of four grades of housing in Accra, namely, high grade, medium grade, low grade, and sub-standard housing.

Another factor which influenced development in Accra is the creation of the new harbour town of Tema 24km east of Accra to carry the major part of the country's export-import trade. By 1958 Accra and Tema appeared to be growing towards each other; the coastal road linking the two towns was becoming congested. Consequently a new plan was prepared linking the two as a single conurbation known as the Accra-Tema Metropolitan Area; a new motorway parallel to the coastal road and starting just north of the Accra airport was also constructed for rapid transit between the two extreme population centres of the metropolitan area. The motorway was intended to serve as the northern boundary of the metropolitan area. Just south of it between the boundaries of Accra and Tema was to be a range of light industries; and between these industries and the coastline were to be a number of institutions, commercial areas and a large residential area from which workers would commute to Accra and

Tema. This was how it was thought Accra and Tema were going to be developed. And it was against this background that the feasibility study for the Accra sewerage system was conducted during the period 1965/1966.

REPORTS PRIOR TO FEASIBILITY STUDY

Three reports on Accra sewerage were prepared by international consultants before the feasibility study was undertaken, one in 1955, the second in 1960 and the third in 1965.

The 1955 and 1960 Reports

These two reports were prepared by the same consultant. The 1955 report recommended conventional sewerage with a submarine outfall located near the Korle Lagoon. Between 1955 and 1960 considerable development had taken place in and around Accra. Consequently a review of the earlier report became necessary. The 1960 report modified earlier recommendations and estimates and provided for a second submarine outfall designed to serve the area east of the Ridge and to be located near the Obenesu lagoon at Labadi, while the original outfall served the area west of the Ridge.

The ultimate boundary for the area proposed for the sewerage system covered about 75% of drainage area number one west of the Ridge and about 50% of drainage area number two east of the Ridge (Fig 1). The design population was 375,000 and the total design sewage flow was about 68,200 m^3d^{-1} (15 mgd). The project was to have been implemented in two stages estimated at 1960 costs of ₤G. 4.25 million and ₤G. 3.25 million for the first and second stages, respectively.

These two reports were formulated before the planning concept of the Metropolitan Area was formulated. It was therefore decided that the 1960 report should not be implemented without first investigating the implications of a comprehensive sewerage system for the entire Metropolitan Area. Accordingly, with international assistance, another international consultant was engaged to prepare a report on a master plan for sewerage for the Accra-Tema Metropolitan Area.

The 1965 Master Plan Report

Unlike the previous reports the Master Plan Report was concerned not only with sewerage but also with water supply; moreover it was not limited to Accra but it covered the entire metropolitan area consisting of Accra to the west, Tema to the east and the Central Area between the two. This paper, however, deals only with that section of the report concerned with the Accra sewerage system.

The report provides for the needs of Accra up to the year 2000, and its proposals were based on design populations of 0.8 million, 1.5 million and 2 million for the years 1970, 1980 and 2000, respectively.

The report recommended conventional sewerage for the entire area of Accra covering all three major drainage basins. Final disposal was to be through submarine outfalls preceded by appropriate pre-treatment facilities. Although the report recognised that the most economic disposal system would have been through a single outfall located near the Korle Lagoon, contemplated development plans for the adjacent beach area dictated the adoption of a system of two outfalls. One was to be located near the Chemu Lagoon near the western boundary of the city to serve the Western Area; the second was to be located near the Kpeshi Lagoon to serve the Eastern Accra Area and the Teshi-Nungua Area. Plans for developing the Labadi beach into a tourist beach led to the choice of the Kpeshi Lagoon over the Obenesu Lagoon recommended in the 1960 report for the eastern outfall.

The report further recommended a two-state programme of implementation, the first to meet the needs of Accra up to 1985 to be followed by a second stage designed to meet the needs of 2000. The boundaries of these stages are shown in Fig 2. Stage I provided for treatment facilities and a sea outfall at Chemu Lagoon, and the second phase provided for similar facilities at Kpeshi Lagoon.

Within the framework of Stage I a Phase One scheme was proposed for the prompt solution of urgent sanitary problems including the alleviation of pollution of Korle Lagoon. It was also intended to meet anticipated needs upon the completion in 1966 of the first stage of a water supply scheme then underway. The boundaries of the Phase One area were as shown in Fig 2. The extent of the area was about 2800 ha and it would embrace about 70% of the population in Accra if the overcrowded areas were served with adequate communal facilities. It provided for new sewerage facilities within its boundaries together with the construction of the first 1524m (5000ft) of the western outfall in 1966. Later, in 1973, this outfall was to be extended to its full length of 2286m (7500ft), and a diffuser system 610m (2000ft) long was to be added. All major elements of Phase One were intended to form an integral part of the recommended long range plan without interfering with flexibility.

Immediate Implementation

The Phase One area was itself divided into construction zones shown in Fig 3, and recommendations were made for their order of precedence. Table 1 shows the order of precedence proposed.

The plan recommended that the overcrowded low grade housing areas within the Phase One area, covering about 810 ha, should be initially served by communal sanitary facilities connected to trunk and main sewers to be laid throughout these areas. The affected areas were generally believed to be scheduled for redevelopment; but no definite plans existed.

It was finally recommended that a feasibility study should be undertaken, an application should be made for financing, and the design work should be undertaken. These recommendations were accepted and implemented by the Ghana government.

FEASIBILITY STUDY

The aspects of the feasibility study concerned with Accra sewerage were limited only to the Phase One scheme which the feasibility report

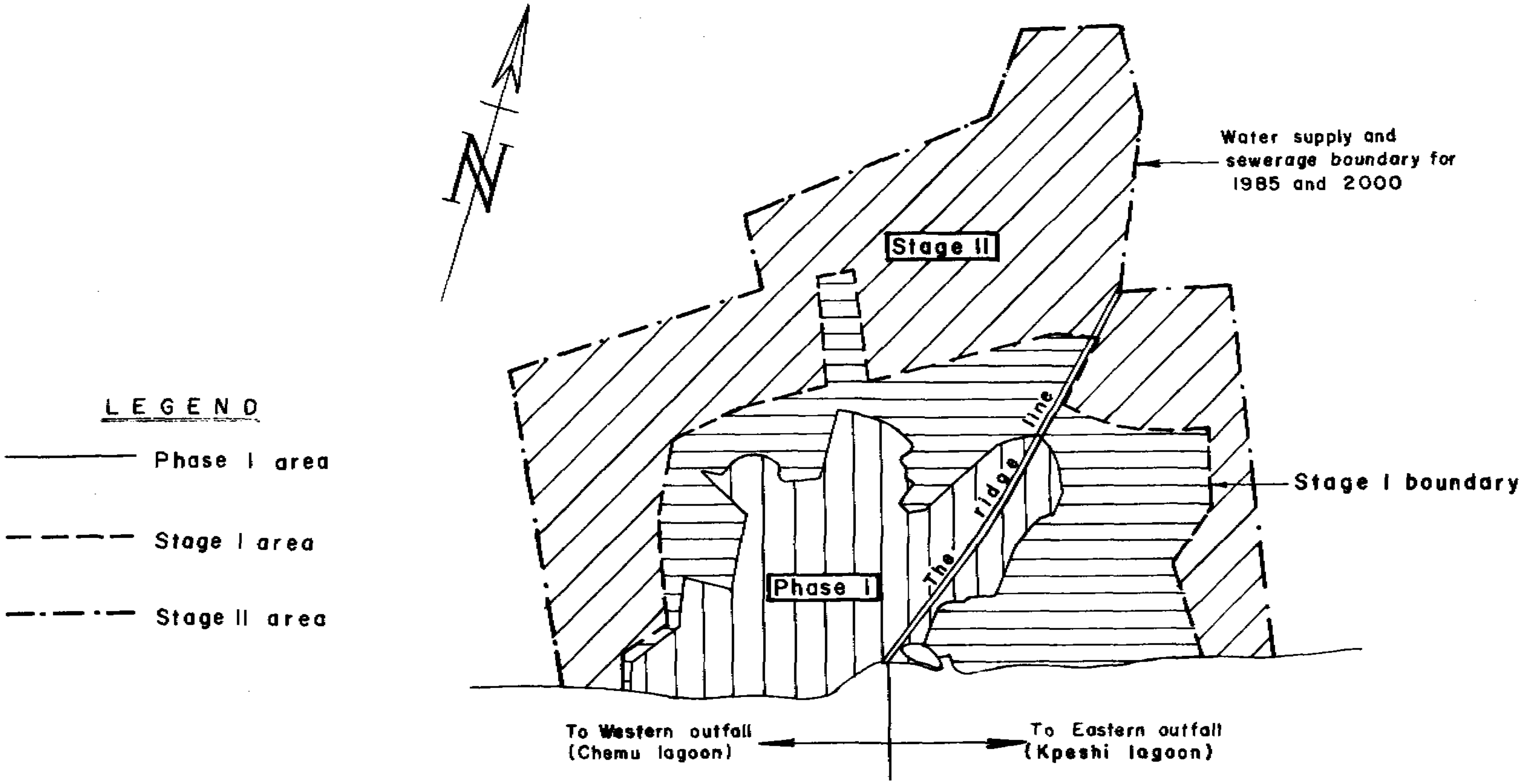

Fig. 2 Master plan and development stages for Accra sewerage scheme (1965).

(Not to scale)

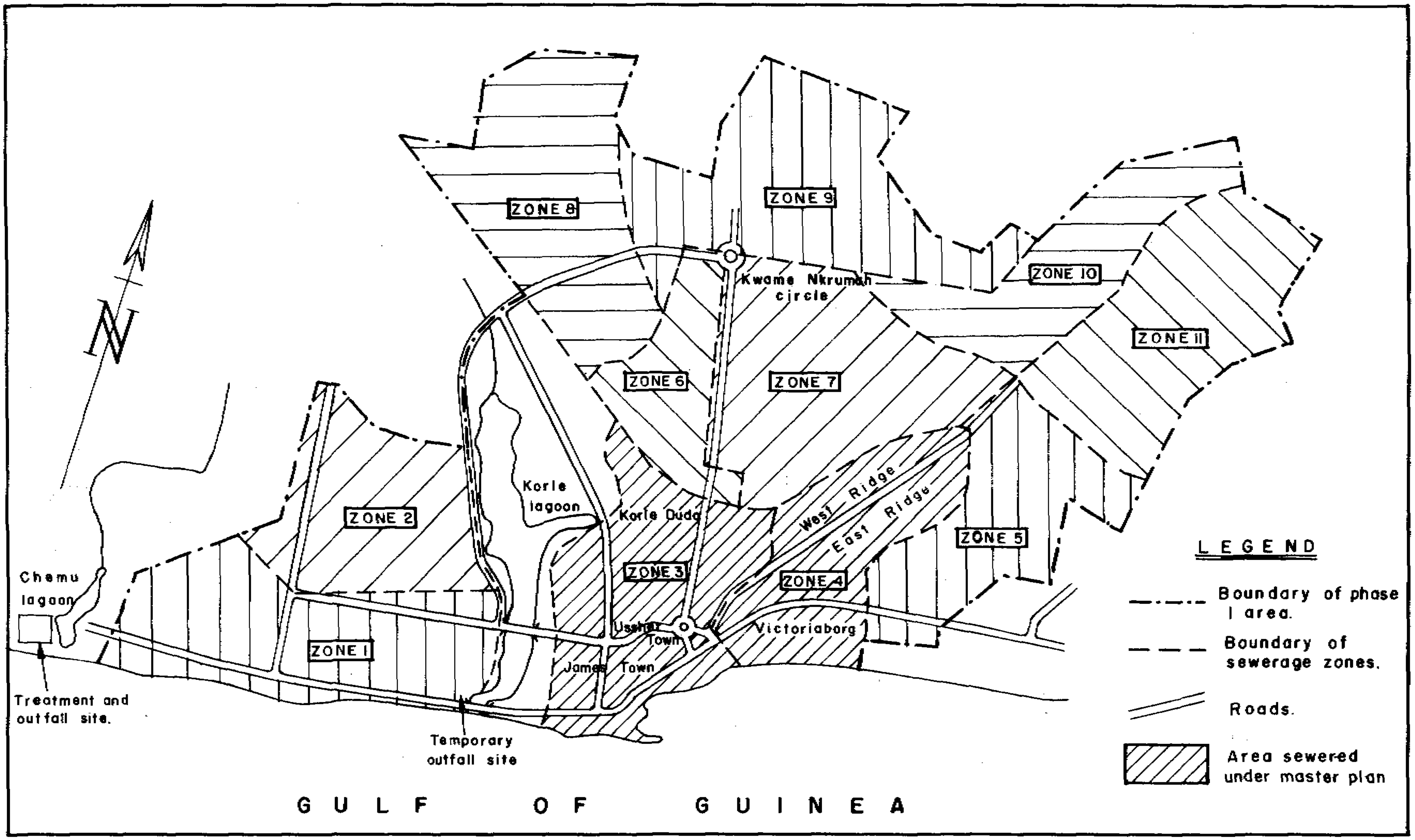

Fig. 3 Accra sewerage scheme: Phase one construction zones
(1965 Master plan)

TABLE 1. Master plan construction programme

Order of Precedence	Year of Construction	Area or Zone Number	Housing Type	Remarks	Area Actually Sewered
1	Year 1	Korle Lagoon Interceptor	None	For lagoon pollution alleviation	Partly implemented
2	Year 1	1	Low grade	Excluded in Feasibility Report	
		2	Korle Bu Hospital and high grade		Existing sewers connected to new system
		3	Low grade and commercial	Includes acute problem areas	Sewered
3	Year 2	4	High grade	No immediate problems but downstream of zones 5 and 11	Sewered
4	Year 3	5	High grade	Difficulties in parts	Partly sewered but problem areas excluded
		6	Low grade and commercial		
		7	Medium grade	Downstream of zone 10.	
5	Year 4	8	Medium grade		
		9	Medium grade		
		10	High grade		
		11	High grade		

recommended for immediate implementation with minor modifications. The original Phase One boundary was modified to exclude zone 1.

The proposed scheme involved the construction of the following:

43km of trunk and main sewers
97km of branch sewers
8100 house connections
8km of pumping mains
2 permanent pumping stations
3 temporary pumping stations
1524m long large diameter ocean outfall.

Redevelopment of the low and substandard housing areas was assumed. It was estimated that 50% of these areas would have been redeveloped and provided with full sewer service by 1980. The remaining areas were to be served by communal facilities. The report recommended that these communal facilities should be provided by the City Council rather than by the Ghana Water and Sewerage Corporation (G.W.S.C.) which had been established specifically to deal with water supply and sewerage. The communal facilities were to include handwashing facilities, baths or shower, urinals, and water closets. The housing areas involved were in construction zones 1, 3, 6, and 12. On the basis of an assumed rate of redevelopment in these areas the anticipated sewer connections to different types of properties were estimated. One set of figures produced in the Feasibility Report is presented in Table 2 without rounding off figures as was done in the original report. This table anticipated that by 1980 there would be a total of about 670 sewer connections within the proposed redevelopment areas alone. Of these connections there would be 420 house connections and 170 communal facilities connected to the sewer system. In view, however, of the tentative nature of the redevelopment programme these figures were intended only to serve as a guide.

Two alternative construction schedules were presented in the feasibility report, one based on design forecasts contained in the Master Plan Report and the other on the minimum forecasts which reflected a general slowdown of the economy of the country. Other recommendations in the Feasibility Report were essentially the same as those in the Master Plan Report with appropriate modifications based on new information that had become available.

The third volume of the Feasibility Report dealt with financial planning. It provided information on expected project costs, total funds to be borrowed from the World Bank and proposals on sewer rates and expected revenues. On the basis of an analysis of the economic implications of the project, the impact of the project on different income groups was assessed.

The report recommended full cost recovery for the proposed sewerage system to cover maintenance, operational, debt servicing as well as renewal and replacement costs. Rates based upon a percentage of water bills were recommended.

TABLE 2. Projected house connections by 1980 in low and substandard areas

Zone	Number of house connections						
	Industrial	Commercial	Institutional	Housing			Total
				High grade	Medium grade	Communal	
1	-	-	10	-	120	30	160
3	1	50	-	-	-	130	181
6	3	20	-	-	100	10	133
12	-	-	-	-	200	-	200
Totals	4	70	10	0	420	170	674

(Source: Ref. 3)

An important additional recommendation was that the proposed sewerage service charges should be applied to all water consumers in the Accra area whether they would be connected to the sewerage system or not. This recommendation was considered justifiable because the entire community would benefit from the improved health and sanitation conditions; furthermore initial sewers were being designed to cater for future extensions to cover the entire area. This means that initial users of the sewerage system would be paying in advance for services to be enjoyed by later users of the system. This being so, it was reasonable to spread this present cost for future users among the entire population. A significant implication of this recommendation is that if it had been implemented it would have served as an incentive for houses to be connected to the system. Furthermore, since the poorer sections of the community were to have been the first to benefit from the sewerage system, spreading the cost recovery over the entire population would have implied an inducement of the wealthier sections to subsidise the welfare of the poorer section in the knowledge that the health of the entire community is not safeguarded so long as health conditions in certain parts are precarious.

These recommendations were accepted by the Ghana Government, and they formed the basis for the design and preparation of contract documents for the construction of the Phase One Accra sewerage scheme. The project was financed through a credit agreement with the International Development Association (IDA) of the World Bank. Construction was started in 1970 and completed in 1973; and the system was commissioned in 1974.

Only a part of the Phase One scheme was implemented, however; the parts that were implemented included the following:

- the provision of an intercepting sewer on the eastern side of Korle Lagoon

- connection of the sewerage system at Korle Bu hospital to the new sewerage system

- sewering of construction zone 3 area which includes the acute sanitary problem areas of James Town and Ussher Town

- sewering of construction zone 4 area which embraces some commercial area and the high grade residential areas of East Ridge and West Ridge

- sewering of a part of construction zone 5 area which is essentially a high grade residential area; that part of the zone 5 area which was not sewered was the section reported in the Master Plan to be experiencing sewage disposal problems in some areas

- construction of a temporary outfall at Korle Lagoon

The system provides for approximately 29km of sewers ranging in size from 230mm (9 inches) to 990mm (39 inches) in diameter. Three pumping stations were built, and a 3658m long existing submarine oil pipeline 300mm in diameter was cut into three equal lengths for installation and use as the temporary outfall near Korle Lagoon.

In addition, some sewers were laid to sewage treatment plants serving certain institutions.

The system has been in operation for nearly seven years; but it constitutes only a small fraction of the proposed Phase One programme for the city, as Fig 3 shows. Meanwhile some 13 years had elapsed since the Feasibility Study was conducted. Consequently, in August 1979, the Government of Ghana signed an agreement with consultants for a review of the original Master Plan and Feasibility Study.

REVIEW OF FEASIBILITY STUDY

From the standpoint of sewerage, the review of the feasibility study involves the following activities:

(i) study and evaluation of available data

(ii) making complementary studies

(iii) review and revision of the Master Plan for sewerage.

The approach being followed is dictated by two significant factors, namely, an evaluation of experience from the implemented portion of the original feasibility report and the nature of the terms of reference.

Evaluation of previous experience

A careful study of the Accra experience has revealed that the implemented portion of the Feasibility Study had failed to solve the basic problems the project was designed to solve. What then was the basic problem to be solved? Basically existing practices for the collection and disposal of excreta and sullage had created public health hazards and aesthetic problems. The prevailing excreta disposal practices exposed a large majority of the people to a wide range of diseases of feacal origin; and the sullage disposal practices, involving the use of a system of open drains created not only the pollution of lagoons but, more importantly, the creation of favourable conditions for the breeding of a variety of mosquitoes. The mosquito types which breed in such drains are reported (Ref. 7) to include the following:

- Culex (Culex) pipiens fatigans (Wied)
- Culex (Culex) univittatus (Theo)
- Culex (Culex) thalassius (Theo)
- Culex (Culex) decens (Theo)
- Anopheles (Celia) gambine (Giles)
- Aedes (Stegomyia) aegypti (L).

These mosquitoes are responsible for such diseases as malaria and yellow fever which are quite prevalent in the country; and they are also responsible for the transmission of filariasis which, though essentially a rural disease in Ghana at present, could easily become an urban disease if conditions favouring the breeding of its vectors continue to prevail in the city.

Thus the evaluation has shown that the basic problem that the sewerage system was intended to solve in the first place was the alleviation of the health and aesthetic problems existing in the community at the time. But the implemented portion of the Accra sewerage system has failed to solve this problem as evidenced by the following:

- Poor rate of connection to the sewerage system
- Sullage disposal problem remains unsolved
- The temporary outfall sytem has collapsed

Poor rate of house connections

Table 3 shows a comparison between the actual house connections as at the end of September 1980 and the house connections predicted in the Feasibility Report (Ref. 3).

The major objective of the sewerage project was to solve domestic sanitary problems. But the table shows that after six years of operation of the new sewerage system only 50 house connections had been made out of the 720 predicted. It also shows that only four out of the predicted 130 communal latrines had been connected to the system; and that only 30% of the predicted commercial connections had taken place.

There are several reasons for the poor rate of house connections. The system was unaffordable in the low grade overcrowded areas where sewers were laid. To make such a connection one needs to connect a water supply system to one's house, install associated plumbing systems, and make a sewer connection. The internal plumbing works alone can cost ₵4000 (nearly $US 1,500). And the connection cost to the nearest sewer is believed to range between ₵600-₵1000.00 (Ref. 8). So the total cost involved can be prohibitive.

In the medium and high grade residential areas house connection rates were low because the system was unaffordable and unacceptable. Where existing septic tank systems were operating satisfactorily, the house-owner saw no reason for incurring the cost of disconnecting his building sewer from the septic tank and connecting it to the sewerage system after which he would incur regular monthly sewer charges. This factor made the connection unacceptable within the medium and high grade residential areas.

Furthermore, there was no incentive for those who could afford it to connect to the system. There was no enforceable legislation on compulsory house connections; the sewer rate policy recommended in the Feasibility Report would have served as an inducement; but this policy was not implemented; no subsidy was provided for prospective landlords who wanted connections, neither was any loan arrangement made for the poorer areas. Moreover, no technical guidance was provided. Model designs for internal sanitary arrangements could have been prepared for

TABLE 3. Comparison between projected and actual connections to sewerage system in Accra by September 1980.

	Industrial	Commercial	Institutional*	Housing areas				Totals of all connections
				High grade	Medium grade	High + Medium grade	Communal	
2nd zone	-	-	-	120	120	240	-	240
3rd zone	1	50	-	-	-	-	130	181
4th zone	-	230	-	210	-	210	-	440
5th zone	-	120	-	270	-	270	-	390
Predicted total connections	1	400	0	600	120	720	130	1251
Actual total connections by Sept. 1980	6	123	47	?	?	50	4**	230
Per cent of predicted connected by Sept. 1980.	600%	30.75%	-			6.94%	3.08%	18.39%

* Institutional includes government departments, and local council schools.
** Only 3 are now in operation.

prospective houses to be connected; but this was not done. A very important act of inducement which was also neglected was promotion and public education on the need for houses to be connected to the system.

What all this amounts to is that critical socio-economic factors were not adequately taken into consideration in the previous scheme. This omission was, of course, consistent with conventional engineering practice of the time.

Sullage disposal

The implementation of the Feasibility Report recommendations on communal facilities would have largely solved the sullage disposal problems. Regrettably, only 3% of the predicted communal latrines had been connected; and these did not have the recommended handwashing and bath or shower facilities. The reasons for this problem are similar to those cited for the poor rate of house connections. The city council could not afford the cost of the facilities and there was no incentive or inducement for the council to comply. Had there been adequate promotion, public pressure alone could have induced action.

Temporary outfall

The temporary outfall system failed on technical grounds largely because of poor coordination between those responsible for the Korle Lagoon dredging operations and those responsible for the Accra sewerage. Here the construction of breakwaters and coastal protection works for the lagoon created swift currents which undermined the support for the temporary outfalls and caused them to fail.

Limited implementation of project

The fraction of the project area that was actually sewered was very small. This was mainly because the proposed scheme was unaffordable to the Ghana government and/or its lending agencies. This was probably because the long design period used was over optimistic.

Nature of terms of reference

The preceding problems were considered inevitable because the terms of reference for the feasibility study constrained the consultants to study only conventional sewerage. The only area where they were able to exercise freedom was the choice of treatment facilities and the method of final disposal. The design of the sewerage system was otherwise dictated by the topographic conditions; and there was a limited range of options available for consideration.

The foregoing considerations led to the formulation of a new set of terms of reference, taking into account current thinking on the solution of such sanitary problems.

New terms of reference

The new terms of reference specify the study of appropriate waste disposal technology applicable to each area. In particular they specify that suitable alternatives for sewerage works should be studied and ranked for priority. Local systems based on appropriate technology should be compared with conventional sewerage systems; the alternatives should be analysed on the basis of initial investments as well as annual expenditures, so that optimal solutions could be selected and proposed for further design. There is an emphasis on considering alternatives capable of meeting immediate needs of different areas, making use, where necessary, of self-contained individual systems which allow for subsequent integration within the overall master plan.

This is an innovative way of formulating the terms of reference for solving sanitary problems of a community. The approach recognises the restrictive effects of conventional terms of reference which limit consultants to conventional sewerage alone. But the latter approach always led to over-optimistic and unaffordable solutions. This has been the cause of the frustrations in the developing countries in their aspirations for conventional sewerage. The real problems to be solved had not been recognised. We had allowed the pursuit of the best but unattainable goals to deflect us from realistic pursuits.

The new terms of reference for the review of the Feasibility Study implies the existence of technological alternatives to conventional sewerage. If indeed the objective is to design satisfactory arrangements for the collection and disposal of excreta and sullage, then a wide variety of options are available, as a recent World Bank study has demonstrated. These options include on-site and off-site systems as well as water-dependent and water-independent systems. The World Bank study has shown that the critical socio-economic factors could be adequately considered only if a multi-disciplinary approach is used. Thus, instead of the traditional approach involving the use of engineers and economists alone, it has now become evident that several factors such as religious and cultural beliefs, prejudices and knowledge of disease causation all play an important role in the success of sanitation projects. Hence the use of engineering personnel must be buttressed by the use not only of economists but also of sociologists, health educators and public health specialists.

In effect the basis engineering approach to problem solution should be strictly followed in solving sanitation problems. This approach requires consideration of the following three important factors in problem solving:

(i) Factors subject to complete control by the designer

(ii) Factors that cannot be changed or controlled by the designer

(iii) Factors subject to partial control by the designer

The engineer can exercise his ingenuity in considering the first kind of factors; but the second set of factors must be treated as constraints that must be accepted as unchangeable design factors. All three types of factors are encountered in sanitation problem solving.

Socio-economic and engineering surveys are required to identify and classify these factors. In some cases it may be found that people can be persuaded to accept a particular type of technology. This is the case where the cultural, religious and other social beliefs may be only weakly held. In such cases good promotion, health education and incentives are sufficient. Sociological findings subject to this treatment belong to the class of factors of the third type. They are subject to manipulation. In contrast there may be other cases where the beliefs may be so tightly held that for them design of technology must be changed to fit the belief. Failure to do so would lead to the technology being rejected. Socio-economic factors like this belong to the factors of the second type.

In effect, the approach to sanitation problem solving should not be rigid. It should be flexible. A multi-disciplinary team should be used; a survey should be conducted to collect engineering, socio-economic, and health data. Such data must be classified into three classes according to the extent to which they are subject to change or manipulation. The results of this analysis should be used for final analysis and comparison of alternative technological options. This approach would help to ensure that the final choice is acceptable, affordable and emotionally and politically satisfying.

This approach may lead to selecting different types of technological solutions for different sections of a community. But if the pertinent factors have been adequately taken into account the project should be successful.

Where a person's aspirations cannot be immediately met for one reason or another, acceptability of an interim or different solution is enhanced if the person would be satisfied that the acceptance of the alternative solution would not prevent him from the eventual realization of the original objective. The application of this principle to sanitation problem solving implies that where initial objective and desires of a community are over-optimistic, the acceptability of more realistic solutions would be enhanced if the selected technologies were known to be improvable or capable of being upgraded when the need arises. This is another important concept that has been incorporated in the new terms of reference for the Accra sewerage scheme, which should be better described as the Accra sanitation scheme.

FUTURE PROSPECTS

This paper has attempted to identify the reasons why developing countries have been unable to achieve their cherished aspirations in the area of conventional sewerage in spite of so much effort in the past. The discussion has shown that the basic problems to be solved by conventional sewerage are the health and aesthetic problems arising from improper collection and disposal of excreta and sullage.

A range of other technological options besides sewerage exist for the adequate solution of these problems. But the success of their application requires a change from the conventional approach to sanitation problem solving. A multi-disciplinary approach is required; surveys should not be limited to conventional engineering factors but should be broadened to include socio-economic and health factors. A rigid approach should not be followed when considering such factors for design.

Instead the factors should be divided into three broad categories, namely, factors where the engineer can exercise complete control and judgement, factors that can be changed to meet design, and factors that cannot be changed and which therefore demand that designs be modified to harmonise with them. Final designs should at once be affordable, acceptable, and upgradable.

It is believed that this approach holds better promise for meeting the aspirations in all countries in the area of sanitation in the shortest possible time. It is basically not a new approach. It is used extensively in other areas of engineering and management. Its application to sanitation problems in developing countries has been recognised, however, only after years of futile, ineffectual, and frustrating efforts in the pursuit of unattainable and over-optimistic goals. If future generations can learn from this experience, then the present and past generations would not have suffered in vain; and there would be good promise for the success of the international drinking water supply and sanitation decade.

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WATER SUPPLY AND SANITATION OPTIONS IN DEVELOPING COUNTRIES - A CASE STUDY (INDIA)

By B. B. Sundaresan*

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ABSTRACT

Technology adopted in developed countries in water supply and sanitation programmes has limited application in developing countries. Engineering design overlooking social customs, cultural traditions and economic levels of community would prove ineffective. Community involvement and health education are as important, if not more, as technology aspects.

One unit process - filtration - has been evaluated with specific reference to slow sand filter (SSF) and rapid sand filter (RSF) for conditions prevailing in India. SSF appears to be better suited in view of low capitalised cost up to 23 million litres per day (mld) capacity, capability to withstand low operating skills and produce water of satisfactory quality. Successful implementation of a village demonstration project with SSF incorporating community involvement and health education has been discussed. Integrated water supply and sanitation programmes in urban squatter settlements as well as small towns have become necessary to maximise benefits to the community.

INTRODUCTION

Technology options in implementing the water supply and sanitation decade programme in different parts of the globe with varying degree of development, rural and urban paradox, different socio-cultural attitudes of the people living in varied hydro-geological regions, with limited resources in the time frame of a decade becomes highly complex and poses a challenge to the professionals at all levels. Technological innovations of the developed countries have made limited impact in urban centres but none on rural setting in developing countries. Could it be the limitations of technology or technologist?

TECHNOLOGY ASSESSMENT

After several centuries of innovations, technology brought safe potable water through closed conduits to the user during the ninteenth century. This further brought the toilet next to the bedroom, which had not been

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considered a few centuries earlier. Demand for large quantities of safe water increased not only for drinking, cooking, bathing and cleaning, but also for flushing toilets. The economic conditions of society allowed the luxury of using clean disinfected water for flushing toilets in developed countries. Urban agglomeration compelled them again to use safe potable water to convey faeces and objectionable matter through a long network of sewers, pumps, treatment units and purify the wastewater again to meet environmental regulations. Engineers involved in planning, design, construction and operation of such systems adopted the line of least resistance to go in for a system, which in their concept, appeared to be modern. Urban centres (towns, cities and metropolitan areas) of developed countries competed with each other, at the instance of professionals to perpetuate the system. As the system consisted of fragile and sensitive biological processes an elaborate operation and maintenance infra-structure became necessary which was also professionalized. Developed countries could afford the luxury of sustaining such extravagant systems consuming chemicals and energy (14).

Civil engineers, who were first involved in water supply and sanitation programmes, modelled them after such other civil engineering structures as buildings, roads and bridges which were not so bio-sensitive. Further, it was assumed that the community - in developed and developing countries - would accept, adopt and adore water supply and wastewater treatment systems also like buildings, roads and bridges. Engineers exposed only to technological innovations of the developed countries, designed and constructed such systems in developing countries unmindful of the socio-cultural as well as economic considerations. Assets have been created, but operation and maintenance have become liabilities, even in urban centres with skilled labour. Instances are not lacking to show that various units in water and wastewater treatment plants stand as monuments in several towns of the developing countries.

URBAN AND RURAL SYSTEMS

Bulk of the population is either thinly spread out in vast rural areas or densely populated urban squatter settlements in developing countries. Urban systems need elaborate and sophisticated techniques where operation and maintentance skills may be available.

The urban dweller is willing to pay for water, as long it flows out of the faucet when turned on. Living and working conditions are such that one has little time to look into, from where the water comes or how the system performs. The professional competence at management is accepted. Yet, in squatter settlement not too far from the urban centre, one would find an entirely different kind of attitude to water supply systems.

It is a misconception to assume small community water supply and sanitation systems as 'scaled down' versions of urban installation requiring less skill and ingenuity. The exact opposite may often be the case.

Since the rural economy is based on agriculture, many communities just cannot afford a system beyond their means. The idea that water is 'God-given' and hence should be provided free is very much deeply ingrained in the minds of rural people. A system, however good it may be, is not likely to be successful unless it is in tune with their social customs and cultural traditions.

The socio-cultural and economic differences between the population in different regions of the same country should be recognized. The concept of commercialization of water supply, let alone a profitable one, has seldom gained acceptance in rural areas of developing countries. The system should not only be technologically feasible, but also economically viable and socially acceptable. Basic mechanisms could be unravelled through scientific efforts and technological adoptions through engineering skills. However, socio-cultural attitudes are entirely different. The system should be self-sustaining, socially relevant and affordable by the community. The community's needs and priorities may be quite different from what the planner as well as the professional may consider essential.

COMMUNITY INVOLVEMENT

Engineers often install water supply systems in small communities expecting the villagers to use them with care and for a long period of time. The people who are to benefit from the system are not consulted on matters of design, construction, water use and maintenance of the facilities. It is difficult, if not impossible, to achieve the continuous functioning of a small water supply without some degree of community involvement. If the installations are not accepted and supported by the community, they are likely to suffer from misuse, pilferage or even vandalism. Conversely, it has been seen time and again that, with proper consultation and guidance, people can be motivated to help in the construction, operation and maintenance of water facilities for their communities.

To ensure that people participate in the water supply system for their community, they should be involved from the planning stage onwards. The community's involvement would deepen to such an extent that they will claim responsibility during implementation. It is true that most communities need the support of regional and national agencies. Increasing participation at the community level, therefore, means increasing the demand for support services on sector agencies at all levels. In particular, heavier demands are made for manpower and training - both of which have been constraints to progress in many countries.

Analysis of existing small community water supplies has shown that participation in the early stages of project design greatly contributes to the success of the project. The choice of alternatives, the level of service are decisions in which the community can be usefully involved. A second consideration for more community involvement in the design stage, safeguarding of the interests of the weaker sections of the community, will be more difficult to accept. Yet, many of the decisions that are taken in this phase may lead to a worsening of the position of disadvantaged groups. A service favouring the richer households, social contacts for women, and the domination of local elite in the water organisation are all possible consequences of a new water supply system.

Community involvement in the construction of small water supply systems can take many forms. Local contributions in cash, labour, materials, services and organisation may reduce the required capital investment, stimulate feelings of local pride and commitment, develop local capabilities, and present opportunities for the selection and training of suitable personnel for maintenance and administration of the system.

The delegation of operation and maintenance tasks to members of a community is more common today than it was some years ago. These delegated responsibilites vary widely, from checking and reporting, or routine maintenance, to the training of caretakers and operators. Local organisation and administration may vary to a considerable extent. Three approaches may be distinguished: a standard approach, individual arrangements and a compromise combination. In Latin America, a standard approach has been used, with fixed selection procedures, formal delegation of responsibilities and authority, supplemented by training and supervision. Elsewhere, individual ad hoc arrangements are common which are adapted to the existing community organization. However, these arrangements lack a legal base, and their effectiveness is often not much. As a compromise, some flexibility can be brought into the standardized approach, to suit local social and cultural pattern. This includes matters such as the selection procedures, scope of community organisation and division of responsibilities and authority.

HEALTH EDUCATION

If the cooperation between the community and the water supply agency or health department is to be effective, whether it concerns design, construction, or operation and maintenance, they should be partners in the full exchange of information and views. The water supply agency needs to set forth the desired goals of the community water supply. Health education may be part of the motivation for the water project, and should start as early as possible. On the other hand, local conditions, expectations and constraints will also play an important role. The water agency, therefore, needs to have some basic knowledge of the socio-cultural and economic background of the community.

The integration of health education as part of the water supply project has been emphasized in relation to project motivation and impact on the health conditions. The provision and use of safe water alone will not be enough to achieve an optimal health impact. Disposal of waste, nutrition, animal hygiene, housing, insect and rodent control, and food hygiene will be needed as well. In some countries, water projects are part of the primary health care programmes, or linked to nutrition projects. However, even when water supplies are planned and implemented independently, engineers should discuss with the community,

TABLE 1 - Status of Urban Water Supply in India (11)

Classification	Total No. of towns	Total population in million	No. of towns served	Population served in million	Per cent population served
Population 100,000 and above	151	53.2	149	50.7	95.2
Population 50,000 - 99,999	219	14.9	206	12.5	84.7
Population 20,000 - 49,999	652	20.0	542	15.2	76.0
Population 10,000 - 19,999	987	13.8	649	8.5	60.8
Population 5,000 - 9,999	820	6.2	423	3.2	51.2
Population less than 5,000	290	0.9	123	0.3	40.1
Total -	3119	109.0	2092	90.4	82.9

the role water can play in local development, and they should stimulate other agencies to link their programmes to the water project. This is even more important in cases where the provision of a safe water supply is not given a high priority by the community. Water supply projects should not be viewed in isolation, but as a catalyst to local development. Successful participation in water projects may lead to greater confidence of the local population and the development agencies in the capacities for self development.

CASE STUDY - INDIA

Water Supply Systems

In India, the awareness to provide adequate and wholesome water to all the citizens became pronounced with the appointment of Bhore committee in 1944 which recommended that the entire population should be covered in about 35 years (14). Several other committees at the national level have further reiterated this. As per 1971 census, the country had an urban population of 109 million spread in 3119 urban centres and a rural population of 438.58 million spread in 5,75,936 villages (Table 1 & 2) (11). About 82% of urban population and about 18% of rural population have been provided with safe water supply. Out of a total of 3119 urban areas, nine are metropolitan areas with population above one million, 142 have population above 100,000. In these cities, well over 60% of supply is from surface source (Table 3) (2). Only 1943 towns with population range 5000 - 100,000 have been covered with water supply, leaving 1025 towns yet to be provided with protected water supply. Out of 575,936 villages, there are about 6332 with population above 5000. In addition, existing systems in those towns which have been provided with water supply, the capacity has to be augmented to meet the requirements of increased population.

TABLE 2. Distribution of Villages in India according to Population

Population Range	Number of Villages	Percent of Total
10,000 and above	1358	0.24
5,000 to 9,999	4974	0.86
2,000 to 4,999	36005	6.25
1,000 to 1,999	81973	14.25
500 to 999	132990	23.08
Less than 500	318633	55.32
TOTAL	575936*	100.00

* - includes 3 villages in Manipur for which details are not available.

Source: INDIA 1979, A Reference Manual. Ministry of Information and Broadcasting.

Groundwater has been the main source of water supply for villages and will continue to be so. Open wells which serve as a major source of drinking water for rural communities, invariably show the presence of faecal pollution due to use of contaminated ropes, buckets, etc. for drawing water. Disinfection of such waters using gaseous chlorine is not feasible. There is no dearth of technology for rural water supply, but the known technology is either inapplicable to a local situation or is uneconomical.

TABLE 3 - Water Supply in Cities with Population
> 1000,000 (2)

Number	Population million	Source: Ground mld	Source: Surface mld	Combined Ground + Surface	Per capita lpd
142	60.25	794	5261	2582	55 to 487
		9 %	61 %	30 %	145

Slow Sand Filters and Rapid Sand Filters

In most of the urban water treatment plants, either slow sand filters or rapid sand filters have been provided. Some of the water treatment plants having slow sand filters were constructed as early as 1890. Additional capacities have been created with rapid sand filters, assuming them to be an improvement over the earlier filters. Evaluation of existing water treatment with slow sand and rapid sand filters, indicate that the former has a better capacity to withstand low operational skills over long period of time.

Design engineers assume that slow sand filters, due to large area requirements are always more expensive than conventional rapid gravity filters with pretreatment. The traditional design practice being conservative, provides for one or two extra units as standby escalating the cost. Further, though there is no economy of scale in slow sand filter construction, they continue to be designed for 30 years into the future. This results in high initial cost which the community or local government is unable to pay due to limited financial resources. In some cases, general guidelines limiting the estimated per capita cost have been laid for the purpose of administrative sanction. Such wrong assumptions have led practising engineers not to consider slow sand filter as a suitable system.

TABLE 4 - Relative Cost of Slow Sand Filters and Rapid Sand Filters
(Capital, Annual OMR Cost) +

in US $ ++

Plant capacity (mld)	Rapid Sand Filters with Pretreatment Units						Slow Sand Filter			
	Capital*	Energy	Chemi-cal	Staff salary	Repairs and repla-cement	Annual OMR cost**	Capi-tal*	Staff salary	Repairs and repla-cement	Annual OMR cost**
1.00	51250	41	2053	4575	1025	7694	36250	1425	363	1788
1.91	101250	78	3924	4575	2025	10602	63750	1425	638	2063
2.27	111250	93	4654	5400	2225	12372	75000	2100	750	2850
6.70	143750	275	13733	6225	2875	23108	250000	2100	2500	4600
15.00	322000	615	30796	11250	8175	50836	560000	6900	5600	12500
30.00	544000	1232	61593	16875	12880	92580	1120000	9600	11200	20800
45.00	966000	1848	92390	16875	19320	130433	1680000	10625	16800	27425

Rapid Sand Filters with Pretreatment Units:

* Capital costs include civil, machineries for flash mixing, flocculation, scraper, wash water pumps and land charges.

** OMR cost includes energy, chemical, staff charges.

Slow Sand Filter:

* Capital costs include civil and land charges.

** OMR cost includes staff, repair charges.

\+ Rates prevailing during 1980 in India

++ 1 US $ = Indian Rs 8/-

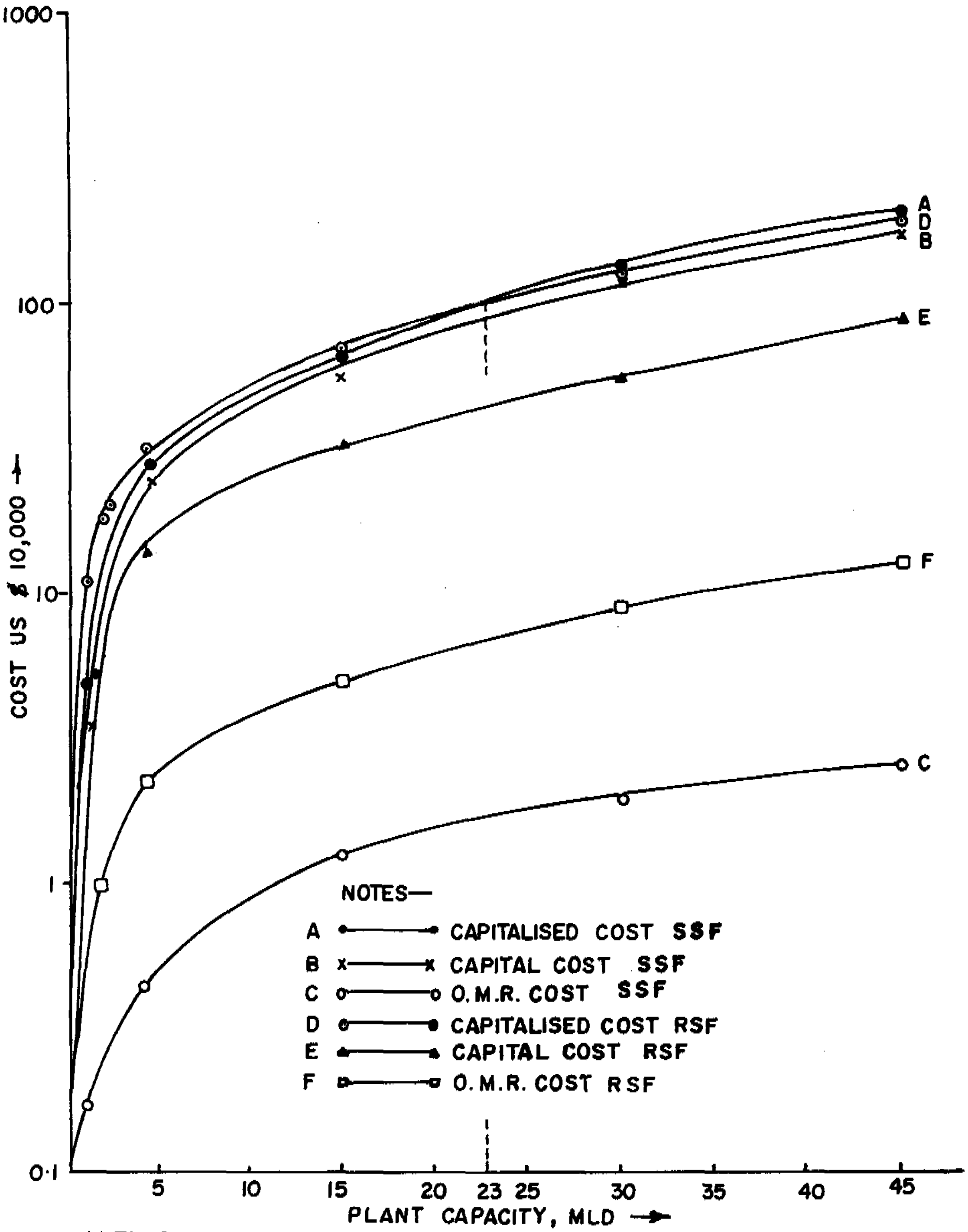

FIG.1 CAPITALISED, CAPITAL AND ANNUAL OMR COSTS FOR SLOW SAND AND RAPID SAND FILTERS.

TABLE 5 - Capitalised Cost Estimates for different Capacities

US $ x 1000

Plant capacity (mld)	Rapid Sand Filter with Pretreatment Units				Slow Sand Filter			
	Capital	Annual OMR	Capitalised OMR	Total Capitalised	Capital	Annual OMR	Capitalised OMR	Total Capitalised
1.00	51.25	7.7	58.52	109.77	36.20	1.78	13.50	49.70
1.91	101.25	10.6	80.50	181.75	63.80	2.06	15.60	79.40
2.27	111.25	12.4	94.24	205.49	75.00	2.85	21.60	96.60
6.70	143.75	23.1	175.50	319.25	250.00	4.60	34.90	284.90
15.00	322.00	50.8	386.00	708.00	560.00	12.50	95.00	655.00
30.00	544.00	92.5	703.00	1247.00	1120.00	20.80	158.00	1278.00
45.00	864.00	130.4	991.00	1855.00	1680.00	27.42	208.30	1888.30

Remarks

Capitalised cost = Capital cost + capitalised OMR cost

$$\text{Cost factor} = \left[\frac{1 - (1 + r)^{-T}}{r}\right] = \left[\frac{1 - (1.10)^{-15}}{.10}\right] = 7.6$$

r = interest rate : 10%

T = design period : 15 years

Cost analyses of rapid sand filter with pretreatment units and slow sand filter for capacities ranging from 1.00 mld to 45.0 mld are shown in Table 4, taking into account costs of energy, chemicals and operation and maintenance. The total capitalised cost in Table 5 and Fig. 1 indicates that up to 23 mld capacity, slow sand filters prove to be economical, beyond which rapid sand filters are preferable. The cost of chemicals and energy are increasing at such a rate that rapid gravity filters may prove to be uneconomical even at higher capacities in the near future. Hence a major part of the urban centres and rural areas with surface source requiring treatment could be provided with slow sand filters.

Filter Plant Evaluation

Fifteen water treatment plants with capacity from 3.0 to 136 mld were selected from different parts of the country for performance evaluation. Some of them had slow sand filters to start with but rapid sand filters were added subsequently to augment capacity (Table 6).

Alum dosing equipment, flash mixers and flocculators were not working in 12 plants; clariflocculators were defective in 10 plants, flow measuring devices and rate of flow controllers were not working in all the 15 plants with rapid sand filters. Only three plants out of the total were found to be satisfactory. One plant out of 15 had trained operators. Algal growth was observed in 5 of the slow sand filters and skilled operators were not available. The filters produced fairly satisfactory quality of water, except during monsoon, when the raw water turbidity was high (Table 7) (7).

The pretreatment units provided for rapid sand filters proved to be a wasted investment, and chemical dosage was arbitrary in the absence of laboratory facilities. Further critical evaluation will reveal higher energy and chemical costs than what is shown now. The slow sand filter has proved itself to be a rugged one, capable of withstanding all limitations, except during monsoon when raw water turbidity was high. By providing suitable summer storage reservoir, the high turbidity during floods could be handled, which may add to the cost to some extent.

Small Water Supply Systems

The WHO International Reference Centre (WHO-IRC) for Community Water Supply, The Hague, Netherlands, initiated a research-cum-demonstration project on slow sand filtration for small water supplies in developing countries. National Environmental Engineering Research Institute (NEERI), Nagpur, representing India, has been participating in this global programme.

The objective of this collaborative project is to establish and demonstrate the efficacy of slow sand filter for treatment of rural water supplies and to promote their large scale application in developing tropical countries in view of its appropriateness. Arising out of the laboratory and field investigations and critical review of current slow sand filtration practice in India, guidelines have been formulated for cost effective design of slow sand filters, construction, operation and maintenance.

TABLE 6 - Evaluation of Selected Water Treatment Plants (7)

Sr.No.	Population	Source	Type of Filters	Capacity (mld)	Number of Filters	Observation *
1	2	3	4	5	6	7
1	12,75,000	River Ganges	S.S.F.	91	36	i, x
			R.S.F.	114	22	i to vi, ix
2	7,50,000	River Gomati	S.S.F.	46	10	i, x
			R.S.F.	136	18	i to vi, ix
3	5,00,000	River Ganges	S.S.F.	63	14	i, x, xi, ix
			R.S.F.	62	9	i to vi
4	6,40,000	River Yamuna	S.S.F.	32	7	x, xi, xii
			R.S.F.	82	12	i to vi, ix
5	4,31,000	River Yamuna	S.S.F.	27	6	-
			R.S.F.	59	13	i to vi, ix
6	3,00,000	Reservoir	R.S.F.	45	5	i to iii, vi
7	3,10,000	Reservoir Canal	R.S.F.	36	4	i, -
8	-	Lake	R.S.F.	14	3	i, -
9	1,75,000	Canal	R.S.F.	14	8	i to vi
10	1,34,000	Reservoir	R.S.F.	7	2	i to iv
11	73,000	River Gomati	R.S.F.	7	2	i to iv
12	50,600	River Ken	R.S.F.	4.5	2	i to vi
13	30,000	Lake	R.S.F.	4	2	-
14	66,000	River Bhavani	R.S.F.	3.5	2	i, ii
15	24,000	Lake	R.S.F.	3	2	i, ii, iii

* Performance as indicated by numbers in Table 7.

TABLE 7 - Observations in Filter Plants (7)

Type of Filter	Observations
Rapid Sand Filter	i) Flow measuring devices are not working.
	ii) Alum dosing equipment is out of order, and alum is being added by dumping alum blocks in the flow channel or tank.
	iii) Mechanical flash mixers are not working, whereas simple hydraulic sump/baffled channel flash mix devices are working.
	iv) Flocculation paddles are not working.
	v) Scrapper arms of clarifier are not working properly.
	vi) Rate of flow controller as well as loss of head indicators are not working.
	vii) Chlorinators are not working and replaced by bleaching powder solution or chlorine gas is being bubbled through the filtered water flow channel.
	viii) Laboratory facilities for routine analysis as well as determining chemical dosage are insufficient. Alum dosage is determined arbitrarily.
	ix) Trained operators are not available.
Slow Sand Filter	x) Algal growth seen on margin of filter beds.
	xi) Manual cleaning unsatisfactory and periodicity of cleaning left to the operator's intuition.
	xii) At times of high turbidity, during floods, plant performance ineffective.

Village Demonstration Plants

In order to test the guidelines arrived at during the first phase under field conditions, four village demonstration plants (VDPs) in four different regions have been constructed and commissioned. While selecting villages for the location of demonstration plants, careful attention has been given to the population size, water supply needs of the village, source and quality of raw water, socio-economic and cultural background of the community and its willingness for effectively participating in the programme.

The salient features of the demonstration plants are shown in Table 8 (6). The projected (design) population for the demonstration plants ranged from 1300 to 12695 persons. Apart from being geographically distributed around the country, they represent typical socio-economic conditions of rural India. A variety of situations have been covered, from engineering considerations as well.

The raw water sources varied from river fed canal, canal fed from an impounded source, and upland perennial river to a river. Summer storage tanks of 30-40 days detention period provide the pretreatment for the first two plants. A plain settling tank followed by a horizontal prefilter in the third and pretreatment through an infiltration gallery constructed across the river bed in the fourth plant.

The process design incorporated the recommendations from the applied research completed during the first phase. Detailed structural designs and the construction were carried out by the respective state engineering departments in charge of rural water supplies with technical assistance from NEERI. The layout and the choice of construction materials were decided, keeping in view the local conditions, availability of materials and their costs.

The filters at two sites are circular in shape while the other two plants are rectangular with common wall construction. The underdrains in one consisted of a system of PVC pipe manifold and laterals with indegenously developed permeable capsules placed at 1.0 m intervals, topped with a thin layer of pea gravel. This type of underdrain has been found to be effective and cheaper than the conventional ones. In the second, the underdrain is made of pre-cast concrete bricks - the bottom layer laid on edges and the top layer laid flat so as to form a series of lateral channels. The top layer of pre-cast bricks has perforations for passage of filtered water. The underdrains for third one is similar, but the top layer of bricks without perforations arranged to provide openings between the bricks as in a conventional brick underdrain. The fourth plant is provided with pre-cast concrete slabs and hard broken stone as supporting gravel layers. Thus a variety of innovations has been incorporated in the design and construction of the demonstration plants. All the four demonstration plants have since been commissioned and are being regularly monitored for their performance under field conditons. Filtered water quality monitored during the year indicates acceptable quality in all the plants.

TABLE 8 - Demonstration Slow Sand Filter Plants in India
Salient Features

Description	Plant I	Plant II	Plant III	Plant IV
State	Andhra Pradesh	Haryana	Maharashtra	Tamilnadu
Village	Pothunuru	Abubshahar (Group of villages)	Borujwada	Kamayagoundan-patti
Population				
Present	3254 persons	8719 persons	699 persons	8500 persons
Projected	6236 persons	12695 persons	1315 persons	10000 persons
Design per capita water supply	45 lpd	45 lpd	70 lpd	45 lpd
Plant capacity	17.5 m^3/hr.	24 m^3/hr	5.75 m^3/hr	22.60 m^3/hr
Raw water souree	Eluru chanal	Bhakra main canal	River Kolar	River Suruliar
Pre-treatment	Storage	Storage	Infiltration gallery	Plain sedimentation + horizontal pre-filtration
Slow sand filters	2 Nos. 10.97mx7.92m each	3 Nos. 10.0m dia each	2 Nos. 5.05mx3.8m each	2 Nos. 12 m dia each
Distribution	Standposts	Standposts	Standposts	Standposts + house connections
Per capita cost	US $ 8/=	16/=	26/=	5/=

(Existing system meets part of the supply)

Health Educaton

An integrated health education and community extension programme formed an essential activity of the demonstration project. The objective of the programme is to develop and implement a methodology for preparing the community for effective utilization of improved water supply and to assess the impact of health education on the overall improvement in health status, personal hygiene andenvironmental sanitation. A health education strategy developed by Central Health Education Bureau with modifications to suit the local needs and requirements is being implemented in the project villages by the state and local agencies with overall coordination by NEERI. Popular lectures are delivered to villagers on various topics such as personal hygiene, collection and disposal of sullage and refuse, hygienic methods of collection, storage and use of water, etc. This is supplemented by audio visual aids and display of charts, posters and flash cards on a number of health related topics like nutrition, family welfare, cholera, malaria, filaria and control of water-borne diseases through supply of safe water. The community response to these programmes has been encouraging.

Another important feature is the integrated, multidisciplinary and collaborative effort among research workers, field engineers, government agencies and policy makers at local, national and international levels. In order to effectively plan, organise and implement the country programme and keeping in view the future large scale implementation of slow sand filters for rural water supplies, a project managing committee has been formed with representatives of all the agencies involved.

Recognising the need for trained manpower in community water supply, due attention has been given to this aspect in the overall programme. Operators selected from among the local residents of the village have been given on-the-job training in the operation, maintenance and management of slow sand filters as well as the distribution system. Wherever feasible, the operator has been associated right from the initial construction stage of the filter plant so as to familiarise himself with the various components of the plant, their inter-relations and principles of operation and maintenance.

SANITATION

Planners and administrators give water supply top priority and rightly so, due to the visible plight of people and their clamour for drinking water. Wastewater collection, treatment and disposal systems are not contemplated initially and may not even be planned for the next three or four decades. As against 18% of rural population provided with safe water supply, only 2% are provided with adequate excreta disposal (Table 9) (15).

Urban Fringe Areas and Small Towns

In urban communities, a good proportion of the population with low income live in densely populated squatter settlements. Wastewater

TABLE 9 - Population Provided with Adequate Water Supply and Excreta Disposal in India and South East Asia Region (15)

	INDIA				SOUTH EAST ASIA			
	1970 in million	%	1975 in million	%	1970 in million	%	1975 in million	%
URBAN								
Provided with water supply	66.30	60	107.00	80	75.75	50	127.50	69
Provided with sewer system	40.00	36	45.5	34	42.42	28	48.16	26
RURAL								
Provided with reasonably safe water supply	25.00	67	8.60	18	63.41	9	145.12	19
Provided with adequate excreta disposal	5.0	1	8.70	2	25.08	8	8.70	6

treatment and disposal systems are given a low priority due to the high cost involved. The present method of providing water supply without adequate provision for collection, treatment and disposal has become a health hazard and unclean environment. Cesspools of wastewater around community taps, streets and houses in narrow streets are commonly seen. An indication of the harmful effects of improper collection, treatment and utilization of wastewater from such communities is revealed by the substantial increase in the population at risk of filtariasis in India (Table 10) (3).

TABLE 10 - Comparative Figures of Population at Risk of Filariasis in India (3)

Year	Population at risk in millions
1953	25.90
1962	65.98
1967	121.81
1970	136.12
1976	236.13

Harmful effects of unhygienic disposal of wastewater and excreta may not be noticeable in sparcely populated rural areas. People living in semi-urban growth centres with population in the range of 5000 - 20,000 as well as those inhabiting urban fringes with population upto 100,000, are ill-prepared and under equipped for urban living. Depending upon the growth potential, these centres grow in size with ill equipped houses, badly formed roads, inadequate water supply and unsightly sanitary conditions.

An integrated water supply - wastewater collection and utilization -energy recovery - composting - nutrient recovery and use through aquaculture and agriculture - has thus become an imperative need for such communities, whether rural or urban fringe growth centres. Planning for water supply in isolation is no longer relevant. An environmentally compatible and well integrated system thus becomes relevant. A conceptual system outlined in Fig. 2 has demonstrated through a series of pilot plant studies at Madras and Nagpur, India for treatment of sewage in waste stabilisation ponds utilizing solar energy. The algal laden effluent used for fish polyculture yield about 11.5 tonnes/hectare/year, and the effluent used for commercial agriculture, such as coconut and citrus crops (12, 13). Additional income generated through fish and crop production would more than offset the operation and maintenance costs of the plant, in addition to combating environmental pollution. Social benefit accruing out of improved health status would further add to its value. The effluent could also be used for developing a green belt around the urban centres. Sectorial approach is no longer relevant in planning water supply and sanitation programmes.

Rural Sanitation

A morbidity of about ten per cent or 60 million persons suffering from intestinal infectins is an indicator of the poor environment (5). This can be partly attributed to direct or indirect effects on hygienic and environmental conditions prevalent in the villages. Sanitary latrines in villages are almost non-existant and unknown. The number and variety of faecally transmitted diseases is greater in the tropical and sub-tropical regions. Further more, the mal-nutrition that is endemic with much of the population, is an additional factor for the high rate of infection. The result is that poor sanitation becomes one of the chief causes for spread of hookworm, diarrhoea, enteritis, cholera and typhoid. The destruction of these pathogens should form the first priority of any tropical waste dsposal system.

Rural Sanitation Pilot Project

A rural sanitation pilot project in collaboration with district authority (Zilla Parishad), Nagpur was initiated to study the impact of various environmental measures such as provision of protected water supply, disinfection of well water, provision of sanitary latrines and disposal of sullage water in soakpit system, etc. in ten villages.

Worm infection is not only the greatest component of infections of the gastro intestinal system but also important because of its chronicity and effect on general health and nutrition, posing a community health problem. Some parasites drain the food, causing mal-nutrition of different types while others cause discomfort and vague sickness like in threadworm infestation though a few remain asymptomatic under host-parasite equilibrium (1). Though there are a number of studies on parasitic prevalence (9, 10), a systematic study of whole or representative sector of population in rural areas is very difficult to organise and has not been done in the central region of the country.

The study was carried out to collect a baseline data on the prevalence of intestinal parasitic infections in rural areas so as to assess whether provision of certain sanitation facilities, mass treatment and similar approaches can mitigate the morbidity. This study involved rapid clinical assessment, stool examination for various enteric parasites and blood examination for haemoglobin and eosinophilia (8). Seven out of ten villages were covered (Table 11).

In order to break the fecoral cycle, provision of sanitary latrines in individual houses has been taken up in the project villages using a handflushed water seal latrine developed by NEERI. The construction cost with cheap superstructures such as brickpanels with burnt brick in mud mortar is in the range of US $ 30 - 40 (Rs 250 - Rs 350) (4). In order to motivate the people and use of such latrines, district authority provided a subsidy to those who are below the poverty line. The house owner contributed labour for latrine construction. NEERI provided a set of pan and trap and connecting pipe free of cost to every individual and rendered technical guidance in selection of site and during construction.

TABLE 11 - Health Status in Demonstration Project Villages around Nagpur, India

S.No.	Name of village	No. of houses	Population	Prevalence of * Enteric Parasites %	Anaemia %	Eosinophilia %	No. of latrines constructed	Water supply
1	Burujwada	110	660	70.0	74.4	91.6	107	Open well. Now SSF.
2	Mahadulla	205	1077	61.6	82.7	87.2	203	Open well
3	Ajani	224	1477	71.2	94.7	74.5	120	Open well
4	Wadoda	377	2202	-	-	-	133	Open well
5	Wadi	301	1593	-	-	-	144	Open well
6	Khursapar	151	827	54.4	68.4	88.6	96	Open well
7	Fetri	159	676	62.6	98.8	76.2	61	Open well/ Tube well
8	Mahalgaon	183	850	74.2	91.3	93.6	90	Open well
9	Waghoda	74	420	47.5	59.1	69.9	30	Open well
10	Gojorkhedi	47	245	-	-	-	5	Open well
11	Asoli +	72	380	77.9	99.0	70.4	-	Open well/ Tube well
12	Avandi +	117	337	63.8	98.6	88.7	-	Open well

* Before construction of latrines

\+ Reference village : No sanitation facilities introduced.

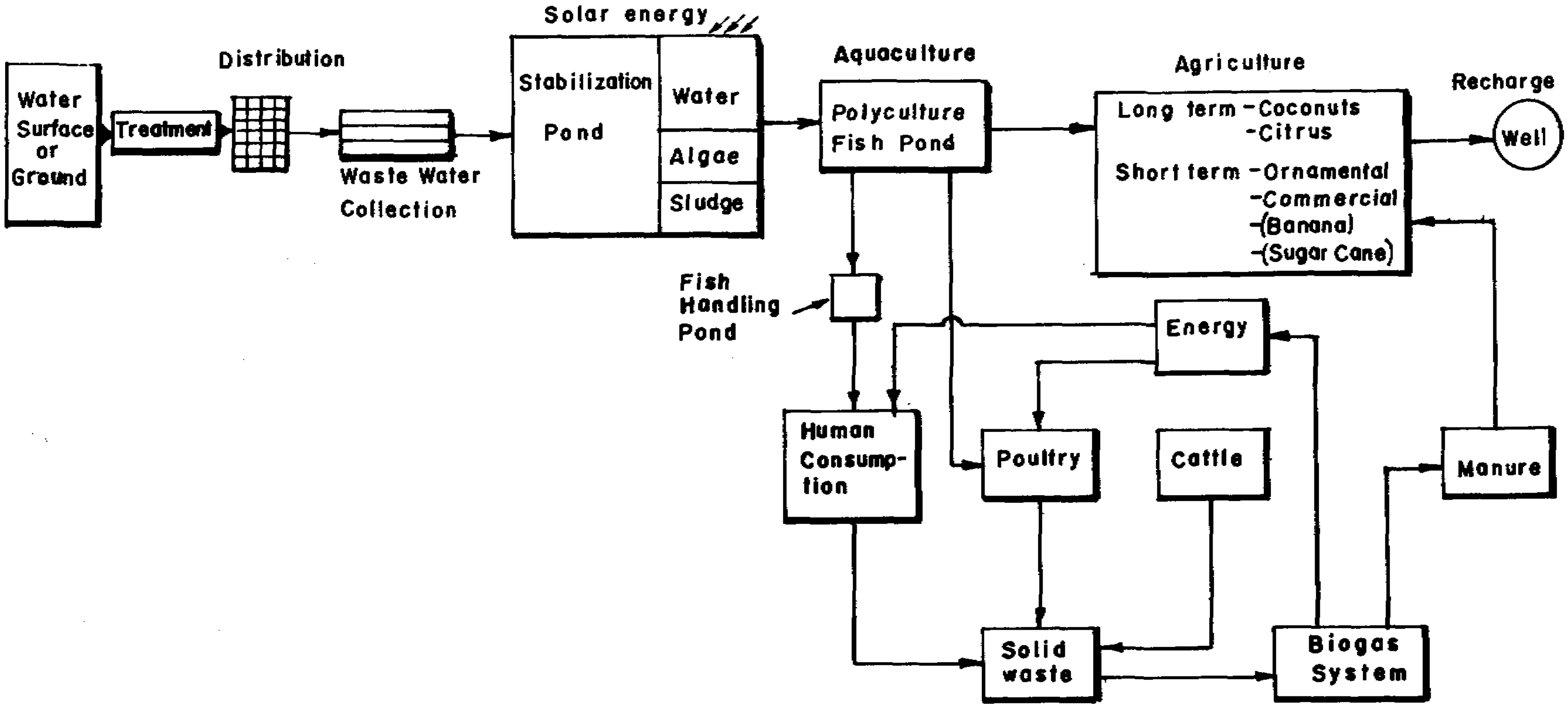

FIG. 2. INTEGRATED ENVIRONMENTALLY COMPATIBLE WATER SUPPLY AND WASTE UTILIZATION SYSTEM

In one village (Burujwada), improved water supply through a slow sand filter and public standposts has been provided after latrine construction. Disposal of sullage water is through a simple soakpit with silt-catcher. Health education formed part of the integrated programme which prepared the community for proper use of potable water, and created an awareness regarding the role of water intransmission of diseases. Mass meetings, group meetings, individual contacts, discussions with families, mass immunization, health survey of school children, film shows, demonstration with the help of microscope and exhibitions have been used in this programme. The general cleanliness of the village has improved over the past few years. The integrated approach to improve the health status of the community has proved to be effective, as against the sectorial approach tried elsewhere. This would then involve a complete reorientation of various agencies involved in water supply and sanitation, health education, community welfare and village development.

CONCLUSIONS

1. Several of the technologies involved in water supply and sanitation systems adopted in developed countries have limited application in developing countries.

2. Socio-cultural attitudes and economic level of communit are factors to be reckoned in the choice of technology.

3. Evaluation of fifteen water treatment plants of varying capacities reveals that slow sand filter has better capability to withstand low operating skills than rapid sand filter.

4. Slow sand filters prove to be cost-effective upto 23 mld capacity in India beyond which rapid sand filters would be economical.

5. Community involvement and health education should form an essential part of water supply and sanitation projects in small communities.

6. An integrated approach to water supply and sanitation programme should be encouraged rather than sectorial approach which has not made significant impact in improving the health status of small communities.

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MARIN COUNTY, CALIFORNIA - WATER USE PLANNING AND REALITY

by

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Abstract

During a recent two year drought, Marin County, one of the wealthiest communities in the United States, reduced its water consumption to levels more commonly associated with developing countries. It achieved these results through re-plumbing, conservation, and residential water reuse. Problems were encountered in conventional water and waste treatment facilities designed for high levels of consumption. It appears that the past and the future may be converging in Marin where the appropriateness of a water or waste disposal option to resource conservation is replacing expensive technology as a status symbol. Planners in both developing and industrial countries may find Marin an interesting case study when proposing "adequate" service levels and alternatives for water supply and waste disposal systems.

I. INTRODUCTION

This is a case study of how Marin County, California, one of the wealthiest counties in the United States, assumed an attribute of a less developed country (LDC) during a two year drought in the 1970s. More important, it is a case study of how the public directed water supply planning before the drought, lived during the drought, and has used the drought experience to alter its approach to future water supply and waste disposal systems. It has implications for both developing and industrial countries.

To many developing countries, Marin could represent the ultimate in development. LDCs have current levels of supply and water use below healthful standards. They need improved hygiene and sanitary disposal systems which prevent direct human contact with disease producing organisms. They also need ready access to a water supply which frees members of the family from time consuming "water-gathering" activities.

Marin, in contrast, has the privelege of modern water using appliances and the public health and environmental advantages of conventional water supply and waste disposal systems. It has the institutional framework for planning of projects and the implementation of environmental safeguards.

The traditional approach has been to assume that LDCs should have the type of technology and service levels typical of the developed world. Elites in decision-making positions have high expectations about

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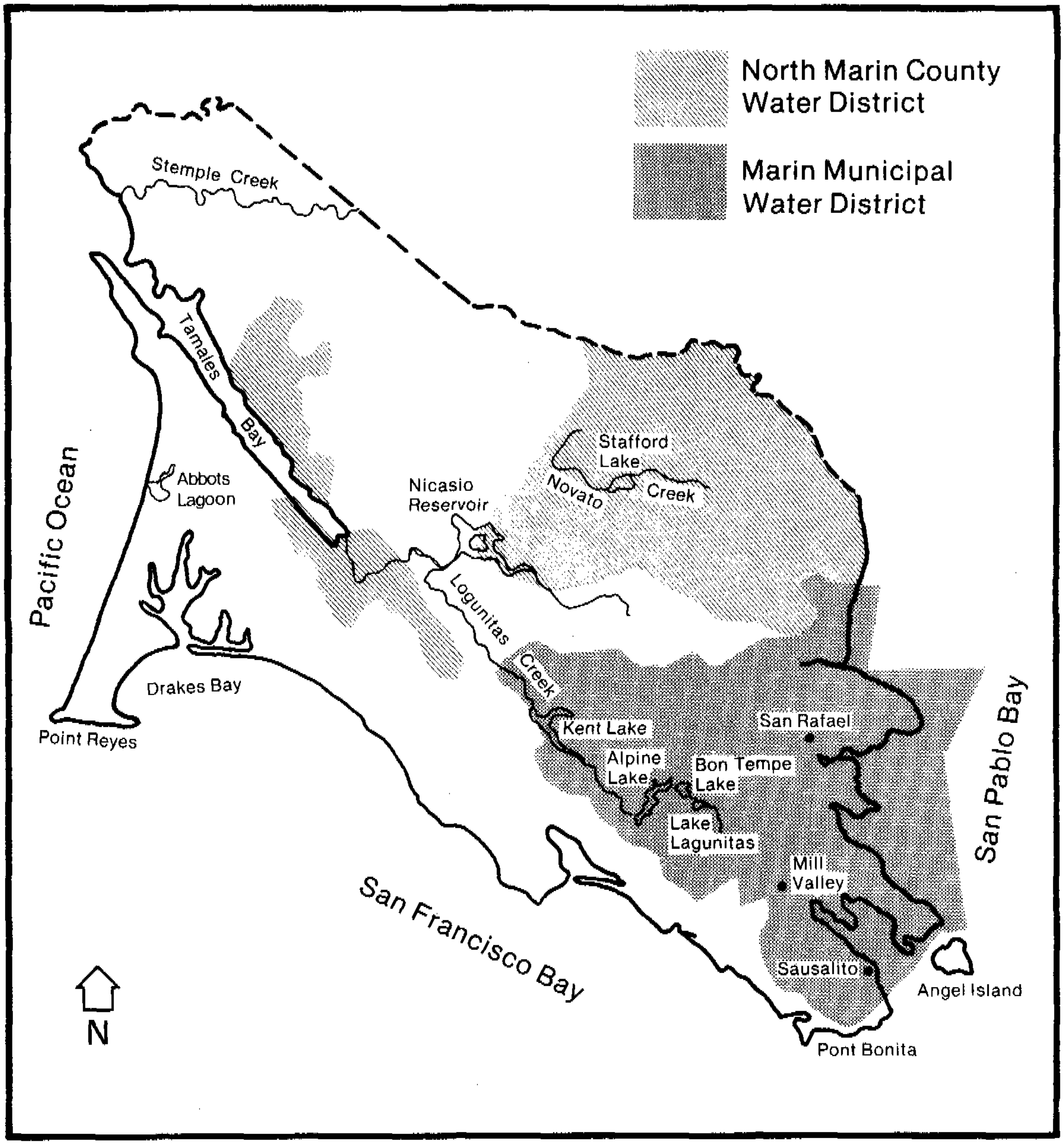

Figure 1. Marin County Cities and Water Districts

water service levels and sewerage systems which greatly increase water demands. These ideas are reinforced by consulting engineers interested in the design and construction of conventional systems.

A more progressive approach begins with an appreciation that developing countries cannot afford to construct these systems, that such systems are not necessary to improve health and sanitation, and that the use of appropriate technology and creative staging of levels of service will be adequate while allowing future improvements if they are desired. However, even this approach implies that the convenience and service levels available from conventional systems are preferable and that LDCs must settle for less than wealthier nations due to inadequate financial resources.

Lessons from the Marin experience may show that the past and the future are converging in water and waste disposal options for those who are willing to redefine status symbols. A large wooden tub filled with water on the back porch would be seen as a bathtub to an individual from a region where indoor plumbing does not exist. However, to an individual from Marin, it is a hot tub, symbol of status, modernism and supreme self-indulgence. If Marin is a symbol of the future, then options still open to developing countries may well place them in the vanguard in resource allocation, without sacrificing public health objectives.

II. BACKGROUND

Marin County is located north of San Francisco. It includes about 120,000 hectares (300,000 acres) of rolling hills, forests, beaches and towns. Approximately three-quarters of the land area is in unirrigated pasture or public ownership. There is little industrial development: most of the population of 220,000 lives in the urbanized eastern part of the county, where 11 cities and several unincorporated communities extend to the shores of San Francisco Bay. (Figure 1)

The population of Marin is white (more than 95 percent), well-educated, with income reflecting an occupational structure heavily weighted toward the professional, technical and managerial categories. In 1979, the average household disposable income (after taxes) was $28,914. The 1970 U.S. Census reported Marin was the fourth highest county in the United States in median family income. Most residences are single-family dwellings. Marin residents are also characterized as politically active, particularly relating to environmental issues.

Water Supply Planning and Public Participation: Pre-Drought

Marin is dependent for the most part on local streams and rainfall for its water supplies. Average rainfall for 100 years of record was 1,327 mm (52.26 inches). The responsibility for county water supply lies with two water districts. Marin Municipal Water District (MMWD) serves 75 percent of the residential population with 50,500 service connections. Up to 1976 MMWD relied on five in-county reservoirs for water storage, the total capacity of which is 64,680 cubic dekametres (52,440 acre-feet) (1).

MMWD was the first water district in California to be organized on a public ownership basis. In 1970 District voters approved bond issue financing for the first phase of a project which would allow MMWD to receive its first supply originating outside the county (5,300 cubic dekametres of 4,300 acre-feet). After the first bond issue approval the tide began to turn. In the midst of a population growth boom and from a desire to control growth and prevent environmental degradation, District voters rejected funding for completion of the previously approved project by a 9 to 1 margin. This project, proposed by district engineers, would have almost doubled available supply. Subsequently a series of public meetings were held on water supply requirements and alternate sources (1).

In mid-1972 the District retained a well-known engineering consulting firm to conduct a study and recommend a water resources management plan. The conclusions of the consulting engineers were 1) that the net safe yield of the existing system of reservoirs was less than previously thought and inadequate to meet existing demands in the event of a dry cycle; 2) that an additional 16,000 acre-feet (20,000 cubic dekameters) would be needed to meet 1980 demands; 3) that a project should be immediately undertaken to import water at a unit cost of \$123/AF (\$0.10/m^3); 4) that water reuse was too expensive to develop (\$220-\$340/AF or \$0.18-0.28/m^3). Reuse as an alternative was included in the study due to public initiative. The consultants based residential demands on the assumption that no conservation program would affect historic consumption patterns (2).

Due to the fact that the newly calculated net safe yield was exceeded substantially by existing demands, the MMWD Board of Directors adopted a water moratorium in 1973, imposing a ban on new water service connections. Within months voters rejected a bond issue by a 2 to 1 margin which would have allowed an additional 4,900 cubic dekametres (4,000 acre-feet) and the eventual total recommended project. While the moratorium had served as an effective interim growth control, combined with voter rejection of water bond issues, it produced a de-facto no-growth situation. From 1973-1974 community workshops were held to develop new water supply management options. Consideration was given to in-county sources, conservation, reclamation and desalinization.

Water Demand: Pre-Drought

Total water consumption in the MMWD service area consists of the total amount of metered water (residential, cormercial and industrial) and non-metered water (e.g. fire protection). From 1963 to 1970 water demand increased from 38,600 cubic dekametres (23,211 acre-feet) to 40,200 cubic dekametres (32,633 acre-feet) with total water use leveling off at about 38,000 cubic dekametres (31,000 acre-feet) per year in 1975 (11).

In 1975 pre-drought average daily per capita residential consumption was 456 litres per capita per day (lpcpd) or 120 gallons per capita per day (gpcpd). Individuals living in multiple family dwelling units used less. (1) Business and public services accounted for an additional

98 lpcpd (26 gpcpd) while unmetered uses required another 91 lpcpd (24 gpcpd). Agriculture was unirrigated pasture. The residential use of about 454 lpcpd (120 gpcpd) for all dwelling types was divided between the components shown in Table 1. Toilet flushing represented 37 percent of all indoor use. Landscape maintenance used 46 percent of all residential water (1).

Table 2 summarizes the supply and demand situation prior to the 1976-1977 drought. The population of MMWD at the end of 1975 was estimated to be 163,000. Residential use made up about 70 percent of demand with an estimated use of 27,137 cubic dekametres (22,300 acre-feet). Total demand in 1975 was estimated at 39,000 cubic dekametres (31,600 acre-feet), already exceeding the estimated safe yield of the existing system should a dry year conditions occur.

TABLE 1. RESIDENTIAL WATER USE: PRE-DROUGHT PER CAPITA CONSUMPTION IN LITRES (AND GALLONS) after Bollman and Merritt (1)

	LPCPD	(GPCPD)	% of Total
Indoor			
Toilet	91	(24)	20
Bathing	72	(19)	16
Lavatory	8	(2)	2
Drinking/Cooking	11	(4)	3
Dishwashing	15	(4)	3
Laundry	46	(12)	10
Outdoor			
Landscaping	209	(55)	46
TOTAL RESIDENTIAL	456	(120)	100

Source: (1) references

TABLE 2. SUPPLY AND DEMAND ANALYSIS: PRE-DROUGHT IN CUBIC DEKAMETRES (AND ACRE-FEET) (a)

Available Supply		Demand	Approved Supply		Demand
Total	Net Safe Yield		Total	Net Safe Yield	
64,700 (52,440)	37,000 (30,000)	39,000 (31,608)	56,000 (45,740)	41,900 (34,000)	44,948 (36,440)

a) includes new water approved by voters prior to drought and to become available May 1976.

Water Rates: Pre-Drought

Since MMWD began operation in 1911 all costs had been covered through the sale of water without additional taxation. The rate for water up to March 1976 was $0.46 per 2.8 cubic meters (100 cu ft) of water.

III. THE DROUGHT YEARS: 1976-1977

Supply

The year 1976 was the fourth driest year of record in California. It was followed in 1977 by the driest year in the State's recorded history and the second successive dry year of the worst drought California has experienced in over 100 years of record.

Marin's water supply is particularly sensitive to rainfall and runoff. During the two drought years the county received less than 75 percent of the rainfall that normally occurs in one year. Average pre-drought runoff from 1960 to 1975 was 90,600 cubic dekametres (73,463 acre-feet). Figure 2 displays the extent of reduced runoff in MMWD's two watersheds during the two drought years compared against normal, and the winter prior to the drought (1974-1975) which approximates normal. High and low average lake storage in a normal year was 63,300 cubic dekametres (51,355 acre-feet) and 37,700 cubic dekametres (30,555 acre-feet) respectively. With the extremely dry winter of 1975-1976, storage continually dropped. It reached a low point in October 1977, when total storage was only 11,700 cubic dekametres (9,510 acre-feet). The amounts of water stored in MMWD's reservoirs from January 1975 to December 1977 are shown in Figure 3*.

Supplemental Water: The Technical Solutions

Coming immediately upon the heels of public rejection of engineering attempts to increase water supply, the drought offered the perfect opportunity for district and consulting engineers to expect vindication. However, it was not the engineering solutions that played a major role during the drought. Two technical projects which helped supplement the supply through the importation of water were the North Marin Intertie, approved by voters before the drought, and the emergency pipeline across the Richmond-San Rafael Bridge.

The Intertie became operational a full six months behind schedule and delivered 2,300 cubic dekametres (1,844 acre-feet) from October 1976 to April 1977. The emergency pipeline, a 610 mm pipe placed on one traffic lane of the bridge, was the result of a complicated water transfer scheme involving many state and local agencies. The first water was not received until June 1977. Total importation from June to January

*The unprecendented reduction of runoff eventually forced MMWD to recalculate the net safe yield to reflect a 29 percent decline.

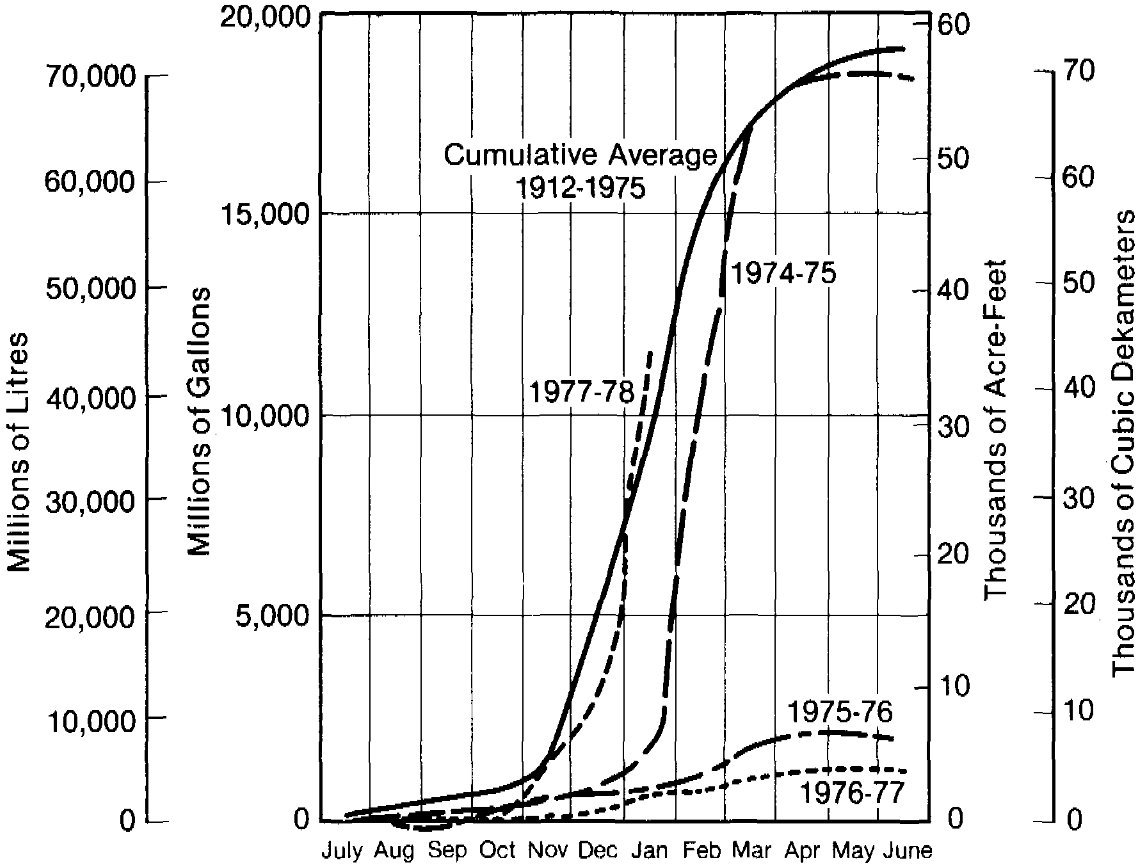

Figure 2. Combined Runoff—Lagunitas and Nicasio Watersheds

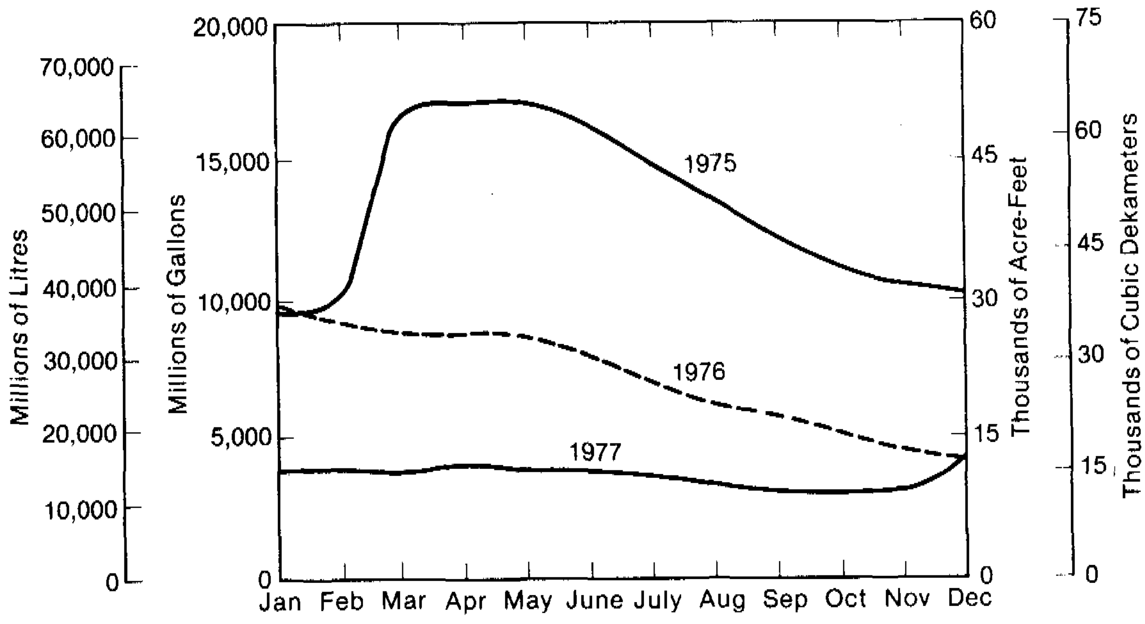

Figure 3. Reservoir Storage—Marin Municipal Water District

1978 (236 days) was 5,000 cubic dekametres (4,595 acre-feet). Drought-breaking rains fell in December 1977 and January 1978. The total cost of the water taken by MMWD was $538,596, or $117 per acre-foot ($0.09/m^3$).

Groundwater did not represent a significant new source of supply. Nonwaterbearing rock underlies most of the county, and as a result, groundwater supplies are spotty and quantities generally low. During the drought some residents, one city and two large schools drilled wells. MMWD estimates that 1,234 cubic dekametres (1,000 acre-feet) was supplied through wells. Other solutions tried and abandoned included floating large rubber bags full of water down the coast, shipping water on barges from the State of Washington, and borrowing portable desalting units from the U.S. Navy.

From February 1977 water in storage remained stable. The technical contribution to this achievement pales into insignificance when measured against the results achieved through residential water conservation and reuse.

Extension of Community Water Supply: Non-Technical

A traditional fear of water supply agencies is that, having been blocked in plans to construct new projects, they will be held responsible for inadequate service levels when shortages occur.

Community Participation - The MMWD took the approach that the level of costs the community is willing to bear in a water short period depends on the degree to which the community understands the seriousness of the supply situation. Marin residents had played an active role in water planning and MMWD management attempted to increase the awareness of the actual conditions while delineating the options for extending the available supplies. Steps taken included informational newsletters describing ways of reducing water use. An intensive educational and retrofitting program was carried out through community groups and the media. Public meetings and opinion polls were taken to obtain input on rationing programs and emergency water supply possibilities. Leak repair and meter reading instructions were provided (1).

Conservation Program - MMWD set a water conservation target of 25 percent below normal for 1976 and 57 percent below normal for 1977. In order to reduce water consumption to levels commensurate with available supplies, the water district explored a variety of rationing and conservation measures. Table 3 shows a summary of the main components of the rationing programs as they evolved from February 1976, including water rate increases. As the water supply situation worsened, adjustments were made (1).

Table 3. SUMMARY OF RATIONING ORDINANCES BY MARIN MUNICIPAL WATER DISTRICT IN 1976 AND 1977 AFTER BOLLMAN AND MERRITT (1)

Effective Date	Rate Change per 2.8 cubic metres (100 cubic feet) Previous Rate	New Rate	Water-use Restrictions/Penalties
1976			
2/11			Prohibition of waste, nonessential uses (gutter flooding)
3/1	$0.43	$0.61	Initial drought rate ($4 meter charge) Prohibition of nonessential uses: 1. Sprinkler systems: hand-held hose only. 2. Washing or hosing of hard-surfaced areas and motor vehicles except with 11-litre (3-gallon) container. Disconnection of service after two warnings and installation of a flow restrictor at the meter.
4/28			Prohibition of filling any swimming pool emptied on or after April 29.
7/28	$0.61	$0.61/ 0.84*	*Two-step (peak load) residential rate structure: $0.61 up to bimonthly usage ceilings established for residential classes. $0.84 for water usage in excess of these usages. Filling of any new swimming pool prohibited.
1977			
2/1	$0.61/ 0.84	$1.22	Rationing rate Penalty rate structure: $10 per 2.8 cubic metres (100 cu. ft.) used in excess of allotments--up to twice said allotment. $50 per 2.8 cubic metres (100 cu. ft.) in excess thereof. Bimonthly usage allotments established for each class of water user. Noncompliance to result in service disconnection and installation of flow restrictor. General Manager may grant variances or adjust allotments.
6/1			Bimonthly usage allotment to nonresidential users increased.
7/1			Rules for noncompliance were eased--no restrictors installed.
8/1	$1.22	$1.34	Rationing rate (10 percent inflationary increase)
10/1	$1.34	$1.87	For consumption over 11.3 cubic metres (400 cubic feet) an additional $0.53 per 2.8 cubic metres (100 cubic feet) pipeline charge is levied to pay for pipeline conveying water across the Richmond-San Rafael Bridge.

NOTE: In February 1978, penalty rates were removed and an interim rate of $0.87 per 2.8 cubic metres (100 cubic feet) established.

In 1976 the goal of 25 percent reduction of normal consumption was to be achieved through rationing to reduce peak water use in the summer months. Non-essential users such as sprinkler systems, washing and hosing of hard surfaces and filling of swimming pools were prohibited. Exceptions were made for health and safety reasons.

In 1977 as the drought increased in intensity more stringent rationing became effective with a per caita water allotment of 175 litres (46 gallons) with no restrictions on how the water could be used. The 1977 rationing program required a 57 percent reduction of total normal consumption.

Water Rates - Water rate increases were used to encourage conservation. In 1976 the rate went from \$0.46 per 100 ft^3 (\$0.16/m^3) to a two step (peak load) residential rate structure: \$0.61 per 100 ft^3 (\$0.22/m^3) up to bimonthly usage ceilings established for classes of residential allotments and \$0.84 per 100 ft^3 (\$0.30/m^3) for water usage in excess of these amounts. In 1977 the new rate became \$1.22 per 100 ft^3 (\$0.43/m^3) with a penalty rate of \$10.00 per 100 ft^3 (\$3.53/m^3) used in excess of allotments up to double the allotment and then the rate became \$40.00 per 100 ft^3 (\$14.12/m^3) in excess of that amount. By the end of 1977 the basic rate, to include inflation (\$0.12) and the emergency pipeline costs (\$0.53) had reached \$1.87 per 100 ft^3 (\$0.66/m^3).

Penalties - In addition to increased rates for excessive use, penalties included disconnection of service and the installation of flow restrictors. However, even in 1977, a two-month learning period was allowed for the customers to monitor water use and alter water using habits. Penalties were not applied during this period.

The rationing program indicates across the board reductions. All segments of the community, including commercial and public sectors, were expected to conserve to the same degree. Thus a strong element of equity existed. Although exceptions were allowed, community pressure minimized their use.

Conservation Program Results

The implications of the Marin experience for both rich and poor areas became meaningful when the actual results, and how they were achieved, are analyzed. Figures 4 and 5 show a comparison of actual water consumption with the district and the consumption levels set as targets for different rationing programs employed in 1976 and 1977. Approximate normal consumption is also shown for comparison. In 1976 actual consumption corresponded with planned consumption with the 25 percent target in conservation achieved. However, in 1977 the actual reduction in consumption for all uses exceeded the targeted 57 percent of normal, at 63 percent (1).

The State Department of Water Resources, in February and March 1977, surveyed water users within MMWD to gather data on the effects of the drought, determine the effectiveness of various conservation measures, document the costs and losses suffered, and assist in the future formulation of drought-related policy. The survey took place as

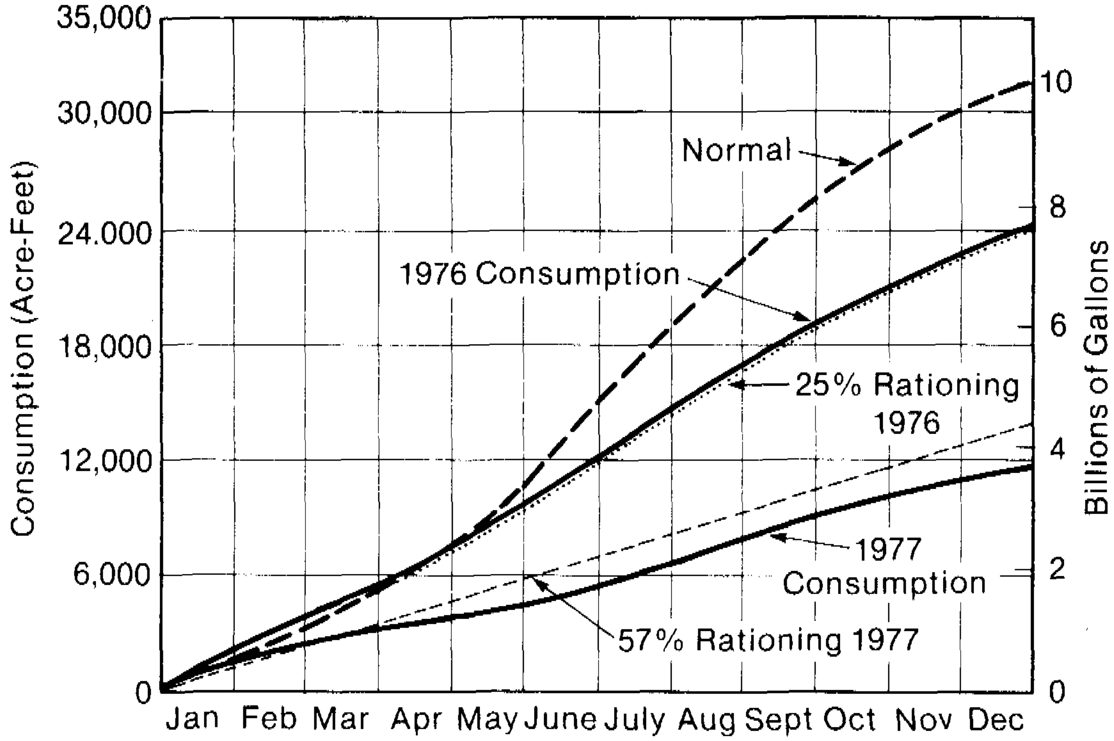

Figure 4 Accumulative Consumption—Marin Municipal Water District

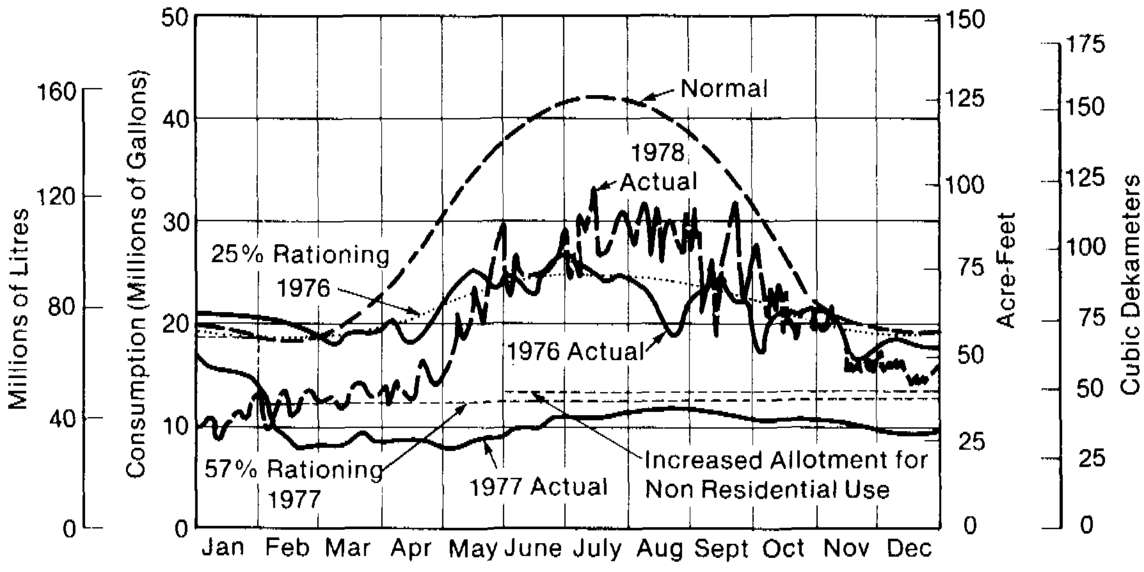

Figure 5. Water Consumption—Marin Municipal Water District

the most severe drought period was beginning in 1977. It included 20 percent of residential users and all commercial and public services. The following analysis includes the most important conclusions and their implications.

Residential Conservation Analysis

Overall residential conservation achieved a 67 percent reduction in use. Single family residences reduced consumption by 71 percent. Table 4 shows the reduction in average daily per capita consumption.

TABLE 4. AVERAGE DAILY PER CAPITA CONSUMPTION IN LITRES (AND GALLONS), after Bollman and Merritt (1)

Water User Type	1975	1976	1977
Single Family	462 (122)	334 (88)	132 (35)
Multiple Family	275 (72)	242 (64)	125 (33)

Figure 6 shows that the variability in water consumption for residents decreased markedly from 1975 to 1977. Extremely high residential water users decreased in number to almost zero when strict rationing was implemented. Water users of all income categories and all household types reduced consumption to an average per capita use of 125 litres (33 gallons) per day.

A great deal of time, education and ingenuity was required by individuals to achieve conservation results. Residents had to re-learn the role that water played in the functioning of their lives, the relationship of water to waste disposal, and the relative amounts of water used to perform different tasks. It became necessary to set priorities and make choices. Essentially the people of Marin were forced to become self-conscious about the use of a resource normally taken for granted.

Outdoor Use - The largest component of residential water use has been landscaping and swimming pools. The filling of swimming pools was prohibited early in the drought. However, residents were faced with a double challenge in trying to conserve water while trying to avoid sizeable landscape losses. Initially most people reduced the frequency of watering, the amount, and altered the time of day to minimize evaporation losses. As allotments were imposed, 58 percent more households favored using greywater (sullage) and recycled wastewater than in 1976. Selective watering was well behind (19 percent) greywater use in popularity. Thirty-eight percent ceased maintenance of landscaping altogether.

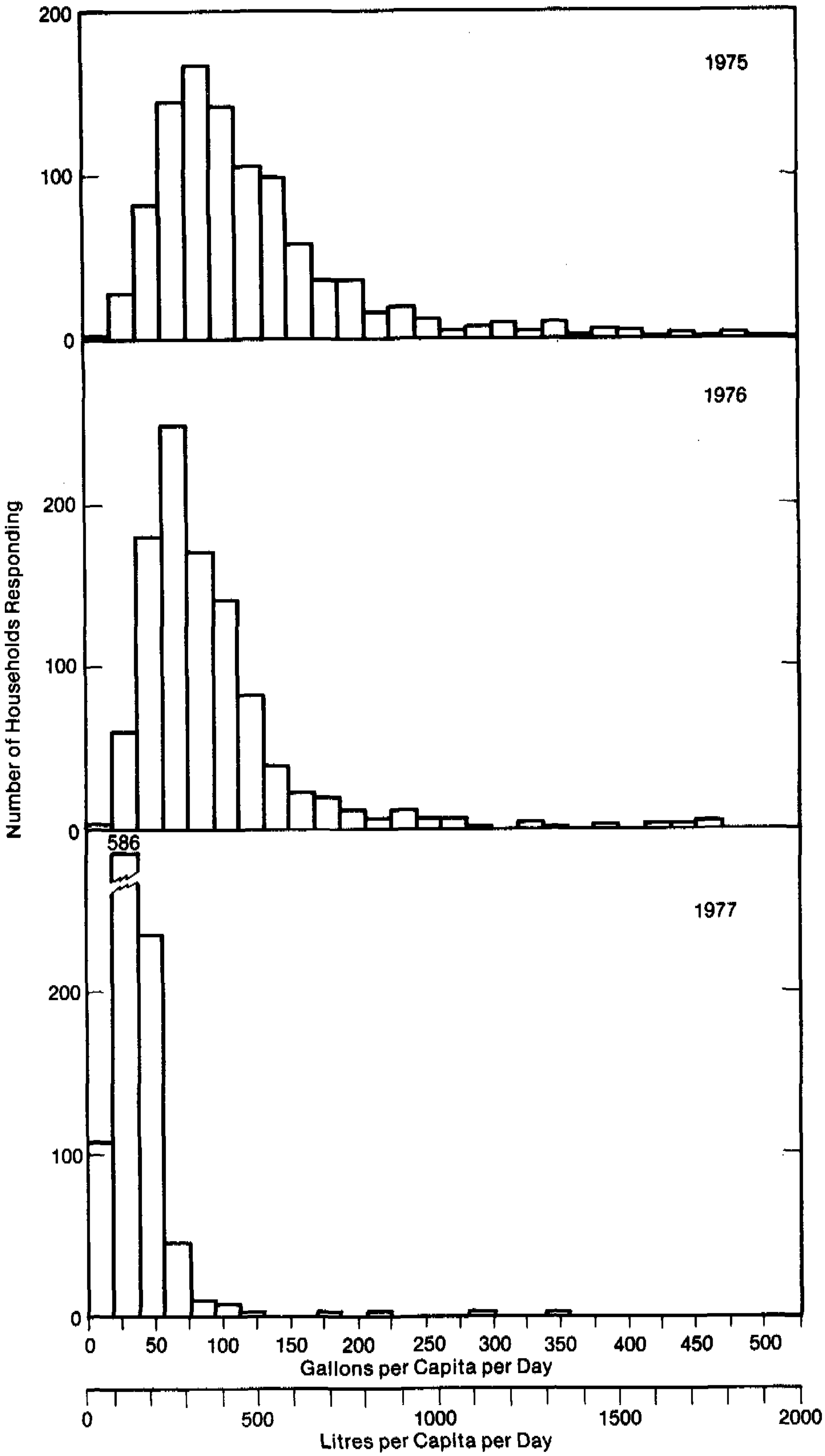

Figure 6. Single Family Daily Household Water Consumption (After Bollman)

Indoor Use - Residents began to refer to those fixtures thought once to be essential to daily life (flush toilets, showers and baths) as water bandits. The greatest reductions took place in the bathroom. Table 5 shows daily use of bathroom fixtures. Toilet flushing was the most drastically cut. Overall, survey respondents decreased their use of appliances by at least half from 1976 to 1977. (1)

TABLE 5. DAILY USE OF SINGLE FAMILY DWELLING BATHROOM FIXTURES PER HOUSEFOLD, 1976-1977 after Bollman and Merritt (1)

Fixtures	1976 (normal)	1977	% Decrease
Showers	2.6	1.5	42.3
Bathtubs	1.8	0.9	50.0
Toilets (flushing)	10.6	4.3	59.4
Sinks	9.7	5.5	43.3

Almost 90 percent of the single-family residents installed toilet or shower water-saving devices. These were considered practical and effective due to ease of installation and relative low cost. Greywater use is shown in Table 6. (1)

TABLE 6. GREYWATER SOURCE AND USE, after Bollman and Merritt (1)

Type of Measure	Percentage Using Each Type	
Reuse of:	1976	1977
Bathwater	5	35
Laundry water	5	14
Dishwater	3	7
Cold water from hot tap	4	5
Reuse for:		
Toilet flushing	14	32
Plants and garden	12	30
Garbage disposal	0.1	0.7
Car wash and cleaning	0.5	2.4
Unspecified reuse	35	43

Many greywater systems required disconnecting existing plumbing and installing individualized distribution systems.

Socioeconomic Factors Affecting Residential Water Consumption

An analysis was made to separate the major factors influencing water consumption from those having relatively little effect. Water consumption was divided into three separate consumption periods. The first period (1975) was considered to be normal since it followed a winter of near normal rainfall. The second period (1976) was considered to be a voluntary rationing period as no stringent restrictions were placed on residents. The third period (1977) was considered to be a mandatory rationing period (1).

Under normal conditions the following indicators were associated with high use: single-family residences compared to multi-family, larger incomes, older age. Indoor household consumption was most affected by the number of people, the number of water-using appliances and the number of people home all day. The fewer people home all day, the more water used (1). Indoor per capita use was a function of the number of water-using appliances and the number of persons per household (the higher the number, the lower the per capita consumption). Income played an important role since it is often a determinant of lot size, landscaping and the number of water-using appliances or the presence of swimming pools.

During the drought in 1977 the distinction between single and multi-family residences ceased to exist with all categories using virtually the same amount of water per capita (19 percent below the allotment). High consumers were those who perceived that they needed more water per person per day to live comfortably. However, high consumers reduced consumption 80 percent compared to 34 percent by low users. While none of the high consumers reduced their consumption to the low consumption level, they were found to have a much more realistic perception of the amount they had conserved. Low users greatly overestimated their achievement. All income classes had reduced household consumption by 25 percent in 1976 and in 1977 per capita consumption for all income groups was between 114-132 lpcpd (30-35 gpcpd). During the strict rationing period the number of people per household became more important with the higher the number, the lower the per capita consumption. Since this could no longer be explained statistically as a greater division of outdoor use, it implies that consolidation of other water using functions, as well as greater social control, amy have been a factor in larger groups. During 1976 an attitude factor of viewing rationing as a great hardship became significant. By 1977 this attitude factor became very significant. It appears that the more one felt he needed to get by, the more he used. People who felt that rationing was extremely inconvenient used more water than people who lacked this attitude. This factor was important in all but outdoor per capita use. The other factor which became evident in 1977 was the number of children per household. This tended to increase per capita consumption.

Table 7 shows some of the factors associated with income that affect water consumption under normal conditions. Table 8 shows that regardless of all the factors which were the cause for higher water use in normal years, essentially everyone brought peak water use per capita

Table 7. SELECTED HOUSEHOLD CHARACTERISTICS BY INCOME CLASS AFTER BOLLMAN AND MERRITT (1)

Characteristics	Annual Income After Taxes					
	$10,000 or less	$10,000 to $15,000	$15,000 to $25,000	$25,000 to $35,000	$35,000 to $50,000	Over $50,000
Average household size	2.2	2.7	3.2	3.5	3.5	3.9
Average no. water-using appliances	6	8	9	10	11	12
Average of lot requiring water (in sq. ft.)	4,100	6,500	5,700	6,700	7,600	12,300
% with swimming pools	5.9	8.5	10.8	17.4	29.1	36.5

Table 8. SINGLE FAMILY RESIDENTIAL WATER USE

Year	Average Daily Water Use Per Capita in Litres (gallons)			
	Indoor	Outdoor (summer)	Total (peak summer)	% Population Using No Outdoor Water
1975	284 (75)	348 (92)	632 (167)	8.5
1976	284 (75)	110 (29)	394 (104)	29.8
1977	98 (26)	34 (9)	132 (35)	22.2

down to 132 lpcpd (35 gallons). Other implications are that although outdoor use decreased significantly from 1976 to 1977, fewer people abandoned outdoor uses, implying that alternate sources such as greywater were introduced. Also, the reduction of indoor use to 98 litres (26 gallons) when, previous to the drought, toilet flushing alone had used 91 litres (24 gallons) per person shows that this use of water was strongly curtailed.

Commercial and Public Conservation

Government agencies were successful in reducing consumption by 38 percent in 1976 and 67 percent in 1977. Methods used included changing outdoor watering practices and sources of water, repairing leaks, altering plumbing with water saving devices and educating employess. Many businesses actually increased use in 1976. While all businesses managed to bring consumption down in 1977, the 57 percent was not reached. Where income was found to be related to water use less of a reduction was found. Most businesses felt the required reduction was too stringent and 25 percent felt that they could not meet it and still remain in business. However, there is no evidence of significant losses to businesses due to conservation measures taken.

Use of Reclaimed Water

Reclaimed water became a part of MMWD's water supply system during the drought. Although the total amount used was only 235 million litres (65 million gallons or about 200 acre-feet) it included both residential and non-residential use. Particularly unique from the institutional perspective was the 1977 granting of a permit from the San Francisco Regional Water Quality Control Board and the State Department of Health Services allowing secondary treated wastewater to be used for residential purposes for the period during which rationing was in effect. Truckers were licensed to haul the water from treatment plants.

Important implications of the reclaimed water use relate to price and willingness to use the water. Under the first permit drivers received the water free and marketed it for 1 to 2 cents per litre (4 to 9 cents per gallon). Under the second permit they paid $1 per 3,785 litres (1,000 gallons). Even if the truckers did not charge the public more than it cost them, the private customers were willing to pay would be more than 100 times the amount which engineering consultants had, three years previously, made reclaimed water uneconomic. Where dual systems were ruled too expensive under normal conditions, they were placed less efficiently and at greater cost under drought conditions. The second important implication was that using reclaimed water for maintaining lawns and gardens became more widely accepted due to the drought. Ninety-four percent of a representative household sample said they would be willing to use reclaimed water for irrigation if it were made available in the future.

Another change which occurred under drought conditions was that the State Department of Health Services raised the quality standards for use of reclaimed water for landscape purposes (7, 10). Rather than responding to a water supply emergency as such, the Health Department perceived the potential for increased risk due to increased use and greater receptivity on the part of the community. Subsequent inquiry revealed that epidemiological impacts of greywater reuse were neither observed nor looked for by the State (8).

Costs and Losses

Sufficient information has not been collected to determine the full costs and losses associated with the drought in Marin. Some indicators are presented here which may have future policy or community implications.

1. The major losses for residents involved losses of landscaping. By March 1977 losses ranged from $5 to $8,000. Three-quarters lost under $600 with the average loss at $570.

2. There was a significant commitment of time and energy involved in developing workable conservation techniques by households and businesses. In other words, the convenience of a developed and sophisticated water supply and waste disposal system was replaced by the "water gathering" orientation found in developing countries. While a basic supply was still more convenient, substantial commitment to "undoing" and "replacing" the conventional system became necessary.

3. Residential and business costs were associated with water-saving plumbing changes and installation of devices and leak detection and repair. The largest single item was for containers in which to catch rainwater. Costs related to indoor and outdoor residential water use ranged from $1 to $5,500. Fifty percent had costs less than $50. Multi-family dwellings had higher costs apparently from the need to hire labor in place of sprinkling systems. Overall water costs increased primarily for the normally low water consumer who could not conserve as much to offset the increased cost per unit of water. Businesses had employee education costs of between $175 and $300. Half of the water saving plumbing change costs were below $150. Leak detection and repair averaged about $375.

The Drought and Livestock Ranchers

Although agriculture constitutes 50 percent of the land use in Marin County, ranchers rely on springs, small dams, creeks and wells for water supply for livestock and washwater for dairy barns and utensils. No "service levels" by public agencies are generally required. However, the similarity of difficulties between such rural areas in "developed" Marin and LDCs stricken by drought is so evident that some discussion of these problems becomes valuable.

Farms in Marin are remote and dispersed making distribution costs of a reliable water supply beyond the ability of most ranchers to pay. Livestock ranchers were severely affected by the drought. The heavy reliance on farm-grown pasture for livestock makes adequate rainfall vital to the farm productivity. While human survival does not become a problem as it does in poor drought-stricken areas of the world, the problem of animal survival, dry fields subject to wind erosion and depleted hay reserves placed similar demands on governmental agencies to provide relief. Feed from Idaho was hauled to keep livestock in some instances barely alive. Water was hauled in daily for 18 months. By September 1976 ranchers were paying $2,000 per month to have water hauled in. At this point Federal and local funds were contributed in the amount of $436,000 for water hauling using 6 trucks hauling 7 days a week in 2 shifts a day. Without this assistance only 18 of the 68 ranchers surveyed could have remained in business. Particularly interesting is that the total amount of water, while substantial when viewed in terms of manpower, cost and materials, represented only 154 cubic dekametres (125 acre-feet) over the two year period. As with any rural domestic or livestock water supply, the massive problems of distribution of emergency supplies when local sources disappear, and the high risks of loss in life and production, completely mask the minimal amounts and service level requirements involved.

Costs of Alternate Sources

1. The purchase of trucked reclaimed water, bottled water and well drilling were costs of the drought. It is estimated that at least $6,880,000 was paid by consumers for the reclaimed water alone. This was at a rate 100 times that estimated by engineers for a non-emergency reclaimed water supply. This does not include the cost of temporary above-ground lines to meet needs of several large water users. It is evident that Marin residents did not think reclaimed water was "too expensive."

2. The cost of hauling potable water was $0.18 per 1.6 km (1 mi). This was done by private trucking companies and supervised by the County Department of Public Works. Expenditures for the emergency water hauling programs totaled $460,336 with 37 percent paid by the Federal Government, 54 percent by the County and 8.6 percent by ranchers, who also paid an additional $24,000 for the water itself.

3. Ranchers also received $901,860 in Federal grants from the Agricultural Stabilization and Conservation Service to pay for livestock fodder and $57,683 from the Drought, Food and Conservation Program to improve water supply on ranches.

4. The cost of graywater approached zero other than the time necessary to collect and distribute it. It is estimated that about 4.94 lpcpd (1.3 gpcpd) was saved in 1976 through graywater use or 774, cubic decametres (0.205 mgd) per day. In 1977 reduced consumption and increased graywater use, resulted in an estimated 30 litres (7.7 gallons) per household per day was saved. If this was used in place of the reclaimed water made available to residents in 1977, it saved approximately $400 per household.

Costs of Supplemental Supply

MMWD received a $5,560,000 loan and a $1,387,000 grant to help cover the cost of the emergency pipeline and other expenses. The total cost of the emergency water taken was $538,596. The cost of the pipeline was translated into an additional $0.53/100 ft^3 ($0.18/m^3) rate increase for users, over the first 400 cubic feet consumed of the bimonthly allotment.

IV. THE AFTERMATH: IMPLICATIONS FOR WATER SUPPLY AND WASTE DISPOSAL PLANNING IN MARIN

Water Supply Planning and Service Levels

The return to normal water conditions did not bring about a return to predrought water use. Water use in 1978 was still down 35 percent and indications are that future annual consumption will continue well below predrought days. The reduction in 1979 was about 25 percent. It appears that many water-saving techniques and devices employed both indoors and outdoors are still in use, saving water, energy, and money with very little expense or inconvenience to the consumer.

Continued conservation should not have come as a surprise to the public utilities. In a survey taken during the drought, respondents were asked to indicate how many gallons per person per day members of a household "could conveniently live with in future years when a water shortage no longer existed." Respondents were given information on daily use for 1975, 1976, and 1977 (462 litres or 122 gallons, 333 litres or 88 gallons, 140 litres or 37 gallons) from which to make an informed judgment. Nineteen percent felt they could live with less than 190 lpcpd (50 gpcpd); another 21 percent thought they would require 191-285 lpcpd (51-75 gpcpd); 42.3 would use 286-380 lpcpd (76-100 gpcpd) and only 10 percent thought they would need amounts reaching predrought levels. Even more impressive was the response to the relative inconvenience of coping with drought conditions: 80 percent considered the 1977 water use restrictions of severe curtailment as moderately inconvenient or not inconvenient. In addition it is hard to estimate the affect of new habits and a new consciousness over a two year period. However, it is unlikely that some new habits will revert to old ways any more than it is that residents will return to old plumbing fixtures.

From an engineering standpoint however, the continued reduced rates did seem to be a surprise. MMWD anticipated that consumption in 1978 would be reduced only 20 percent primarily as a result of plumbing changes. Budgets drawn up in early 1978 were based on a possible reduction of 25 percent in the first half and 15 percent in the second half of the year. When water use remained low, revenues remaining low and MMWD was caught in a cost-revenue squeeze.

Conservation, Water Rates and Water Revenues

After the drought water revenues for the water district declined as rates were dropped and water use remained low. The reduced rate of water use itself saved money. In 1978, MMWD's electrical energy requirement for treatment and distribution was down 37 percent--a total of 1,300,000 kilowatt hours. Another result, if incorporated into water supply planning, is that the construction of additional facilities for future supplies with an estimated cost of $11 million (1978 dollars) may be deferred. Some of the questions raised by the successful conservation program relate to water pricing and the fees charged for many public services.

In the past the fee structure for services such as connections and repairs was nominal or standard or free. The costs of such services were spread over all users. For example, a fee of $3 was charged to turn off a water service when the actual cost was $13. In the future these costs will not be lumped into the costs of operating the utility. Customers will pay the full costs of the service provided. Unfortunately, while some fees such as the cost of connection could dampen the rate of connections and save water, other such as leak detection may result in water waste.

Price increases have been examined primarily with the purpose of increasing revenues. However, this could easily backfire on the water district since it may induce further conservation resulting in lower use and lower total revenues. The survey conducted during the drought showed that 58 percent felt that the rationing rate of $1.22 per 2.8 cubic metres (100 cubic feet) was not a major incentive to save water. Two factors, the high income of Marin residents and the fact that residential customers used 15 percent less than that required by the rate structure, support the conclusion that price was not the main reason people conserved. On the other hand, if a community commitment to conservation was the reason, a subsequent raise in rates would hardly be accepted by the community as a proper reward. A change in the present pricing system is being carefully analyzed due to the conflicting results which could be achieved.

Planning for New Supply

As a result of the drought there are some changes and some similarities in Marin's approach to water management. The drought demonstrated that the safe yield of the existing reservoir system was less than engineers had anticipated in a dry period. It also demonstrated that conservation and reclamation were viable extensions of existing supplies. As a result MMWD has recommended increasing supplies by 19,000 cubic dekametres (15,400 acre-feet) to meet demands to the year 2000. This is less than the amount that consulting engineers had recommended for the year 1980. Of this amount, 63 percent (12,088 cubic dekametres or 9,800 acre-feet) is to be met through some form of conservation including leak detection and wastewater reclamation. On the other hand, a "cushion" of 3,700 cubic dekametre (3,000 acre-feet) has been added to the demand side in case conservation and reclamation do not reach their expected goals. For the most part the faith remains in systems not people. The lines remain drawn in much the same way as before the drought. The level of awareness is higher. The residents have been tested. Those concerned with environmental issues and opposed to reservoir development continue to oppose new projects and engineers use the conservation effort as an example of why it should not be allowed to happen again. However, the numbers of supply and demand, the use of conservation and reclamation are more propelled by changing reality than by traditional engineering practice.

Waste Disposal Planning

Conservation and Treatment Facilities During the Drought - Existing treatment facilities were clearly affected by water conservation and reduced flows during the drought. In terms of volume and strength of wastewaters, Las Gallinas Valley showed a 61 percent reduction in flow attributed to water conservation. BOD influent concentration increased 61 percent while there was a 38 percent decline in per capita BOD load. This decrease has been attributed in part to reduced use of garbage disposals (3, 5). The increase in influent total suspended solids (TSS) concentration as a result of water conservation was 28 percent and the per capita TSS load declined 54 percent.

Decreased flows were found to result in increased sedimentation, hydrogen sulfide generation and clogging in sewers . Detention time in all unit processes of the treatment works increased. Combined with an older influent wastewater of high concentrations, this resulted in septic conditions, particularly in primary sedimentation tanks. Virtually all units of the system were adversely affected. On the other hand, a decrease in effluent load reduced the effect on receiving waters. It is clear that in existing wastewater systems that are designed and operated for high per capita water use, reduced hydraulic loadings with attendant increases in concentration lead to operating problems, particularly if the existing systems lack the flexibility to maintain minimum flow rates. If conservation continues, changes must be made. New systems designed with water conservation assumed would allow for the reduction in size and capacity of facilities and lead to savings in capital expenditures and operating costs.

On-Site Disposal, Greywater Reuse and New Programs - As a result of the drought, public demand for waterless toilets and greywater reuse systems has increased. Counties and local health departments are responseble for policies toward such alternative systems. Prior to the drought all counties maintained policies which completely prohibited the use of greywater. After the drought 40 percent permitted greywater systems under some conditions. The State of California, in an attempt to better understand alternative wastewater disposal systems has initiated a study to evaluate waterless toilets and greywater reuse systems. The Rural Wastewater Disposal Alternatives Project objectives are to evaluate the public health acceptability and performance reliability of certain waterless toilets and small scale greywater reuse systems and to develop guidelines and educational criteria for the installation, maintenance and operation of systems found to be acceptible for use (12). There are 30 waterless toilets and 10 greywater reuse systems under study, located in 11 counties, including Marin. Within Marin itself, a solar village including waterless toilets and reuse systems, is in close competition for a prime piece of public land, having won out over more obvious commercial uses.

During the drought no special epidemiological studies were conducted in Marin County. According to the Marin Department of Health and Human Services, there was an apparent modest rise in enteric infections. However, "...the relationship was not to greywater use per se, and especially not to the use of greywater to irrigate ornamental plants. Rather, people tended to be so very conscientious about conserving water that we felt the risks arose from inadequate cleaning of counter tops, utensils, sponges, bathrooms, etc." (6). This quote is sufficiently telling that it offers an important base from which to summarize the Marin experience and its implications for developing countries when choosing water and waste disposal systems.

V. SUMMARY AND CONCLUSIONS

It is often popular to explain sacrifices made during natural disasters by saying that a community is drawn together in times of crisis. The drought in Marin required two years, day after day, of altering habits consciously which had unconsciously been acquired over a life time. It required a re-orientation of status, whereby a well-kept lawn became a sign of wastefulness and community disregard. Some of the implications of the Marin experience are as follows:

1. Regardless of socioeconomic categories or prior history of water consumption, residents reduced per capita consumption from 456 lpcpd (120 gpcpd) to 125 lpcpd (33 gpcpd). This consumption level is close to the upper limit of service levels recommended for developing countries. Since Marin County is one of the wealthiest areas in the United States, the across the board reductions and the levels achieved should serve as an important lesson for planners prepared to make assumptions about adequate service levels.

2. Even the consumption levels of 125 lpcpd (33 gpcpd) allowed flexibility since toilets continued to be flushed 40 percent of the time and water using luxury appliances rarely accessible to LDCs continued to be used.

3. Residents achieved greater reductions than requested with the largest group showing a 15 percent greater reduction than required.

4. Reductions were achieved by essentially un-doing and unlearning conventional methods of water use and waste disposal. Marin began to emulate the poorer countries of the world. Toilets were left unflushed. Wastewater was reused on a house-by-house basis. Plumbing was changed to lower the water requirement of various facilities. A no-flush water closet became a status symbol.

5. With the steps to conserve water came the requirement to return to basics and understand how modern technology tied water use and waste disposal systems together. People became aware of how and why they used water and questioned the need at each point. At the same time, they needed to be told that wash water from baby diapers could be hazardous to other infants.

6. Most people did not feel that being severely limited to 125 lcprd (33 gcpcd) was more than a moderate inconvenience, even though they previously had the privelege of using 456 lcpcd (120 gpcpd).

7. There is now a stronger push by residents of Marin for types of appropriate technology which minimize the use of other resources such as certain forms of energy and water.

8. Problems encountered by the water district in terms of a cost-revenue squeeze show that revenue requirements based on conventional use and conventional systems run counter to the goals of conservation. Had systems, pricing, and levels of service been designed differently from the beginning, these contradictions would not exist.

9. Problems encountered in the operation of waste treatement facilities are due to the sizing of facilities for high water consumption. This means that once high technology options are developed, a vested interest exists to maintain high levels of use.

Marin is a rich "country" with adequate financial resources to develop additional water supplies. In conventional engineering and financial analysis terms the least cost solution is necessarily the engineering solution. However, either (1) financial analysis in which technical adjustments are made for costs of unused capacity or (2) economic analysis, in which marginal costs are used and marked distortions are removed may show that least-cost technical solutions are not the best allocation of resources for society as a whole (9). The primary lesson to be learned from Marin County is that financial resources did not determine the best economic allocation of natural resources. For engineers, this means that behavioral and institutional constraints (which often change) and accurate costing are at least as important as financial benefits in project assessment.

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NEW YORK CITY - COSTS, FINANCING AND BENEFITS OF CONVENTIONAL SEWERAGE

By

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ABSTRACT

Water supply and waste disposal in the New York metropolitan area have followed conventional engineering practices in providing ever-increasing service levels, convenience, and costs. Aqueduct systems supply 1500 mgd (66 m^3/s) against safe yield fixed by the 1961-66 drought at 1290 mgd (57 m^3/s). Revenues and expense are managed within the general city budget; in 1976 these were $202 million and $138 million, respectively. Mainentance has been increasingly deferred for many years. The physical condition, losses, and adequacy of the system are unknown, prompting calls for Federal assistance to complete a third supply tunnel at variously estimated costs of $2 to 3 billion. Costs of waste disposal, here as elsewhere, exceed costs of supply. An average 2600 mgd (114 m^3/s) of sewage and runoff are discharged through a combined system. Total (1980) capital and recurring costs of sewage collection, treatment, and disposal are estimated at $1.05 billion per year. Receiving water benefits of these costs are elusive. Increasing competition for financial and natural resources and a decreasing margin for error in allocating them require reassesment of present practices. Technological, economic, institutional, and policy options include close matching of capacity to demand, dual systems for both supply and disposal, accurate pricing of high water-use applications and convenience, proper costing of unused capacity, universal metering and increasing block tariffs, evaluation of economic costs to local institutions and infrastructures of Federal and State funding and interventions, and conservation of water, energy and space.

INTRODUCTION

Water supply and waste disposal in the New York metropolitan area developed along conventional, ancient lines (24, 48). The city (then New Amsterdam) was discovered by the Dutch in 1626 who recognized its water-based resources for town water supplies, trans-portation and fisheries and purchased the island of Manhattan in 1653 for 24 dollars. Periodic flooding has always been a problem in low-lying metropolitan areas so that stream channels were gradually improved to handle the runoff. As population densities increased several things happened: 1.) local water supplies became inadequate and had to be supplemented by development of increasingly distant supplies, beginning with the Croton aqueduct in 1842; 2.) manual conservancy systems for utilizing nightsoil

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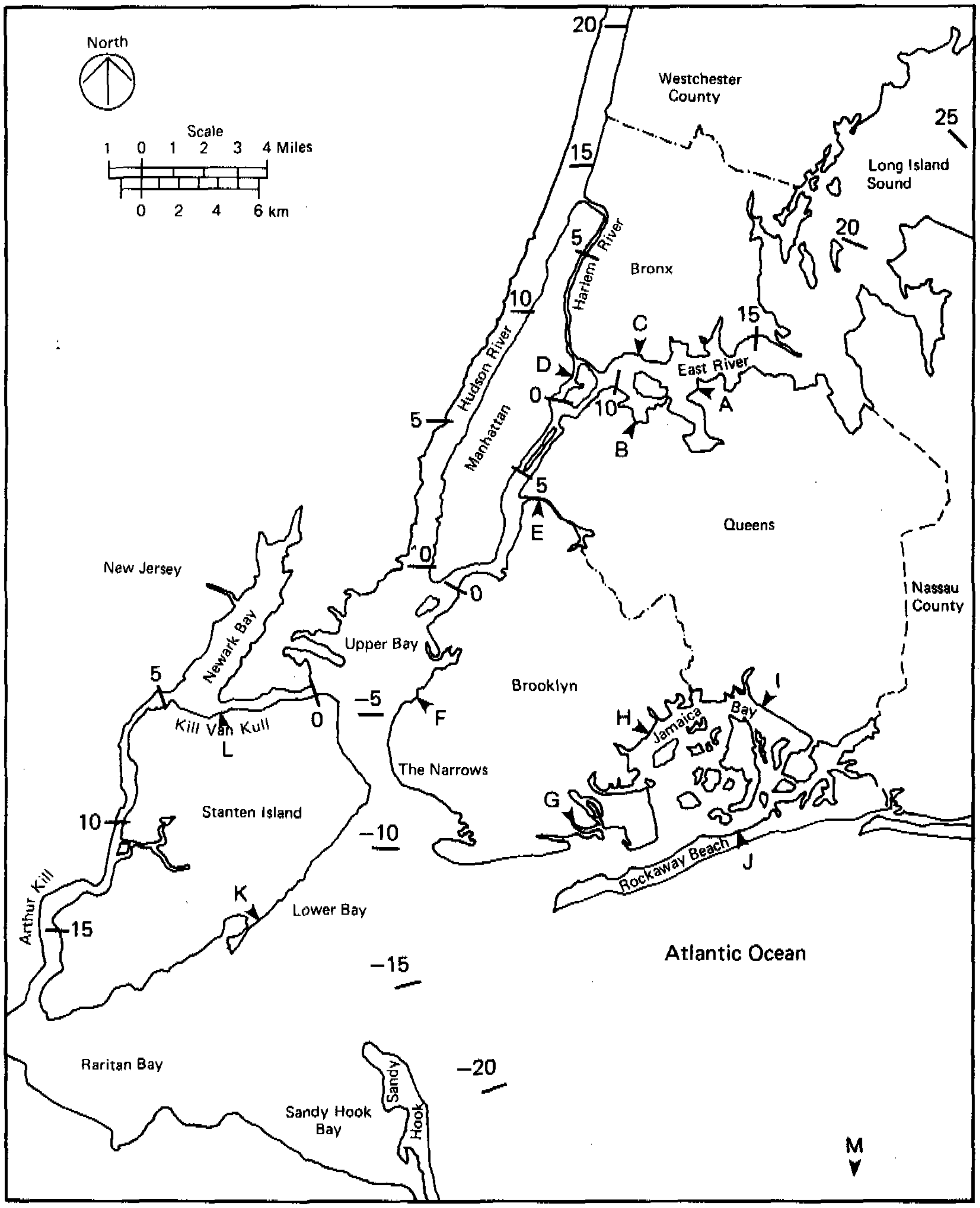

Figure 1. Locations of major New York City sewage discharges listed on Table 2. Figures show distances in miles from the Battery. Not shown are locations of sewers discharging a total of 8.8 m^3/s (200 mgd) of raw sewage from western Manhattan and a portion of Brooklyn. After Hazen and Sawyer (27) and Mueller and Anderson (37).

from buckets or pit latrines became overloaded and people began using drainage channels for disposal; 3.) ordinances were passed forbidding but not preventing placing of human wastes in drains; 4.) increased availability of water permitted introduction of flush toilets and cesspools; 5.) pollution of local ground water supplies from increasing amounts of water discharged to overloaded cesspools which "constituted a means of distributing fecal pollution over immense areas" (32); 6.) loss of local water supplies leading to even greater dependence on imported water; 7.) piping of dilute household wastes to storm drain and inadvertently creating combined sewers discharging into the Hudson, Harlem, and East Rivers, Raritan River, and the Kills (Figure 1); 8.) gradual construction of separate and combined sewers serving 18,032 hectares (44,557 acres) and 63,543 ha (157,015 ac), respectively by 1977 (2); 9.) local nuisances and possible public health risks, losses of fisheries, and other ecosystem damage first in the smaller rivers and embayments and, continuing to the present, throughout the estuary; 10.) beginning in 1924 treatment and removal from dry weather flows of putrescible materials which resulted in increasing amounts of sludge being disposed of at a convenient site about 12 miles seaward of New York harbor; 11.) enactment of Federal and State legislation mandating increased removals of solids (sludge) which will then have to be disposed of; 12.) increasing competition for space so that people increasingly object to other peoples wastes being dumped on or near them (their own wastes are bad enough); 13.) increasingly restrictive environmental protection mandates, and 14.) increasingly expensive and energy intensive remedial technological responses and proposals.

Similar technological development has occurred in industrial waste treatment. The common characteristic of both the municipal and industrial approaches is that water supplies have been developed and rate structures set with no regard for the costs of getting rid of the water; sewerage and industrial waste systems are designed and optimized with no regard for the costs of flushing water (note that the costs of sewage treatment are not those getting solids out of the water, but getting water out of the solids - the greater the dilution, the greater the cost). Cost figures are further distorted for both water supply and sewerage by failing to consider costs of unused capacity during all but the last year of the design period (30). Meanwhile, local, State and Federal fiscal practices have weakened some of the local institutions responsible for operation and maintenance (O&M)

It is the objective of this paper to summarize the costs and benefits of these conventional approaches. Emphasis is on sanitation, waste disposal, and water pollution and their technological, environmental, economic, and institutional interrelationships with water supply service levels.

BACKGROUND

Rapid population, commercial, and industrial growth of the New York metropolitan area began with 24,000 people in 1786 in lower Manhattan. Within New York City the most rapid growth rate was between 1900 and 1930; since then, population changes have been mostly internal ethnic ones. By 1970 the metropolitan area included Long Island, coastal and

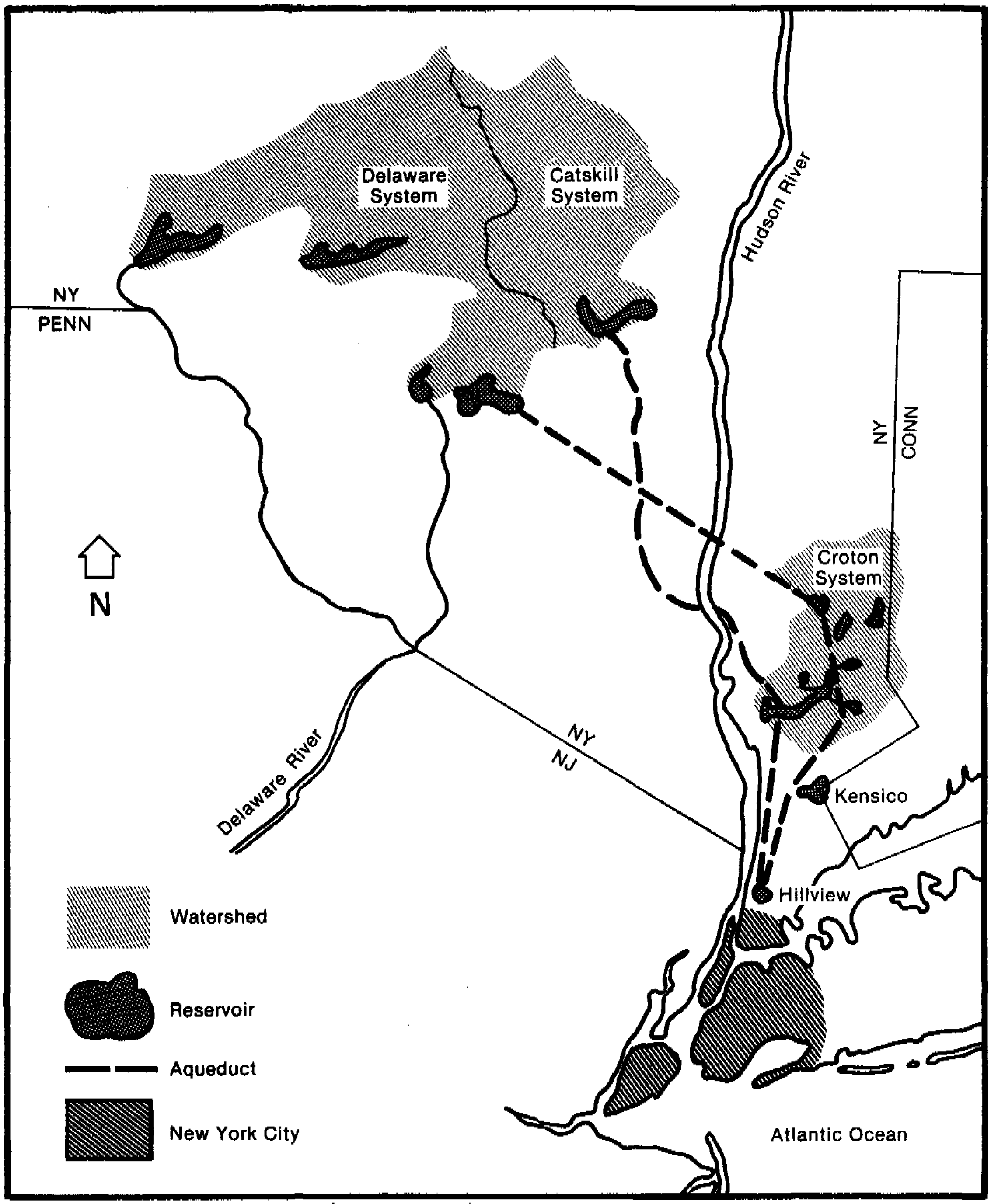

Figure 2. New York City water supply system. After Grossman (2]).

northeastern New Jersey, Dutchess County in New York, Fairfield and New Haven Counties in Connecticut, and 19.3 million people. This figure may reach 25.8 million by the year 2000 (31). 1977 population densities range approximately from $1/km^2$ ($3/mi^2$) in the lower Hudson Valley to $21,000/km^2$ ($67,000/mi^2$) in New York City.

While much of the economic activity in the New York Metropolitan Area is in the commercial, transportation and service sectors, manufacturing has increased steadily since 1939, with a shift toward fewer numbers of establishments and employees since about 1950. By 1972, 1.8 million manufacturing employees in the metropolitan area contributed over $28 billion worth of value added, approximately half from the chemical, publishing, and textile industries (37).

Water Supply and Demand

New York City's water systems are shown on Figure 2. The Croton System began delivery in 1842, the Catskill System in 1915, and the Delaware System in 1944. The aqueduct systems deliver about 1400 mgd to the City and 100 mgd to other communities. The City draws another 60 mgd from wells in Queens for a total of 1560 mgd (21). The safe yield of the aqueduct systems was assumed to be 1800 mgd (79 m^3/s) until the 1961-66 drought revealed a yield of about 56 m^3/s (1290 mgd) (11, 12). Other concerns for water supply include encroachment by urban development in the Croton watershed, by recreation pressures in the Catskills, and by increasing demands from Suffolk and Nassau Counties whose ground water supplies are threatened by pollution and salt water intrusion.

The distribution system begins with tunnels constructed in 1917 and 1936 from the Kensico Reservoir to Jerome Park and Hell View Reservoirs. Construction of a third tunnel which began 1970 has been plagued by tunneling difficulties and a default and lawsuit by the contractor for the first stage ($200 million) of a loop now estimated to cost $2.7 billion (40). The City's financial crisis has prevented completion of the first stage, estimated in 1978 to require $600 million and construction of an extension to lower Manhattan at another $600 million (21). The existing and proposed tunnel systems feed into 6150 miles (9900 km) of 4 to 96-inch (1.0 to 240 cm) diameter mains, many of which are deteriorating. Present condition of the aging system is indicated by 483 breaks repaired, 720 valves replaced, and 37.6 miles of pipeline replaced in 1976 (39). Data for comparison with four other water systems are listed in Table 1.

During the period of system expansion, demand for water increased to match the assumed supply. Most of the water is not metered (New York City is unique among major cities of the world in this regard) and total per capita consumption increased from 380 lcd (100 gcd) in 1900 to 660 lcd (175 gcd) in 1977 (11). System losses are unknown because of unmetered service and of leakage which has presumably increased since systematic leakage detection and control activities were suspended in 1955 (12, 13).

Per capita consumption in New York City is relatively high in comparison with other U.S. cities. Of 30 cities with populations of

Table 1. Comparative Data for Five Major Water Systems

	Year	Miles of mains	Number of breaks	Mains replaced, miles	Tariff $/2000 ft^3	Immedi-ate capital needs(a)	Condition of system	Leakage detection program	Percent leakage
Cincinnati	1978	3900	723	2	$6.00	-	Good	Yes	11
Cleveland	1978	6900		negl.	6.37(c)	$42m	Major deficiencies	No(d)	24
Dallas	1978	3770	2234(b)	negl.	17.23	-	Good	Yes	3
New York	1976	6150	483	38	21.00	60m	Reasonably good	No(e)	8 to 25(f)
Washington	1980	1440				25m/y			

Sources: City of New York, Bureau of Water Supply (39)
Grossman (21)
Humphrey et al (28)
Wilson (52)
Personal communications, Messr. Ed Zima and John Neal, City of Cleveland,
Richard Koopman, City of Cincinnati

Notes:
(a) Needs due to deferred maintenance
(b) Usually 1400 to 1800 due to corrosive or heaving soil and too rapid temperature changes in terminal reservoirs
(c) $4.60 prior to June 1976
(d) Suspended 1978, scheduled to resume 1981
(e) Suspended 1955, scheduled to resume 1981
(f) Unpublished estimates vary according to source. Note that residential water is not metered. Leakage from tunnels is considered a major problem.

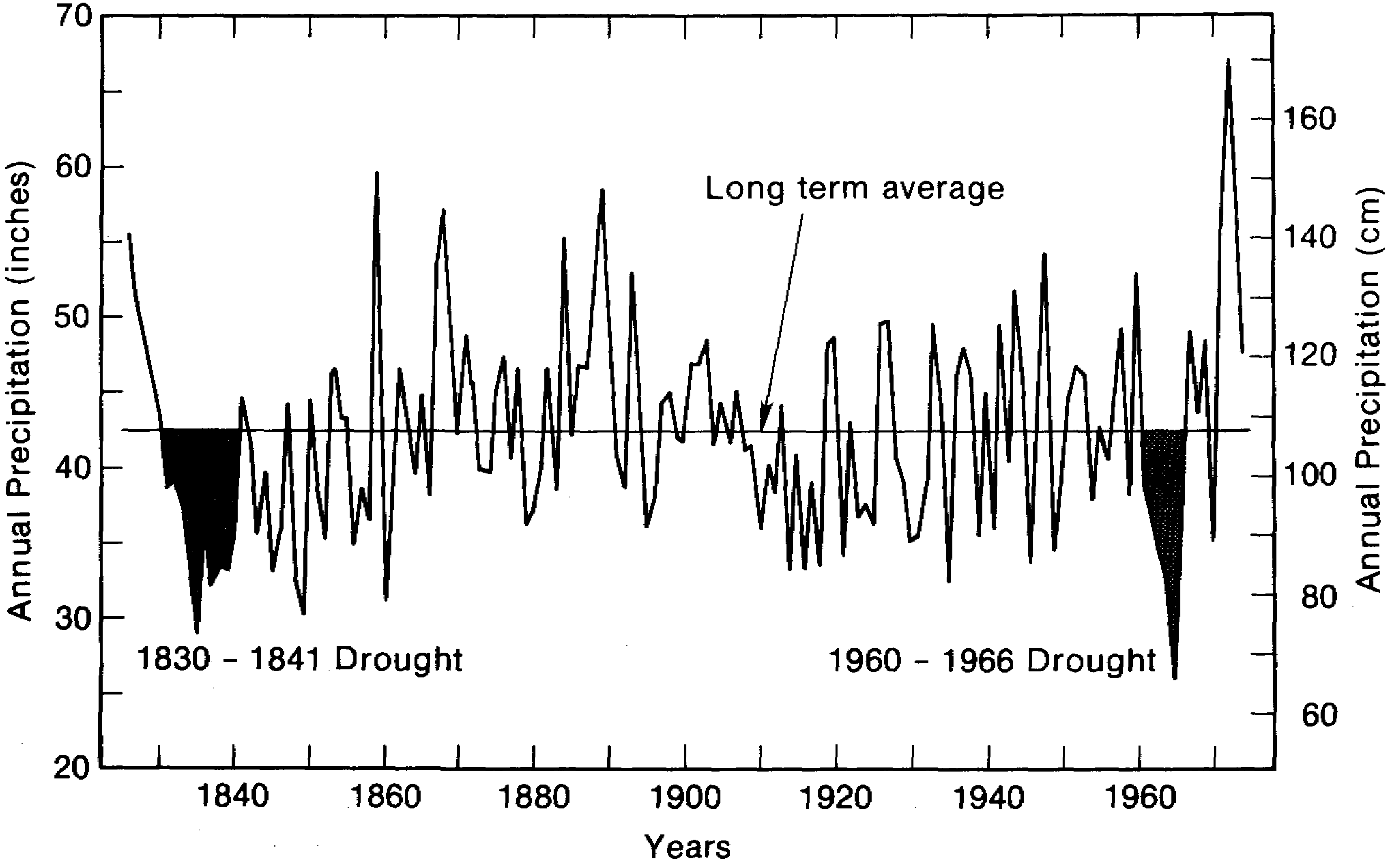

Figure 3. Rainfall in Central Park, New York City. After Corps of Engineers (12).

250,000 or more, the 1960 domestic consuption in New York of 338 lcd (89 gcd) was exceeded only by Cincinnati with 347 lcd (92 gcd) from local Ohio River sources and by Los Angeles (365 lcd or 96 gcd) and Denver (550 lcd or 145 gcd). Like New York City, Los Angeles and Denver rely largely on imported supplies but receive less than 40 cm (16 in) per year precipitation compared to about 120 cm (48 in) in the New York metropolitan area. Other cities in the comparison used from 138 to 291 lcd (36 to 77 gcd) with mean and median values of 212 lcd or 56 gcd (13).

At the time of writing (February 1981) another drought is in progress. Reservoir storage on January 7 was 35 percent of capacity, approaching the 29 percent figure which characterized the 1965-66 drought period. More severe droughts can be expected. Figure 3 shows that from 1830 to 1858, cumulative annual precipitation was far below that for any subsequent period. Numerical integration of precipitation deficiencies reveals that the precipitation deficit during the drought of 1830-41 was almost twice that of 1960-67. If these Central Park data are representative of the watershed, they indicate a further potential reduction of safe yield to some 900 mgd.

Based on a return period of 100 to 150 years for the drought of the 1960's, the Corps of Engineers prepared plans (12) to overcome temporary shortfalls of 102 lcd (27 gcd) at a 1976 cost of $3.7 billion ($4.9 billion 1980 dollars). The plan recognized, but did not consider water conservation measures which, in 1965 and 1966, reduced consumption from the 1960 level of 570 lcd (150 gcd) to 480 (127 gcd). Potential water conservation measures published by the Corps could yield 23 (6 gcd) from metering, 11 lcd (3 gcd) from leakage control, 15 lcd (4 gcd) from domestic conservation devices, and 68 (18 gcd) from drought contingency measures for a total of 117 lcd (31 gcd) by the year 2000 for New York City. In contrast, Bollman (6) reported conservation during the 1976-77 drought in Marin County resulted in reduction from 462 lcd (122 gcd) to 132 lcd (35 gcd). An additional reduction of 265 lcd (70 gcd) is pre-dicted to result from industrial recirculation mandated by PL 92-500. Following conventional engineering practice, the Corps (12-15) disregarded even these minimal potential savings and predicted an increase in service levels from a 1970 level of 670 lcd (177 gcd) to 685 lcd (181 gcd) in the year 2000. These figures yield average water uses of 61 m^3/s (1400 mgd) in 1970 and 67 m^3/s (1530 mgd) in the year 2000.

The Corps' extrapolations of water consumption are based on average values. Year-to-year variations are shown on Figure 4. Historical decreases in water use correspond roughly with drought and/or wartime emergencies. Long-term trends of the sort shown on Figure 4 lead to such responses as: "... We must think ahead today for the future is tomorrow. It is predicted that within the next 25 years, at the turn of the 21st century, the world population will double from the present four billion to about eight billion people. That's an increase of nearly 400,000 persons every DAY. And everytime population doubles, water use TRIPLES.....where is all the water coming from? From research, that's where!......" (24). Perhaps, although conservation has obvious economic advantages, particularly when the costs of waste disposal are considered. Even though the latter have been shown to be 5 or 6 times those

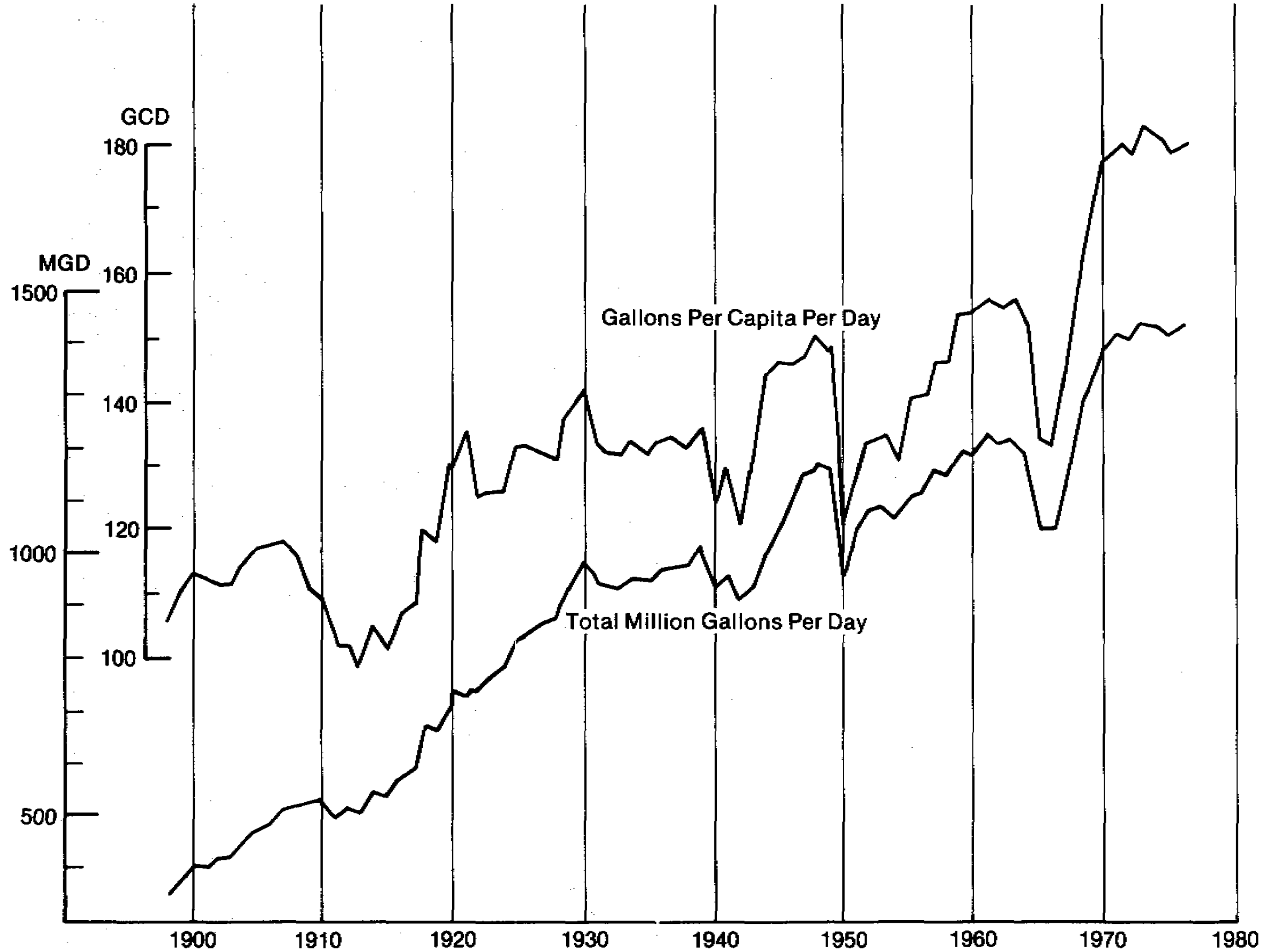

Figure 4. Total and per capita New York City water supply. After Corps of Engineers (12) and New York City Bureau of Water Supply (39).

of supplying the water (30), these costs are ignored in designing and setting rate structures for water supply. Similarly, federally financed Section 208 studies (Public Law 95-200, as amended) of sewage disposal requirements neglect both the marginal costs of flushing water and the long-range plans of water-supply agencies (27). These separate approaches may be consistent, but they are inherently expensive.

The physical condition and adequacy of New York's water system are a matter of increasing concern (Grossman). The increasing age of the system, continuing reductions in manpower for operation and maintenance, 25 years without a leakage detection program, the uncertain condition and imputed leakage of the existing tunnels, a lack of metering, and consequent inability to determine actual system losses and to charge for actual water delivered, a backlog of capital program needs for system replacement, and now another drought have led to increased calls for Federal funds to complete construction of the third tunnel shown on Figure 5 (40). Although water systems are ordinarily considered among the most viable of municipal infrastructures, these calls for external funds are increasing throughout the world. Even when they are successful, because of their emphasis on construction rather than O&M, the calls result in further weakening of local institutions and infrastructures (see paper on Istanbul in this volume by Cuellar and Vogel). Assessment of conventional emphasis on supply rather than demand and upon construction rather than conservation is presented later in this paper.

Financial and institutional improvements came slowly. Public water supply in New York began in 1658 when Dutch settlers dug a well for public use. In 1664, the British occupied the city and continued to develop ground water which became notoriously foul by 1748 (56). The Manhattan Company was chartered by the Legislature in 1800 at the behest of Aaron Burr to provide fresh water, banking, and investment services to the city. While the company was well served by the latter, the public was not served by the former. Most of the better water was sold by vendors to those who could afford it (5). In 1835, frequent fires and warm weather outbreaks of enteric diseases prompted the citizens and their Common Council to finance the Croton System which, beginning in 1842, promptly put the Manhattan Company out of the water business. Completion of the system was delayed by political battles fought with technological arguments. Local Democrats prevailed in their insistance on the use of cast-iron pipe while Albany Whigs succeeded in imposing a high (rather than low) bridge over the Harlem River. The Croton Aqueduct and distribution systems cost $10.3 million, almost twice the estimate (33).

In 1905, the Board of Water Supply and the Bureau of Water Supply assumed responsibility for design and construction and for operation and maintenance, respectively. Revenues and expenses, capital and recurring, are both part of the general city budget. Bonded indebtedness as of June 1977, the period of the city's financial crisis was $728 million (21). O&M funds are acknowledged to be less plentiful than capital funds (88). Fiscal year 1977 expenses were $137.6 million of which $48.4 million was for O&M. Corresponding revenues were 201.7 million (34). Revenues clearly exceed expense, but at the cost of system main-

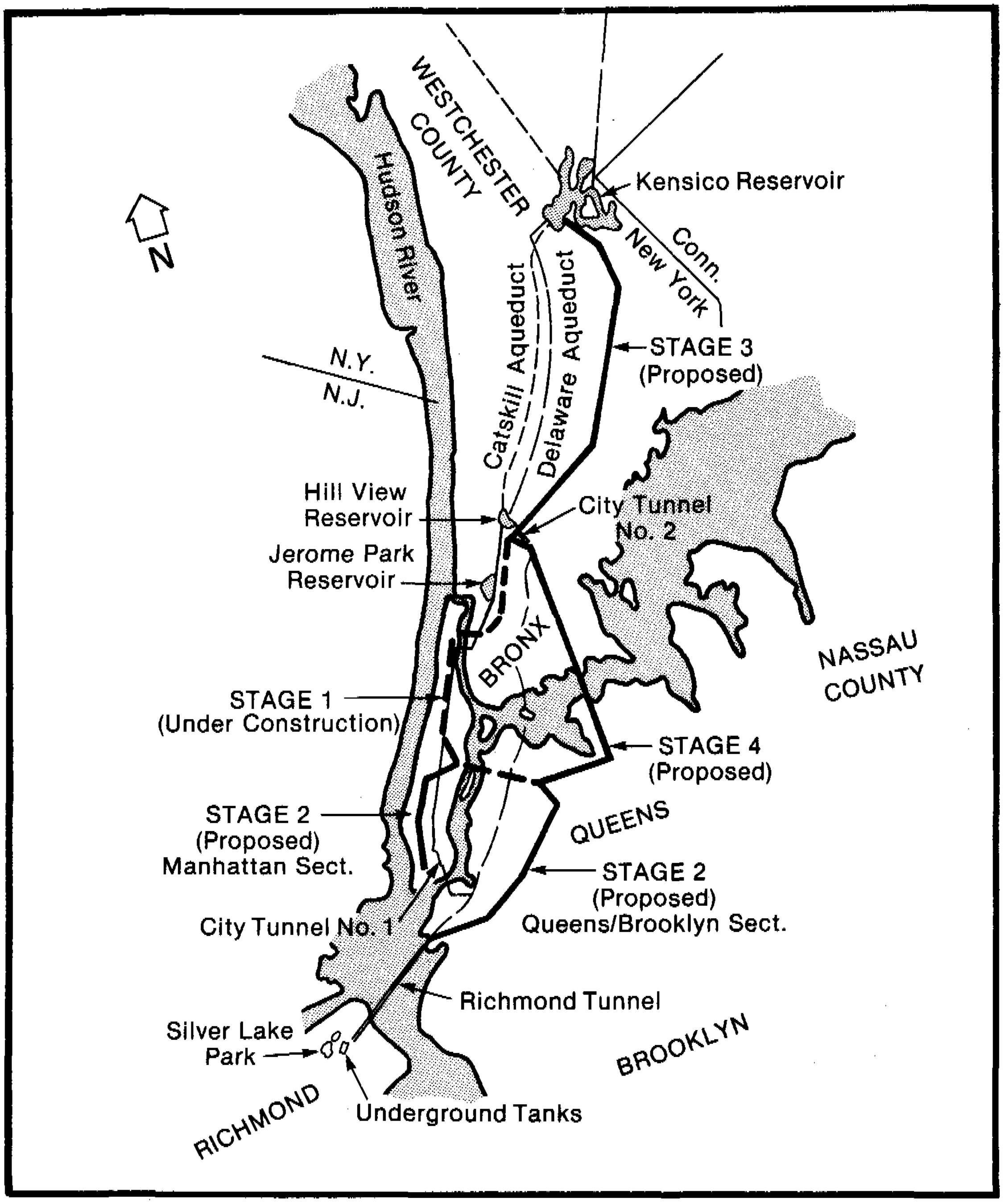

Figure 5. Water supply tunnels. After Grossman (2]).

tenance so that a 1979 estimate of critical capital needs was 1 billion for mains and $1.1 for completion of the third tunnel (more recently estimated at 2.7 billion (21, 40).

SEWERAGE AND WATER POLLUTION

Sewerage

Combined sewers have, since about 1830, been the rule in New York City. By 1950, there were 130 km (80 mi) of sewers for 700,000 people mostly in Manhattan (50). Since then the system has grown to 9900 km (6200 mi) of sewers with some 90,000 catch basins. Locations of major municipal discharges have been presented on Figure 1.

Mueller et al. (35, 36); Gross (20); and Hazen and Sawyer (27) have compiled information on waste loadings (which derive from both water supply and storm flows) to the New York Bight. In 1972, 127 major municipal discharges contributed 114 m^3/s (2,600 mgd) of sewage of which 21 m^3/s (480 mgd) were untreated. By 1978, the untreated sewage had been reduced to 9 m^3/s (200 mgd). 1972 industrial discharges process amounted to 27 m^3/s (610 mgd) of which 47 percent went through municipal systems. Another 210 m^3/s (4800 mgd) of cooling waters were discharged. Of the total, New York City discharged 59.8 m^3/s (1410 mgd) of treated sewage and 8.8 m^3/s (200 mgd) of raw sewage (Table 2).

Sludge from the treatment plants, amounting to 6 million tons (5.5 tonnes) in 1979 was dumped 12 miles from the entrance from New York Harbor into the New York Bight (Figure 1). With 5 percent solids, the sludge accounts for 5 to 15 percent of the pollution loading of the Bight, depending on the parameter measured. Most of the pollution comes from the Hudson River outflow and from dredge spoil dumping 5 miles west-southwesterly from the sludge site. Nevertheless, the USEPA has mandated a ban on the sludge dumping after December 31, 1981, by which time greater solids removals at treatment plants will have increased the amount of sludge to 9 million tons (8.2 tonnes).

The mandate is based on equity policies which require 85 percent removals of BOD and suspended from sewage and hence from all receiving waters of the United States, whether fresh, brackish, or salt. It is not based on efficiency since no measurable improvements are expected in New York Bight water quality.

A minimum estimate of average annual costs in 1980 dollars of the present conventional approach to New York metropolitan area sewerage is $1,050 million. This is based on an estimated $2 billion in construction costs since 1950 and another $3 billion required by the year 2000; an annual capital recovery factor of 10 percent (equivalent to 8 percent interest for an average service life of 20 years, to 9 percent for 27 years, etc); annual O&M costs at 30 percent of capital costs; plus $400 million per year marginal costs of 25 to 30 gallons of water per capita per day (11) used to flush only the sanitary portion of the wastes. In spite of these expenditures, degradation of receiving water quality apparently continues. Increasing competition for fiscal and other

Table 2. New York City Sewage Discharges(a)

Location (Fig. 3)	Treatment Plant	First year	1972 Flow(b) m^3/s	mgd	% Indus- trial	Treat- ment (c)	Tributary population 1975
A	Tallman's Island	1938	3.1	70	2.6	S	405,000
B	Bowery Bay	1942	5.6	128	6.8	S	698,500
C	Hunts Point	1952	7.0	160	0.9	S	717,200
D	Wards Island	1936	11.0	245	1.0	S	1,278,400
E	Newtown Creek	1967	13.0	300	6.8	MA	968,300
F	Owls Head	1952	4.4	100	1.3	MA	720,800
G	Coney Island	1935	4.4	100	0.3	MA	692,900
H	26th Ward	1945	3.5	80	1.6	S	338,200
I	Jamaica	1943	4.4	100	2.1	S	573,500
J	Rockaway	1952	0.9	20	0.1	S	118,700
K	Oakwood Beach	1954	0.9	20	0.01	S	156,600
L	Port Richmond	1953	1.6	36	14.	P	171,600
M	Sewage sludge ocean dumping site						
	Total		59.8	1409			6,839,700

Note: (a) After Mueller and Anderson (35, 36, 37)

(b) Not including 8.8 m^3/s (200 mgd) raw sewage from Manhattan's West Side and from a portion of Brooklyn

(c) 1980 treatment: P - primary; MA - modified aeration; S - secondary resources clearly indicate a need to examine alternative institutions and technologies for New York metropolitan area waste management.

Seventy-five percent of conventional construction costs (or 82 percent for those portions identified as innovative technology) are borne by the Federal Government, 12½ percent by the State of New York, and the balance by the City. The City has been unable to raise its share of construction costs on schedule so that there have been construction delays. It has also been unable to raise adequate operation and maintenance funds to maintain existing sewers and treatment facilities, resulting in various recommendations for Federal assistance in annual O&M funding. O&M funding for sewerage facilities is particularly vulnerable during periods of declining or even steady-state economic conditions and is often diverted to more visible activities. The resulting lack of maintenance activities, staffing, supervision, and laboratory control is revealed in effluent quality which falls far short of the engineering design assumptions (18, 51).

The above costs do not include those to either government or industry for control of toxic or hazardous substances now discharged as industrial wastes or by the consumer into the sewerage system. Presently mandated, although not yet achieved, source control measures will eventually reduce discharges of these materials to the New York Bight. In the near term, toxic materials stored in river and estuarine sediments will continue to be released to the water. Also, in spite of large investments in conventional sewerage systems made since 1950 and scheduled by the year 2000, the total loadings of BOD and suspended solids to the Bight have and will remain essentially constant (1).

If the environmental benefits of Federal and State funding for construction of conventional sewerage systems are elusive, the institutional consequences are not. Funds from Washington and Albany are welcomed as public works programs that provide local employment. While they may (with some reservations) be considered as entitlements, they are not free since both Federal and State governments, here as elsewhere, must stay in fiscal steady state to stay in office. It is a zero-sum game (49). Sewerage system construction grants represent tradeoffs with other regional and local uses of these funds and in any event carry with them a mortgage on the future because of their requirement for local operation and maintenance funds. The worst part of the problem, here as elsewhere (17, 21, 28), is that when these and other infrastructures have deteriorated sufficiently to require major replacement (construction) programs, they once again become eligible for Federal assistance. Both the infrastructures and the institutions responsible for financing and carrying out operation and maintenance are thus weakened.

It does not follow that receiving water quality should not be protected. However, progress in reducing pollution in the metropolitan area has been mixed.

<u>Estuarine Pollution</u>

The conventional oxygen balance approach to sewage treatment and

Table 3. Estuarine Pollution in the New York Harbor Area

Transect (Fig. 1)	Dissolved Oxygen, mg/l		Fecal Coli per 100 ml		Total Kjeldahl Nitrogen mg/l		Phosphate-phosphorus, mg/l		Zinc, µg/l		Cadmium, µg/l		Copper, µg/l	
	Mean	Mean of lowest values	Mean	Mean of highest values	Mean	Mean of highest values	Mean	Mean of highest values	Mean	Mean of highest values	Mean	Mean of highest values	Mean	Mean of highest values
Hudson River	5.0	2.0	800	10000	0.8	1.0	0.3	0.4	48	140	2.0	5.5	5	10
Kills	2.5	0.7	8000	50000	1.9	2.3	0.6	0.7	80	110	1.8	4.0	15	22
Harlem River	2.0	1.0	10000	100000	1.3	1.3	0.8	1.3	5	7	<1	<1	10	11
East River	4.0	2.0	900	7000	0.8	1.0	0.6	0.9	30	60	<1	<1	<5	10
Hackensack River	3.0	2.5	7000	10000	1.8	1.9	0.5	0.6	75	90	1.8	2.5	25	37
Raritan Bay	6.0	4.0	100	500	1.1	1.5	0.4	0.4	50	130	<1	<1	5	9
Jamaica Bay	6.0	4.0	300	1100	1.0	2.0	0.3	0.4	35	50	1.0	2.0	<5	5
Rockaway Beach	7.0	7.0	30	70	1.3	2.3	0.3	0.3	20	20	4.0	8.2	5	15

Notes:

1. D.O., F. Coli, and NO_3-N data obtained during Summer, 1977
2. PO_4^5-P data obtained during September, 1975
3. Heavy metals data obtained during Winter, 1976
4. Any "<" implies that the data obtained was below the limit of detectability

Source: Hydroscience, (1978) in Hazen and Sawyer (27) stream sanitation has been established for some 60 years (46). It relies upon BOD and suspended solids removals by treatment, provides fish in streams with necessary oxygen, and is unrelated to pathogen survival (16, 30, 45, 53). The latter came as a surprise to City officials during the 1950's and 60's when major treatment works began to remove increasing amounts of BOD and solids. Harbor D.O. levels increased as expected. So did coliform levels. The reason for this was that the suspended solids containing coliforms were reduced only slightly while the effluent suspended solids with which the remaining coliforms were associated in effluent concentrations had slower settling velocities in the receiving waters. The remaining coliforms lingered longer and increased the numbers of survivors in the harbor. Effluent chlorination became the standard treatment for coliforms and presumably other pathogens.

Meanwhile, oxygen levels have improved although they are still low in some areas. Figure 1 shows locations of estuarine transects for which present water quality values are listed in Table 3. Mean values for dissolved oxygen concentrations are as low as 0.7 mg/l in the Kills and 1.0 mg/l in the Harlem River. High Kjeldahl nitrogen and phosphorus levels are found in the Kills, Jamaica Bay, and Hackensack River. Mean high concentrations of heavy metals occur throughout the estuary, with 140 mg/l Zn in the Hudson River, 8.2 mg/l Cd and 10 mg/l Cu at Rockaway Beach, 37 mg/l Pb in the Hackensack River, and 50 mg/l Ni in the Kills. The Hudson carries average and high concentrations of 0.1 and 0.2 ug/l of PCB's mostly resuspended from bottom sediments contaminated several years ago by discharges from General Electric's transformer plant (10).

Bacteriological pollution is greatest in the Harlem River with up to 100,000 fecal coli/100 ml. Steady-state levels of coliform pollution explained by times of 40 to 70 hours for 90 percent reductions due to net mortality and sedimentation. Coliforms ordinarily disappear much more quickly from marine surface waters except for areas such as the mouth of the Rhine where they are resuspended by waves, currents, and ships propellors from contaminated bottom sediments (22, 26, 45).

Shoreline Pollution

Surf zones and beaches are polluted by enteric bacteria in the water and by floating and stranding material from sewers and other sources of anthropogenic flotsam. It does not come about by the resuspension and shoreward transportation of sewage sludge dumped offshore. Nearshore coliform bacteria concentrations reflect proximity to waste discharges and differences in sampling, analytical procedures, and methods of data analysis and reporting. Differences between years at infividual stations are due to changes in waste treatment and in runoff. Coastal waters generally meet bathing water standards.

Public health benefits of ocean bathing water protection are elusive. Nevertheless, bacteriological standards have been applied, beginning with the California bathing water standard of 1000 total coliforms per 100 ml for at least 80 percent of the time (19). This is comparable to the current USEPA guideline of a mean fecal coliform density of 200/100 ml. The California standard has been copied or adapted through-

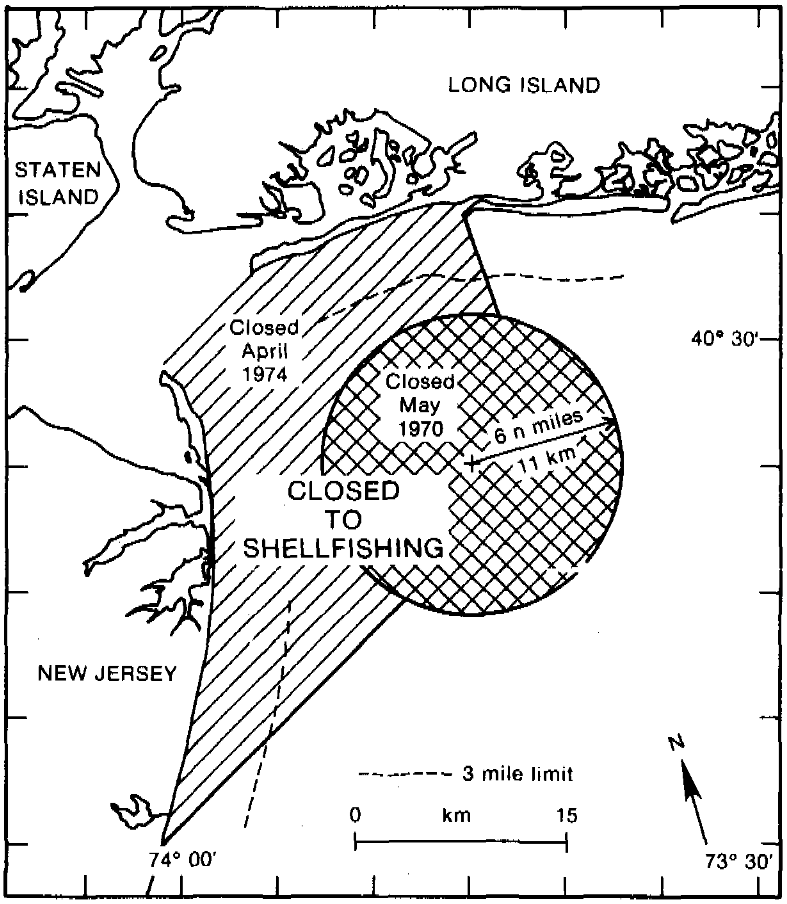

Figure 6. Nearshore areas closed to shellfishing because of pollution.

out the world although it is strictly applicable to populations with low incidence of disease. Recent work by Cabelli and his associates in the New York Bight and elsewhere provides a measure of the risk involved in swimming in polluted water. A low incidence of subclinical respiratory and gastro-intestinal symptoms varies with bathing water pollution and population immunity at New York, Boston, Lake Ponchartrain, and Alexandria, Egypt (9).

Occasionally severe shoreline pollution is due to stranding of floating materials of obious sewage origin. In June 1976, beaches were closed because of materials from storm water overflows and from explosions of two sludge storage tanks on Long Island. The latter spilled 1 million gallons of sludge into the water including an unknown amount of floatable plastics, rubber, and grease balls which had accumulated in the tanks for 12 years, into the water. Decisions to close or reopen beaches were not based on bacteriological monitoring of surf waters. While precise contribution of the sludge tanks is unknown, the event clearly reveals the narrow operating margin within which sewerage systems can handle materials manufactured with no regard for their disposal. As a result of the incident, one manufacturer changed from plastic to biodegradable tampon applicators.

Neashore Pollution

Bacteriological contamination of shellfish has resulted in the quarantine of areas shown on Figure 6. The circular area is centered on the sludge dumping site and the shoreward areas are affected by the estuary. Within New York Harbor, shellfisheries and finfisheries have long been affected by bacterial and chemical pollution.

Further offshore, oxygen depletion in bottom waters was observed in five summers during 1968-76. In 1976, much of the nearshore area was anoxic (Figure 7). Swanson and Sinderman (47) described the event. Mass benthic mortalities occurred over approximately 8600 km^2 (2500 $n.mi^2$) along the New Jersey coast. Surf clams, ocean quahogs, finfishes, lobsters and sea scallops (in decreasing order) were most affected. Immediate losses were estimated at $7.9 million for commercial fisheries and $3.7 million for sport fisheries. The kill was attributed to a combination of atypical natural events in spring weather, plankton (Ceratium tripos) blooms, Hudson River runoff, bottom water upwelling, ocean currents, water stratification, and decaying plankton in bottom waters. While sludge dumping was not a factor, excess nutrients in New York Harbor outflows could have contributed. However, there is slight evidence of a gradual decrease over the last 10 years in bottom D.O. and,

> "...the sensitivity of the system might therefore be changing such that a slight imbalance (either due to natural causes or increases in waste loadings) in the 'normal' cycle of environmental conditions is sufficient to drive the system towards anoxia with increasing frequency. If this is true and if the slight decreasing trend in bottom D.O. over the last three decades is real and monotonic, then there is an increasing probability of low D.O. events in any year..." (44).

MONITORING AND REAPPRAISAL

O'Connor's (44) warning is sobering. It comes at a time of increasing competition for resources and a decreasing margin for error in allocating them. It is a reminder of the need for integration of monitoring environmental, fiscal, demographic, technological and institutional change so that policy and its implementation are appropriate. An operational definition of monitoring is that which measures those things to which there is a response. Flexibility and efficiency maintained by keeping the number of parameters, sampling frequency, sampling points, etc., to an essential minimum.

Environmental Monitoring

Environmental monitoring includes pollution effects monitoring such as that required for compliance with bathing water or shellfish standards. It also includes ambient or imprecisely defined ecological monitoring. Although many ambient monitoring data are collected, very few are used, exceptions being use of filtered or otherwise selected monitoring data for research or for demonstrating hoped-for improvements after a remedial program in water supply or waste disposal has been implemented. Water management and operating decisions are based primarily on other considerations. It follows that analytical quality control (AQC) programs add a further degree of refinement to environmental measurements in operational monitoring activities. (It seems that there are no examples where AQC in ambient measurements have made a difference in management or operating decisions). Reasons for failure to use ambient monitoring data include failure to commit resources for data management, assessment, and dissemination, failure to identify the operational use of the data, blurring of the distinction between research and monitoring, and inflexibility of monitoring programs where employment security is traditional.

Successful monitoring and prediction require system understanding based upon previous research and observation. Fixed - term baseline investigations of waste discharges and effects usually provide the criteria for pollution control policy development, for legislation and regulations, and for design, construction and operating criteria of treatment facilities.

A Reappraisal of Costs, Financing and Benefits of Conventional Sewerage.

Cost and pollution data presented in earlier paragraphs reveal that the benefits from an estimated $1.05 billion in annual costs are at best elusive. Clearly a reappraisal of current water supply and waste disposal practices is in order. Some of this is already taking place. The present drought is resulting in challenges to the dogmas that water metering for New York is politically impossible and that metering leakage detection and control, and conservation measures are not cost-effective. New York's mayor has ordered a study of water metering in unfinished apartments (43); the city is shutting off water in vacant apartments from which faucets have been stolen and is repairing fire hydrants (41) penalties are imposed for washing cars, driveways, or buildings with a hose, for ornamental use of water, or for serving water in

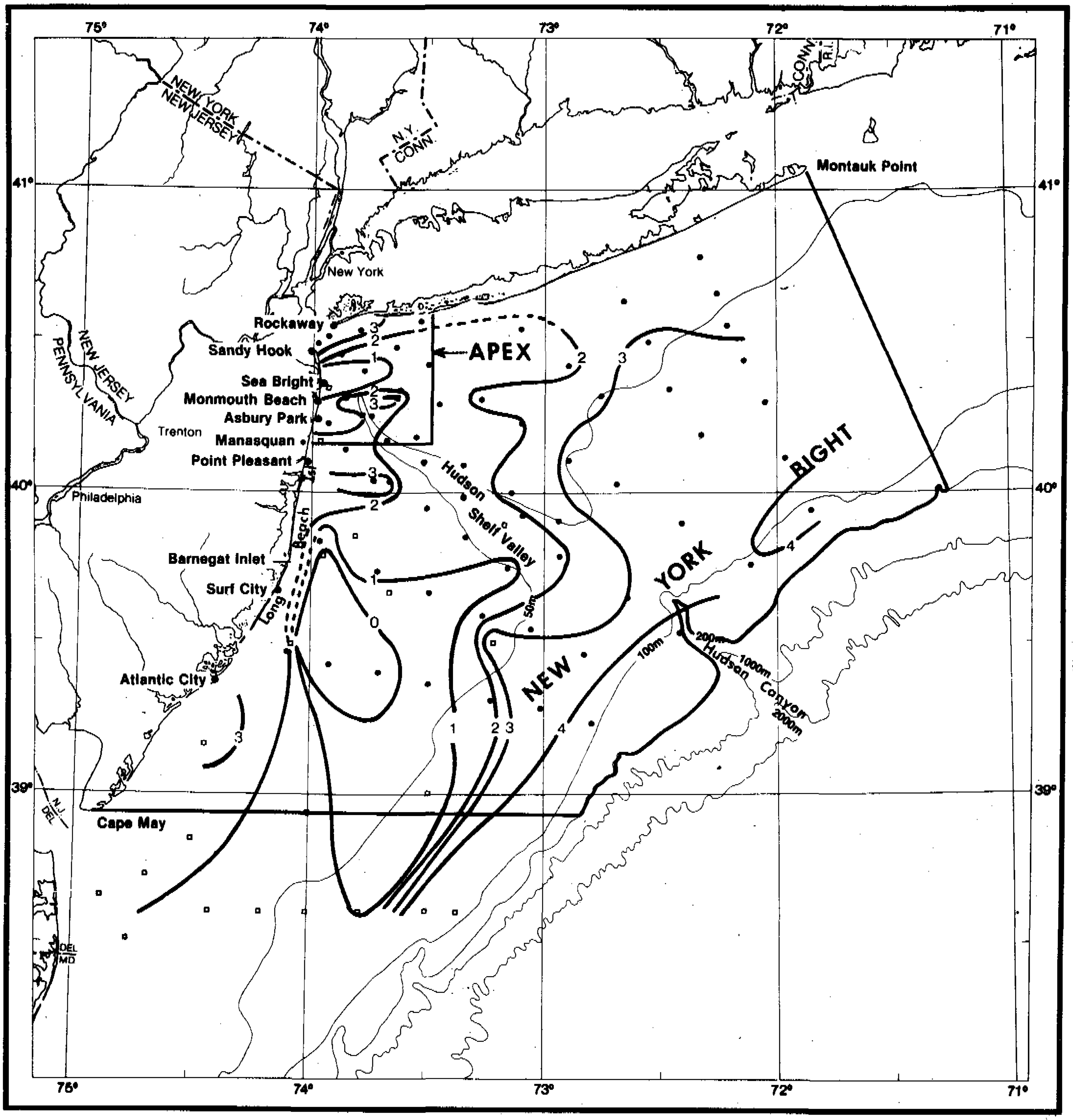

Figure 7. Oxygen depleted bottom water in New York Bight, August-September 1976. Oxygen content in ml/1 (note: 1 ml/1 equals 1.43 mg/1). From Swanson and Sinderman 9470.

restaurants unless specifically requested (42); and using harbor water for some fire-fighting (43) There are other institutional and technological options such as increasing block tariffs for metered water, dual systems for water supply, and separate systems for disposal of black and gray water (the latter may be a potential health problem, but it is a very low priority one for which no epidemiological support has been found (30).

An essential point is that conservation provides the least cost and most immediate source of additional water. Another is that the even greater costs of sewage collection and disposal are saved. The cost is the loss of the convenience or privelege of using much more water per capita than the vast majority of people in North America or Europe. Whether the loss of this privelege may be temporary and therefore superficially acceptable remains to be seen (7).

There are both analogs and paradigms for popular acceptance of variable service levels in water supply and waste disposal during climatic or economic droughts. One of the best documented analogs is from the history of transportation. The wheel is considered a landmark discovery of civilization. Nevertheless, the cost of maintaining roads throughout North Africa and the Middle East from Morocco to Afghanistan between the third and sixth centuries AD was high. As a result, the lower technology but economically superior camel replaced the wheel for about a thousand years (8). Paradigms include droughts that have caused temporary or sustained reductions in water use, and in extreme cases permanent population shifts. The latter include those in California in 1966-67 (6) and in the North American mid-west during the 1930's in the Sahel during the 1970's, and in Egypt during the third millenium BC (where Bell (3, 4) reports that written records and hence civilizations disappeared after two separate droughts of about 20 and 100 years).

Finally, the unique requirements for community sewer systems are revealed by their having been developed during only three periods in history. Each of these periods was one of extraordinary economic growth. The Roman Empire received, from the 4th century B.C. through the 1st century A.D., ever greater resources from North Africa which were used to finance aqueducts and drains. The Roman Cloaca Maxima was constructed about 200 B.C. to drain surface and ground water from the Colosseum and the Forum areas and is still in use (interestingly, Lewis Mumford (38) presents the Cloaca as a paradigm of Roman engineering, waste and decadence. 19th Century England utilized revenues which formerly went to the East India Company to implement recommendations for bringing water to tenement areas not to drink but to flush wastes. The third period is during the mid-20th Century's unprecedented economic development of North America and northwestern Europe. A major source of this recent wealth was cheap petroleum energy whose supply was controlled by the corporations of industrial countries.

In any event, continued urbanization (31) of the northeast coastal region will, with conventional practices in water supply, utilization, and disposal, result in increasing severity and frequency of environmental crises. These crises can be minimized by developing analytical tools for predicting economic, social, and evnironmental impacts of alternative strategies for waste management. However, waste management is only one element of resource management. Other elements, with examples of policy options to deal with them, are as follows.

Scale and coordination. Economies of scale are usually achieved by loss of redundancy and system resilience so that small perturbations cause greater total damage as system size, regionalization, and interdependency increase. This increase is accompanied by (and possibly causes) increasig compartmentalization of planning effort. For example, the 1977 Northeast Water Supply Study (11-17), makes no reference to the costs of disposing of additional water for the New York City. Similarly, the 1978 City of New York Section 208 (PL 92-500) Area Waste Treatment Management Planning program (27) makes no reference to disposal costs for the planned increase in water supply or to the costs of flushing water. It is probable that institutions exist at all levels which could develop needed coordination; that they are not used suggest problems of local jurisdictional boundaries. These may be resolved with coordinated guidance from the 14 Federal agencies involved with the 418 local, State, and interstate agencies concerned with the New York Bight (26). However, local participation and direction is essential to avoid the problems of scale described above.

Service levels and willingness to pay. During periods of rapid economic development such as 1950 to 1973, willingness of beneficiaries to pay for improved service levels and convenience has generally been assumed by engineers, planners, and administrators. Unfortunately, the costs of convenience are rarely, if ever, borne entirely by the beneficiaries; water-carriage waste systems do not imply or require equity. Insofar as water supply and sewerage are concerned, policies leading to reevaluation of major household water uses (including flush toilets, garbage grinders, dishwashers and washing machines), commercial and industrial applications, dual supply and disposal systems, close matching of capacity to demand, proper costing of unused capacity, and conservation of materials, energy, and space lead to a variety of technological alternatives and minimum economic (including social) costs. Institutional alternatives include metering and increasing block tariffs, and greater involvement of individuals and communities in system planning in order to provide adequate and equitable water and sanitation services.

CONCLUDING REMARKS

The few policy, economic, institutional, and technological options which have been identified above are only a sampling of alternatives to the conventional approaches to waste disposal in the New York metropolitan area. While additional research and observation are needed in many areas, improved definitions and practices in system monitoring and reappraisal should go far toward realizing potential technological and economic improvements.

Meanwhile, a useful analytical tool in project appraisals is to consider the fit of benefits and costs to a logistic curve. The basic model has been developed by Shuval et al in studying the effect of water supply and sanitation investments on health benefits (45), but is equally applicable to amenities and other cultural values. The model reveals that first stage investments have low benefit: cost ratios but are necessary to implement second-stage improvements with high ratios. The third stage, in which the logistic curve flattens and benefit: cost ratios decrease, represents for example, luxury consumption of water and increasing costs of waste disposal. Shuval's approach permits rigorous comparisons of alternative policies and projects in waste management. It also provides for assessment of the cost-effectiveness of the estimated $1.05 billion per year being spent on conventional sewerage.

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DESIGN GUIDELINES FOR LOW-COST WATER AND SANITATION

by

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ABSTRACT

Design standards for water and sanitation systems fall into two categories (1) level of service and (2) technical efficiency. The level-of-service problem is to decide system characteristics, and the technical efficiency problem is to satisfy target service levels at minimum cost. The guidelines herein re optimal levels of service are based on an analysis of incremental costs. Technical efficiency can be obtained by using the computer with mathematical optimization. The per capita construction cost of water networks depends on population density, design flow, and number of persons per service. For standpost systems, persons per service is the most important variable; its cost elasticity factor is about -0.3. For house connection systems, per capita flow is the most important variable; its cost elasticity factor is about +0.5. Yard faucet water systems have about twice the cost of public standpost systems, single house tap systems are twice as expensive as yard taps, and full plumbing systems cost twice as much as single house taps. If a water system is to be upgraded from standposts to house connections within 5 years of initial construction, the initial facilities should be planned with sufficient capacity to meet ultimate demands; otherwise capacity should be provided in stages. For each year of delay in upgrading from standposts to yard or single house taps, the savings in present cost over providing the higher service initially is about US$1 or 2/capita. The savings in present cost due to delaying upgrading to full plumbing is about US$3 to 5/capita.

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During the past few years, preparation has been underway for the International Drinking Water Supply and Sanitation Decade, which was officially launched in fall 1980 at a meeting of the United Nations General Assembly. Meeting the overall goal of the Decade of providing adequate water supply and sanitation for all the world's inhabitants by 1990 will cost hundreds of billions of dollars, even by conservative estimates. Such costs are prohibitive: neither the developing countries nor international donor or lending institutions have sufficient financial resources, and even if they did, the beneficiaries in most cases could not afford to repay the loans. As a result, low-cost "appropriate" technologies that provide lower levels of service than those used in the economically advanced countries must be used.

A broad decision to employ low-cost water supply and sanitation technologies raises difficult questions for planners and engineers. What are the alternative technologies that can be used? (e.g. public standposts and yard taps for water supply? pour flush toilets and ventilated improved latrines for sanitation?) What are the appropriate standards for these technologies? (e.g. how many persons per standpost? what minimum size pipe in water and sewer networks? what minimum allowable pressure in water pipes and minimum allowable velocity in sewers?) How can engineers quickly and efficiently design systems to meet these standards?

The World Bank has sponsored several research projects on design guidelines and standards for appropriate water supply and sanitation. This paper summarizes some of the findings to date, particularly with respect to water supply.

Design Standards

Questions about design guidelines and standards fall into two categories: appropriate or optimal levels of service, and optimal use of resources for meeting standards. Under the first category, the problem is to decide the best level of water supply and sanitation service to be provided for system users, and under the second, the problem is to decide how the selected level of service can best be met through engineering design. This section explains some of the differences between these categories.

In the field of water supply, the major variables to be decided by the planner or engineer which define the level of service include (i) the daily amount of water per capita for which the system is to be designed; (ii) the location of water supply delivery points or stations with respect to users, (iii) the safety of the water that is supplied, and (iv) the reliability of the system for meeting demands. In regard to (i), the engineer can realistically design systems for flows as low as about 20 liters per capita per day (lcd), in which case only the minimum essential demand is met, or as high as, say, 600 or 800 lcd, in which case sufficient water is available even for such less important needs as lawn irrigation. Clearly, higher per capita supply implies a higher level of service.

Under item (ii), the engineer can decide to supply water through public standposts, which may require substantial walking and water carrying, or through yard taps for individual or clusters of houses, or through single or multiple taps within houses. The level of service increases with increasing proximity of water to users. Regarding item (iii), water safety is provided through treatment, which can be accomplished to varying degrees using different processes. Safety also depends on the pressures for which the water network is designed, high pressures providing good assurance that polluted ground water will not be drawn into the network through leaky pipe joints. Finally, system reliability under item (iv) is largely a matter of providing back-up and stand-by equipment that can be placed in service in the event of mechanical failure. For networks, system reliability depends on alternative piping routes and looping that can provide multiple pathways for meeting demands in the event of breaks in mains.

Overriding these variables is the question of when to stage system upgradings. The engineer must select not only the level of service to be provided today, but also service levels for the future. For example, it is possible to design the initial water system using standposts that in time are replaced by yard taps, and later yet by taps within houses. Selection of the times for upgrading, therefore, are decisions which fall into the category of service level standards, similar in this respect to decisions on the location of water distribution devices, the amounts of water, and the levels of safety and reliability to be provided at each stage of system development.

The variables that define the level of service for sanitation systems are similar to those for water. The proximity of facilities to users is perhaps the major determinant of service quality. Sanitation facilities can be communal, which require walking to and from the house, or on-site in the case of yard privies and latrines, or within the house. The other major indicators of service level are aesthetics and safety. For example, wastewaters can be collected in open ditches or closed pipes, they can be disposed above or below ground and in watercourses, and they can be disposed after no or with some or complete treatment. Additional variables which indicate sanitation service level include ease-of-use and system reliability.

The second category of design guidelines and standards pertains to the optimal use of resources for meeting target levels of service once they have been selected. In the case of water systems, this includes such questions as where to lay pipes in the water distribution network, how large to make them, and how much excess capacity to include in components of the system given that demands (and service levels) increase over time. The optimal design questions for sanitation systems are similar and include such items as whether to provide ultimate disposal of wastes at or away from the house site, whether to collect wastewater and solids separately or together, where to lay pipes of the collection network, what minimum size pipes to use, and what minimum velocities to maintain.

The methodology for developing design guidelines for the two categories (optimal service level and optimal design) are different. In the first case, the level of service is an unknown variable or set of variables that must be decided. In the second, the level of service is known and the only question is how to meet it through efficient use of resources. The first case, then, is a problem in setting standards whereas the second is a problem in design. These words "optimal standards" and "optimal design" will be used throughout this paper to describe the two categories of concern.

With respect to optimal standards, the costs and the benefits accruing to society at each level of service are different. For example, a water system that provides house connections is more expensive than one that provides yard taps, which in turn is more expensive than public standposts. At the same time, the benefits of these service levels are different, with standposts at the lower end of the scale and house connections at the upper. What is sought, then, is the level of service (called the optimal standard) for which the difference between benefits and costs is a maximum, assuming economic efficiency is to be maximized. Alternatively, in the face of limitations on the ability of beneficiaries to pay, the highest level of affordable service is sought, assuming that net benefits increase monotonically as the level of service increases.

The problem with this approach for determining optimal standards is that the benefits of different water and sanitation service levels cannot be satisfactorily quantified. Hence, the method must be modified. In this research, the procedure was to determine the cost of each level of service. Having done this, it is left to the planners and engineers to decide whether the incremental increase in cost of improving service from a lower to a higher level is sufficiently offset by what are judged to be the benefits. If so, then the incremental increase of upgrading to the next level is considered and so on until the level of service for which the incremental (i.e.

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*This is the well-known optimality condition where present value marginal benefits equal present value marginal costs.

marginal) costs and benefits are equal is reached. Clearly, this is a matter for subjective judgement which is a risky exercise since the likelihood of different persons agreeing on the benefits is poor. On the other hand, just to trace out the sensitivity of cost to service level is a valuable endeavor since so little information on this is currently available.

In regard to the question of optimal design where guidelines are sought for the optimal use of resources for meeting selected service levels, the approach is to determine such things as network layout and pipe sizes that minimize present value costs. Fortunately in this case, little or no consideration needs to be given to benefits since for any target level of service that has already been decided, the benefits are fixed. Economic efficiency is thus maximized by minimizing costs.

The next section of this paper presents the tools that were used in this research for optimal design. These include mathematical models and computer programs for identifying system characteristics that minimize cost while assuring that target demands (i.e., levels of service) are met. Having done this, the following three sections address the question of optimal standards; they present findings on how costs change with changes in the level of service. The first of these sections deals exclusively with water distribution networks under the assumption of static demand, the next deals with integrated water and sanitation systems also assuming static demand, and the following section is concerned with integrated water and sanitation systems under conditions of upgrading and increasing demand over time. These middle three sections of the paper correspond to the three separate phases of research that have been sponsored by the World Bank. Finally, the paper ends with implications and conclusions regarding design guidelines for low-cost systems.

Tools for Design

The basic design questions to be answered given prior decisions on the level of service include (i) the location, (ii) construction timing and (iii) capacity of facilities. In general, questions of location (for treatment plants, pumping stations, storage tanks, dams, pipelines, etc.) seem to be adequately handled through engineering judgement and do not particularly lend themselves to mathematical models and computer programs, except perhaps in the case of regional planning. The other two questions, however, have been the subject of much research using quantitative methods. Particular attention involving municipal water and sanitation systems has been focused on water distribution and wastewater collection networks because of their large expense and difficulty of design.

The problem of deciding optimal capacity for water networks is mainly a problem in selecting pipe sizes. Assume, for example, that decisions have been made to use public standposts, where the number of persons per standpost and the target flow per capita have been decided. Assume further that the minimum allowable pressure in the network has been selected. Then in order to minimize cost, the standposts should be connected to the source of water supply using a network in which total pipe length is minimized; this will result in a branched network with a tree-like structure in which circuits are open (i.e. no loops). Because the network is branched, the design flow in each link of the network is known which enables optimal design using linear programming (LP).

The approach described in ref. 9 is as follows. Assume each link in the network consists of several pipes with different commercially available diameters but unknown lengths linked together in series. The problem is to determine the optimal length of each diameter pipe in the network. The objective function to be minimized is total pipe cost, which is the (known) cost per unit length times the (unknown) pipe length summed over all links and diameters. Two constraint sets complete the model. The first is that the sum of all pipe lengths comprising each link must equal the length of that link. The second is that the head loss between the source of supply and the terminal node for each branch of the network must not violate the minimum allowable pressure constraint for the system. A computer code for this model called Linear Programming for Branched Networks (LPBN) was written and used throughout the World Bank research described in this paper. The program can handle both multiple and single sources of supply, and it can determine optimal hydraulic gradients at sources as well as optimal pipe sizes.

While LPBN is well suited for branched networks used with public standposts, it is less applicable to looped networks used with yard taps and house connections. For these levels of service where a pipe is needed on nearly every street resulting in a network with closed loops, flows in the links of the system are unknown, which prevents the use of LP for design. Although the literature contains papers dealing with the optimal design of such systems (e.g. refs. 1 and 11), the models are not very satisfactory and are not widely used.

The approach to design in this case is to use a computer program that simulates network behavior; Hardy Cross and Newton Raphson models are commonly used. This research employed a computer program called FLOW which was developed by Epp and Fowler (3). Design work proceeds by first preparing a layout of the network and estimating demands at nodes based on the designated level of service. The engineer then selects trial diameters for all pipes in the system and uses FLOW for calculating pressures at nodes. If network pressures are too high, pipe sizes are reduced, and if too low, they are increased. Thus through trial and error, diameters are adjusted until satisfactory network pressures emerge. While FLOW does not guarantee a least-cost design, its use by skilled engineers can produce designs very close to optimal.

The problem of network design for wastewater collection systems is similar to that for waterworks. The engineer must select sewer pipe sizes and slopes so as to convey wastewaters from points of discharge to a downstream sink, minimizing pipe and excavation cost in the process. Several computer programs are available for this, most of which employ dynamic programming (e.g. ref. 8) and are limited to relatively small systems. In this research, a quadratic programming model called SEDES was used which was developed by Sousa (10).

Sewer networks are branched and have a tree structure like that of water networks for public standposts; the design flow in each link is known once the level of service has been selected. Unlike water networks, pipe depth must be decided by the designer. Using an approach similar to LPBN's, each link of the network is assumed to consist of several different size pipes (with different slopes) laid end-to-end in series, with the larger diameters downstream and the smaller ones upstream. The design problem is to determine the optimal length of each pipe, which in turn affects excavation depth. Because the problem contains two sets of decision variables, length and depth, which are multiplied by each other, linear programming cannot be used for solution. Quadratic programming, however, is suitable for this problem, and it is nearly as efficient and powerful as LP.

Each of the above computer programs for network design considers only static demand conditions. That is, the user must decide the flows which the networks must handle. In the face of demands that change over time, either through population increase, upgrading from lower to higher service levels, or both, this is tantamount to selecting a design period. Thus, the final set of models used in this research were for determining optimal design periods and staging. They were patterned after those in refs. 6 and 7.

Assume demands into the future are known. The facility that is constructed now, whether pipe network, pumping station, or whatever, must have capacity to meet existing demand plus some increase for an unknown future period. When excess capacity is exhausted, expansion will be needed which must again provide excess capacity for some unknown period into the future. This pattern of staging construction to meet increasing demands must be repeated throughout the duration of the planning period. The problem for the desinger is to determine the unknown periods of future excess capacity for each construction stage, which are called design periods. This can be done using simple mathematical models that employ the calculus for solution assuming construction cost functions and future demands are known. If during the planning horizon construction is to take place in not more than two stages, simpler break-even models can be formulated which do not require an optimization technique for solution.

These are the major tools used for the research reported herein, given decisions in advance on the level of service. For more detailed information, the reader should consult the references.

Water Network Costs

In 1976, the World Bank commissioned a study for improving the design of secondary water distribution networks that serve the poor in developing countries. Of particular concern were public stand-post systems, although attention was also given to systems that use yard taps. The study focused only on water networks and did not consider source, treatment, and transmission facilities, nor did it examine wastewater collection and disposal facilities. The goal of the study was to determine how network costs change as the level of service increases as an aid to decision makers in selecting appropriate service standards. No attempt was made to quantify the benefits associated with different service levels. A report on the study is in ref. 5.

The study methodology included five major steps which are described in the remainder of this section. (i) select cases, (ii) develop cost functions, (iii) select standards, (iv) generate designs, and (v) analyze network costs and characteristics. Case studies were selected in Brazil, Indonesia, Philippines, Upper Volta and Yemen. The cases included eight areas, some of which were neighborhoods in large cities and others of which were separate small communities. Field visits were made to some of the areas, the others being studied through maps, reports, and available data. The study areas varied in size from 5 to 185 hectares (ha), with population densities from 100 to 1000 persons per ha.

In each country, current data were obtained on water network construction costs. These came from contractors bid data which were analyzed using regression techniques to obtain pipe cost functions. These equations varied from country to country, but the following was found to be fairly typical.

$$C/L = 0.03\ D^{1.4} \qquad (1)$$

where C = cost of furnishing and installing pipe in US$, L = pipe length in meters (m), and D = nominal pipe diameter in millimeters (mm). Using eq. (1), 50-mm diameter pipe is seen to cost about US$ 7 per m. As with all the equations in this paper, eq. 1 is approximate and is used only for rough estimation; it must be used with caution when greater precision is required. A graph of eq. 1 is shown in Fig. 1.

For each study area, 2 or 3 network layouts were made using different spacings of public standposts; a total of 15 different designs were prepared for the eight areas. The number of persons per standpost was varied from about 90 to 2000, with an average of about 700. In addition, the average design flow per capita was varied from 20 to 100 liters per capita per day (lcd); in all cases, networks were designed for a peak flow 3 times the average. In addition to the standpost systems, eight designs using individual yard taps were prepared, with design flows of 50 or 100 lcd. In all, a total of 72 different designs were made for the eight study areas. Branched networks for the standpost systems were designed using the LPBN computer program described in the previous section, and the looped networks for yard taps were designed using FLOW.

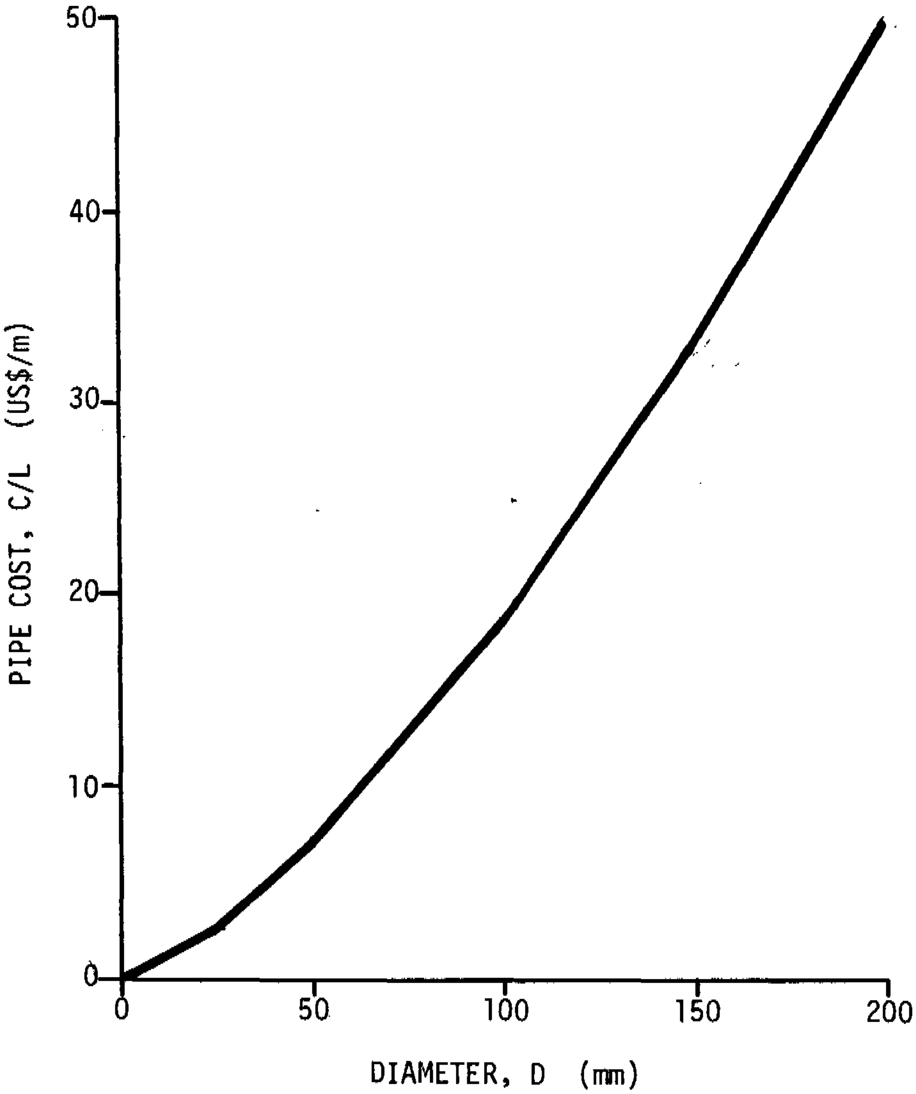

FIG 1 - PIPE COST FUNCTION

The characteristics of the resulting branched and looped networks were noted and analyzed. As expected, the total length of network piping increased as more standposts were used in a given area (i.e. as the number of persons per standpost decreased). Several equations were fitted to the length data using regression analysis, with the following being most appropriate for this paper

$$L/P = 82\ (P/A)^{-0.49}\ (P/N)^{-0.55} \qquad (2)$$

where L/P = pipe length (m) per capita, P/A = population density in persons per ha, and P/N = persons per standpost; L = total length, P = population, A = area, and N = number of standposts. Attempts to verify this model were not entirely successful; prediction errors ranged from about 7 to 21%. This equation, which pertains only to standpost networks, must be used with caution, especially outside the range for which it was developed.

Eq. 2 says that the length of pipe per capita in a standpost network (L/P) depends on population density (P/A) and the number of persons per standpost (P/N). A graph of this function on log-log-paper with isolength lines is shown in Fig. 2. By designing for 50 persons per standpost in an area with 200 persons per ha, the required pipe length per person is seen to be about 0.75 m.

In addition to pipe length, network designs were analyzed to determine pipe diameters. For each design, the average network pipe diameter (D) was calculated by dividing the product of individual pipe diameters (d) and lengths (x) summed over all pipes in the network by total pipe length ($D = \Sigma dx/L$). Regression analysis was used to relate average diameter to system characteristics. Of the several resulting equations, the following is most appropriate for the rough estimation of concern herein

$$D = 4.5\ (P/N)^{0.21}\ (Q/P)^{0.39} \qquad (3)$$

where D = average network pipe diameter in mm, Q/P = average design flow in lcd, and P/N is the number of persons per standpost. Eq. 3 says that average diameter depends on the number of persons per standpost and the per capita design flow (Q/P). A graph of this function on log-log paper with isodiameter lines is shown in Fig. 3. Note that a network with 50 persons per standpost designed for 50 lcd will require about 50 mm diameter pipe, on the average. Since the peaking factor of 3 is built into eq. 3, a network with this average size pipe could actually deliver 150 lcd. Using eq. 1, it is seen that 50-mm diameter pipe costs about US$ 7 per m, and from eq. 2 about 0.75 m of pipe is required per capita. Multiplying these values, it appears that a network with these characteristics will cost about US$ 5 per capita.

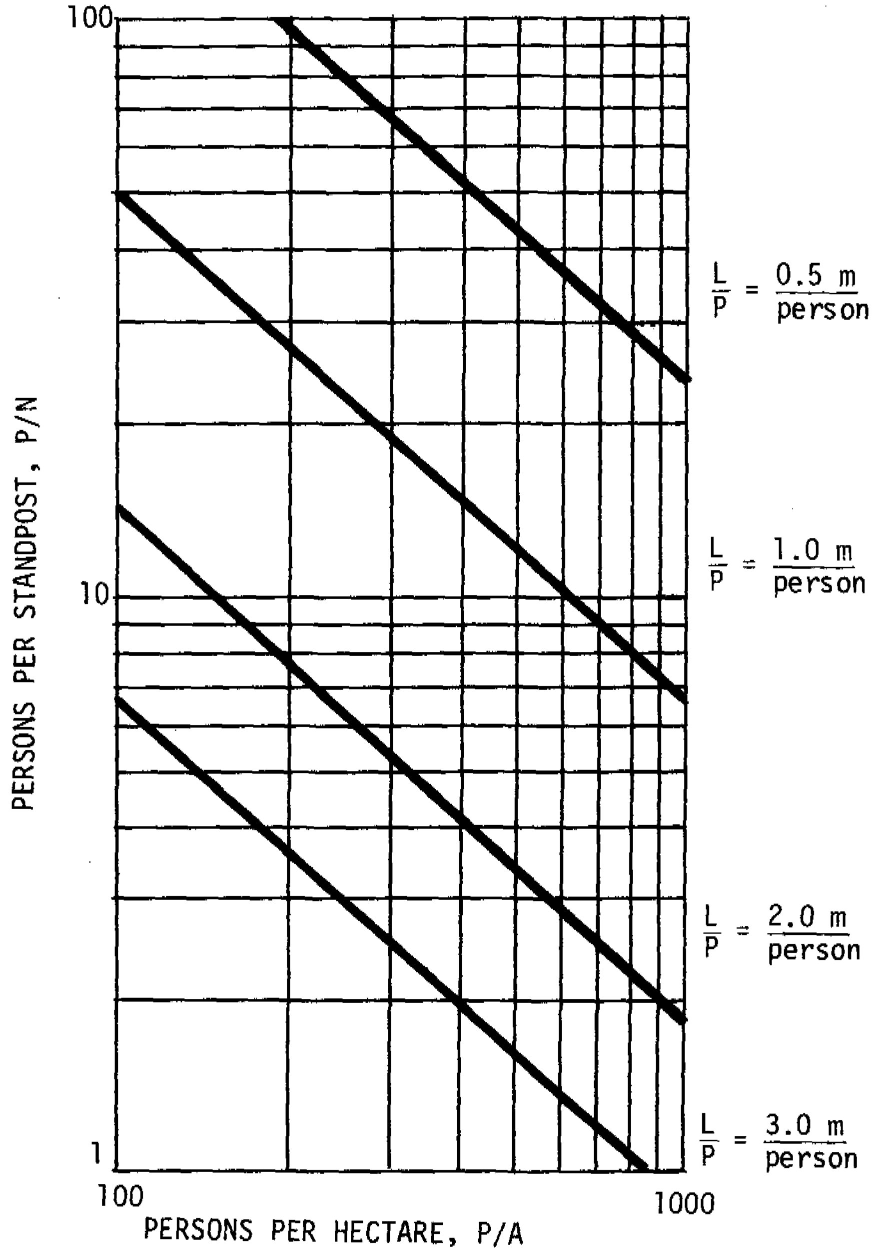

FIG 2 - NETWORK PIPE LENGTH

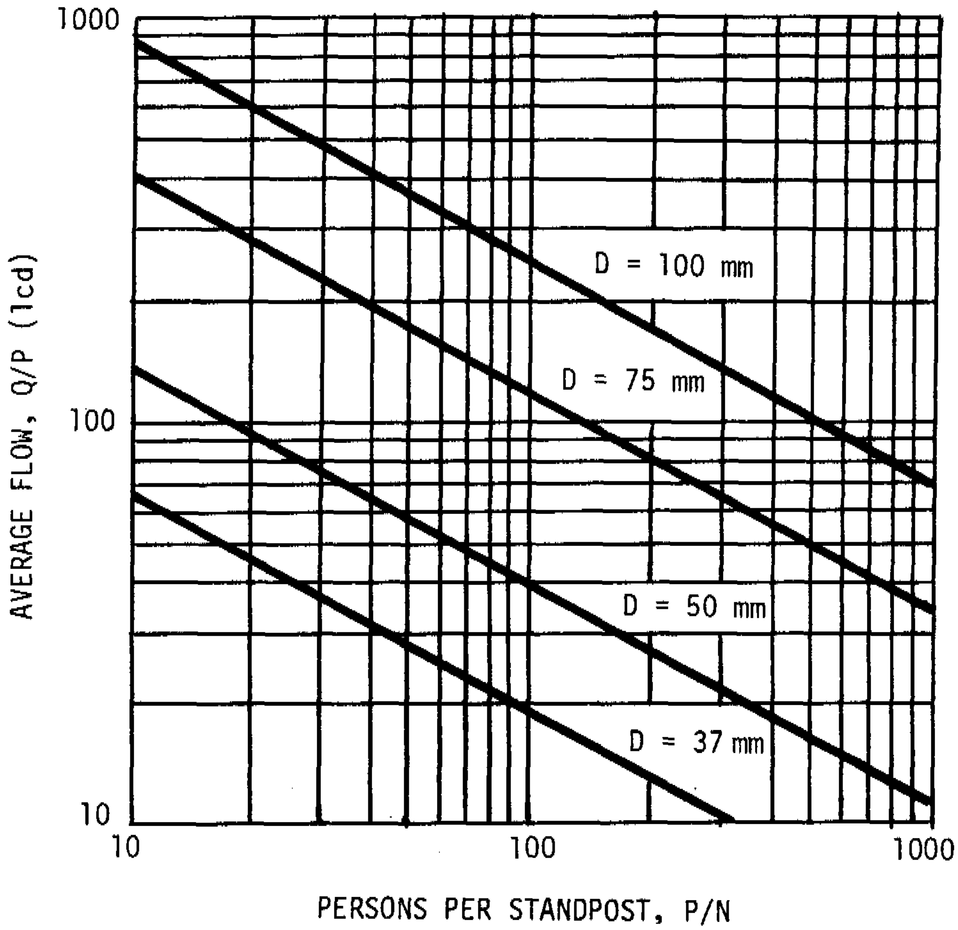

FIG 3 - AVERAGE NETWORK PIPE SIZE

Eqs. 1, 2 and 3 can be combined into a single equation to indicate the approximate cost of network piping. By substituting the right hand side of eq. 3 into eq. 1 for D, an expression is obtained of cost per unit length as a function of persons per standpost and per capita flow. This expression is actually in error because average diameter in eq. 3 is not equivalent to the pipe diameter of eq. 1; however, the error is not excessive for our purposes.* Next, this expression can be multiplied by eq. 2 to obtain the following equation of pipe cost per capita (C/P) as a function of persons per standpost (P/N), average per capita design flow (Q/P), and population density (P/A).

$$C/P = 20\ (P/N)^{-0.26}\ (Q/P)^{0.55}\ (P/A)^{-0.49} \tag{4}$$

As we have already seen, substitution of P/N = 50, Q/P = 50 and P/A = 200 results in C/P = US$ 5 per capita.

The exponents of eq. 4 are of special importance. They represent the percentage change in per capita pipe cost per percent change in the variable to which they are attached. Hence, per capita pipe cost is seen to increase about one-half percent for each 1% increase in design flow. By designing for, say, 100 lcd instead of 50 lcd (a 100% increase) per capita pipe cost will increase about 50%. Similarly, by designing for, say, 100 persons per standpost instead of 50 (a 100% increase), network pipe cost will decrease about 20%, as indicated by the exponent of P/N.

Eq. 4 is thus seen to be useful for estimating the sensitivity of network cost to changes in the decision variables that define the level of service. It can be used with different values of P/N to help decide how close water should be brought to users (i.e. the optimal spacing of standposts), and if we assume that roughly this same equation applies to networks that provide house connections, it can be used with different values of Q/P to help decide whether to use yard taps (Q/P = 50 lcd), single house taps (Q/P = 100 lcd), or full house plumbing (Q/P = 200 lcd or more). While eq. 4 is probably alright as far as it goes, it doesn't go far enough since it considers only network costs. The costs of the other water system and sanitation components are therefore considered in the next section.

Water and Sanitation System Costs

To obtain information on the complete costs of water and sanitation systems with different service levels, including all components and not just the water network, a case study was made for a small town in Brazil. Designs were prepared based on a population 20 years hence of 10,800 and an area of 83 ha, which implies a design density

*The resulting expression would be errorless if the regression analysis which produced eq. 3 had been made with D_1 instead of average diameter, where $D_1 = \Sigma d^{1.4}\ x/L$.

of 130 persons per ha. The average household size for this town is 6, which results in 1800 connections for the future design population. The town is divided by a river and has somewhat irregular topography.

The study methodology was similar to that described in the previous section; it included (i) development of cost functions for water and sanitation components, (ii) selection of target levels of service, (iii) preparation of alternative designs to meet standards, and (iv) analysis of costs. For item (i), costs were developed using regression analysis; the complete list of construction, operation and maintenance functions is in ref. 2.

Five different levels of water supply and sanitation service were investigated, as shown in Table 1.

Table 1

Levels of Service

Level	Average Demand (lcd)	Maximum Daily Demand (m^3/d)	Water Distribution Facilities	Sanitation Facilities
I	25	405	Standpost	Latrines
II	50	810	Yard Tap	Soakaway
III	100	1620	Sanitary Core	Septic Tank
IV	100	1620	Sanitary Core	Small Sewers
V	200	3240	Full Plumbing	Conventional

For Level I, 27 standposts each with service radius of about 100 m and each serving about 400 persons were selected, and ventilated pit privies were used for sanitation. For Level II, yard hydrants at each house were provided for water supply, and pour flush toilets with soak pits were used for sanitation. For Level III, a single kitchen tap and shower (called a sanitary core) were used for water supply, and a septic tank with drainfield was used for sanitation. Level IV also used a sanitary core for water supply and a septic tank for on-site sanitation; however, the drainfield was replaced by small bore street sewers from which sewage solids are excluded, with sewage lagoons for treatment. Finally, Level V assumed multiple house taps for water supply and conventional waterborne sewerage and lagoons for wastewater. Minimum sewer sizes for Levels IV and V were 100 mm and 150 mm, respectively, and minimum design velocities were 0.3 and 0.6 meters per second, (m/s), respectively.

For each of the above service levels, a separate water supply and sanitation design was prepared. It was assumed that none of the existing facilities of the study community was incorporated in these designs, nor were any facilities carried from one level of service to another. The water distribution and wastewater collection networks were designed using the computer programs described in the earlier section.

Per capita construction costs and present value per capita operation and maintenance (O&M) costs in US$ based on the design population of 10,800 were determined for each level of service. The O&M costs were based on a period of 20 years and an annual interest rate of 10% for which the capital recovery factor is 0.12. The resulting values are shown in Table 2.

Table 2

Present Value Costs, US$ per capita

	I	II	III	IV	V
Water Construction	12	29	45	45	74
Water O&M	3	5	9	9	17
Total Water Costs	15	34	54	54	91
Sanitation Construction	12	25	50	77	88
Sanitation O&M	5	5	5	10	8
Total Sanitation Costs	17	30	55	87	96
Total Water and Sanitation	32	64	109	141	187

The breakdown of construction costs by percentage among system components is shown in Table 3.

Table 3

Percent of Total Construction Cost

	I	II	III	IV	V
Upstream Water	26	18	15	12	14
Water Distribution	22	13	10	8	9
On-Site Water	0	23	22	17	23
On-Site Sanitation	52	46	53	39	24
Sewage Collection	0	0	0	17	21
Sewage Treatment	0	0	0	7	9

Upstream water facilities include source development, raw and finished water pumping, transmission, and treatment. Water distribution facilities include the network and storage tank (and standposts in the case of Level I). On-site water facilities include connections and water-using appliances, and on-site sanitation includes house connections (for Levels IV and V) and disposal facilities.

From Table 2, it is seen that water system construction costs range from US$ 12/capita for standposts to US$ 74/capita for house connections, and sanitation costs increase from US$ 12/capita to US$ 88/capita. The per capita costs appear to be low, which seems due primarily to the rigorous design of water and sewerage networks that resulted in more efficient and less costly systems than those usually found in practice.

Table 2 shows that house connections (Level V) are 6 times more expensive than standposts (Level I); the per capita cost of yard taps is more than twice that of standposts. Conventional sewers are 7 times more expensive than pit latrines; 3.5 times more expensive than pour flush toilets with soak pits, and 1.8 times more than septic tanks with drainfields. This table also indicates that the small bore sewer system of Level IV is significantly more expensive than the septic tank and drainfield system of Level III; yet they probably render comparable service. Actually, the conventional sewer design of Level V is not much more expensive than small bore sewers. Level IV sanitation costs are relatively high because the expensive sewage collection network must be constructed and maintained, sewage lagoons must be built and operated, and individual on-site vaults must be desludged.

Table 2 indicates that at every level of service, the costs of water and sanitation facilities are about the same. The figures in Table 3 show that except for Level I, upstream facilities represents about 30% of total water system cost, the distribution network is about 25%, and on-site facilities represent nearly 50%. Table 3 also shows that wastewater collection networks for Levels IV and V are about twice as costly as water distribution networks. On-site sanitation facilities are seen to represent a very large proportion of total system cost.

Although they cannot be quantified, speculation can be made about the water supply and sanitation benefits for this study; they are probably of two types: convenience (i.e. accessibility) and health. Upgrading from Level I to II, convenience benefits probably increase sharply, but thereafter they are subject to diminishing marginal returns. Once water is on the premises, it may not be much less convenient to get it from a tap in the yard than from a tap in the house. Health benefits, however, probably do not change much at lower levels of service until Level V is achieved, at which point they increase sharply. The resulting total benefit function, which is the sum of the health and convenience benefits, probably has an inflection point between Levels III and V. Maximum net benefits presumably occur at Level V. Among the three lower levels of service, however, maximum net benefits may occur at Level II, which employs yard taps for water supply and pour flush toilets for sanitation. This level provides a high degree of convenience and is probably not much worse in health benefits than Level III. Hence, where affordability is an issue, yard taps seem to merit serious consideration.

Upgrading over Time

The alternative designs of the previous section assume that construction of major facilities (e.g. networks, source works, etc.) takes place at the beginning of the planning period and that the level of service remains constant over time. In reality, developing countries are more likely to provide a lower level of water supply and sanitation service during the early years when systems are first put into operation, followed by higher levels in subsequent years when beneficiaries are better able to pay. Such staged upgrading is less expensive than providing a high level of service at the outset and is usually more affordable.

This type of staging raises important questions about optimal standards and engineering design.Research commissioned by the World Bank to consider some of them has been underway since 1979; it has focused on both water supply and sanitation and is not yet complete. Sufficient findings have been obtained, however, to address three questions pertaining to water supply: (i) when should upgrading from lower to higher levels of service occur, (ii) what level of service should be provided initially, and to what level should systems be upgraded, and (iii) since distribution networks are the most difficult facilities to design, how much capacity should be included in piping at each stage of development. The results summarized herein are presented in more detail in ref. 4.

Question (i) regarding the optimal timing of upgrading is a problem in standards setting. Total present value water system costs decrease as upgrading is delayed as a result of discounting. At the same time, present value social costs rise due to benefits foregone from not having a higher level of service. Total present value system and social costs, therefore, are probably high at the begining of planning, decreasing to a minimum as upgrading is delayed, and increasing thereafter. The conceptual problem is to determine the upgrading time for which total costs are a minimum. Because the social loss function is unknown, the approach taken herein is to determine the amount of present value savings in construction and O&M obtained by delaying upgrading, leaving it to others to make assumptions about the beneftis.

The second question (ii) is also a problem in optimal standards setting. Assuming in the case of water supply that public standposts are used initially, the problem is to determine whether upgrading should improve service to yard taps or single house taps (sanitary cores) or multiple house taps. This, of course, assumes that the upgraded level of service is controllable; that people will be contented, for example, with yard faucets if they can in fact afford multiple house taps. Selection of the standard in principle requires knowledge of the social loss function. Consequently, the approach herein is to trace out the sensitivity of system cost to different service levels, leaving it to the decision makers to decide whether marginal savings offset marginal benefits.

Question (iii) is not a problem in standards setting but rather pertains to engineering design. Assuming that future demands are known with reasonable accuracy, should the water network constructed for the initial level of service have capacity to meet ultimate system demands, say 20 years hence, or should it only have capacity to meet demands until the time of upgrading, in which case capacity expansion will be required. This is a problem in selecting optimal design periods.

To answer these questions, three communities were selected for case studies; only two are reported herein, one in Brazil and the other in Indonesia. The Brazilian town is the same one used in the previous study; its design population, area, and density are 10,800, 83 ha and 130 persons/ha, respectively.

The Indonesian community is a slum neighborhood in a large city with design population, area, and density of 9,100, 9 ha, and 1000 persons/ha, respectively. The town in Brazil has a surface source of water supply, whereas the neighborhood in Indonesia must rely on wells which are relatively expensive since they have almost no economy of scale. Because of these source differences, the per capita water costs for Indonesia are generally higher than those for Brazil.

As in previous studies, it was necessary to develop cost functions for water supply and sanitation components; they are not included in this report. Next, standards were selected for different levels of service, and alternative designs were prepared. The levels of water supply service are identical to those in Table 1 except for Indonesia where a 50-m service radius was selected for standposts instead of 100 m. On the averge, each standpost there served about 800 persons compared to 400 in Brazil. The average per capita flows for the three levels of water supply service are shown in Table 1, and as before, water networks were designed for maximum hourly demands using a peaking factor of 3.

The planning horizon for this study was 20 years. Upgrading from one service level to another was assumed to occur either 5, 10, or 15 years after time zero. During the period following initial construction, the level of service remained constant; total demands, however, increased due to population growth. A jump in demand would then occur at the time of upgrading followed by another period of smoothly increasing demand, and so on to the end of the planning horizon.

Water distribution networks were designed using the LPBN and FLOW computer programs described earlier. In the case of public standposts, which were normally used for the initial (low) level of service, branched networks were laid on principal streets, and for upgrading to yard taps or house connections, pipes were laid on new streets to close circuits, resulting in looped designs. In cases where the capacity of initial networks had to be subsequently increased to meet ultimate demands, this was accomplished by laying new pipes parallel to old ones rather than by replacing small diameters.

Table 4 includes present value per capita costs showing the savings that can be obtained by delaying the time of upgrading. These values are based on the expected populations at the end of the planning horizon. The costs in this and the following table cover only construction of water facilities, including source, treatment, transmission, distribution and connections (or standposts in the case of the lowest service level); a 10% interest rate was used for discounting. In Brazil, it is seen that the cost of using sanitary cores at the outset is US$ 43/capita. However, if public standposts are used initially followed by upgrading in the fifth year, the cost would be only US$ 35/capita, a savings in present value of US$ 8/capita. By delaying upgrading for 10 years instead of only 5, present value construction cost would be still lower at US$ 27/capita. It therefore appears that an average savings in present value cost of about US$ 1.6/year per capita can be obtained by delaying installation of sanitary cores and using standposts in the interim. Similar interpretations can be made from Table 4 for the other levels of service.

Table 4

Cost Reductions Due to Delays in Upgrading*

	Year 0	Year 5	Year 10	Average Savings $/yr/capita
Upgrading from standposts to yard taps				
Brazil	26	23	19	0.7
Indonesia	29	23	19	1.0
Upgrading from standposts to sanitary core				
Brazil	43	35	27	1.6
Indonesia	58	41	28	3.0
Upgrading from standposts to full plumbing				
Brazil	69	52	36	3.3
Indonesia	99	68	48	5.1

*Table entries are present value construction costs/capita for water facilities in US$.

The savings from delaying upgrading are clearly greater for the higher levels of service. In the case of yard taps, a delay of 10 years reduces present value cost only about 25 to 30%, whereas for full plumbing, a 10-year delay would reduce cost about 50%. The last two lines of Table 4 suggest that a delay of only 5-years in providing full plumbing would save more than US$ 15/capita in present value cost, which seems significant. Of course, sizable savings can be obtained by never upgrading. The key question then is whether these savings outweigh the loss of benefits, for which no easy answers are available.

Table 5 includes present value per capita costs associated with upgrading to different levels of service. If upgrading occurs in year 10, for example, and the initial service is through standposts, the cost of upgrading to full plumbing in Brazil is US$ 36/capita, which drops to US$ 19/capita if the upgrading is only to yard taps, a reduction of nearly 50%; in Indonesia, the savings is greater than

50%. This table suggests that substantial savings can be obtained by designing for a level of service lower than full plumbing. As before, the savings are greatest by never upgrading, which makes these values difficult to interpret without some knowledge of benefits. Overall, sanitary cores seem to be significantly more expensive than yard taps, and full plumbing is much more expensive than a sanitary core, especially in light of the fact that all three service levels provide water on the premises and wastewater disposal is so much more difficult once water is piped inside the house. This seems to suggest, as in the previous section, that yard taps deserve careful consideration in the face of tough affordability constraints.

Table 5

Cost Decreases Due to Lower Levels of Service*

	Full Plumbing	Sanitary Core	Yard Taps
Upgrading from standposts in Year 5			
Brazil	52	35	23
Indonesia	68	41	23
Upgrading from standposts in Year 10			
Brazil	36	27	19
Indonesia	48	28	19
Upgrading from yard taps in Year 10			
Brazil	58	32	-
Indonesia	-	42	-

*Table entries are present value construction costs/capita for water facilities in US$.

The last of the three questions raised at the outset of this section pertains to optimal excess capacity in water distribution networks It has been suggested by some designers that if public standposts are used for the initial level of service, and these require only branched networks, that the pipes in these systems should probably be sized with sufficient capacity to meet ultimate demands (i.e. flows at the end of the planning period, which in this study occurs 20 years hence). The only construction needed at the time of upgrading, therefore, would be new pipes on streets not previously served, thus closing the loops of the network. The question arises, however, of whether the initial network should have capacity less than that needed to meet ultimate demands. In many cases, the answer seems to be yes, which would make subsequent capacity expansion of the initial network necessary.

In this study, numerous network designs were prepared for the Brazil and Indonesia cases assuming different levels of initial and final service and different waiting times before upgrading. Two approaches were taken for the design of the initial network. On one hand, the network was given adequate capacity to meet ultimate demands, and on the other, it was designed with just sufficient capacity to meet demands to the year of upgrading, after which expansion through parallel piping was provided. Present value costs of the alternatives were calculated, and their analysis resulted in the graph of Fig. 4.

The ordinate of this graph is the annual discount rate, and the abscissa is the ratio of ultimate community demand at the end of the planning horizon (D) to demand at the time of upgrading (d). The curves show the breakeven conditions for three different waiting times before upgrading occurs (t).

Consider the top curve (t ≈ 5 years), which applies to upgrading in the fifth year. A discount rate of about 10% and a demand ratio D/d of about 6 lies on this curve, which implies that the engineer is indifferent between designing the initial network with ultimate capacity or with only sufficient capacity for meeting demands through the first 5 years followed by expansion at the time of upgrading. However, if the demand ratio D/d were greater than 6 or if the discount rate were greater than 10%, the point would fall above and to the right of the curve, indicating that the initial network should be sized for only the first stage (i.e. that capacity expansion in year 5 of the initial network is less expensive than providing full capacity at the outset). Similarly, points falling below and to the left of the curves indicate that full capacity to meet ultimate demands should be provided in the initial network at the beginning of the planning period.

Inspection of the curves for upgrading in years 10 and 15 shows that if the demand ratio is greater than about 3 at current interest rates, it will be optimal to expand the capacity of the initial network at the time of upgrading. Keeping in mind that the demands of concern are peak hourly flows used for network design, the ratio will almost always exceed 3 if standposts are used for the initial level of service. Hence, very seldom will it be optimal with these waiting times to design the initial network with full capacity to meet ultimate demands; rather, the network should be constructed in two stages.

Now consider the top curve for upgrading in year 5. At current interest rates, single stage construction of the initial network will be optimal if the demand ratio is less than 5 or 6. In this case, it is conceivable that the initial network should have full capacity at the outset. Overall, it seems safe to conclude that if upgrading is going to be delayed more than 5 years, the capacity of the initial network should probably be expanded at the time of upgrading, but if upgrading occurs in 5 years or less, full capacity should be provided in the initial network at the outset. A separate analysis is required for planning horizons other than 20 years.

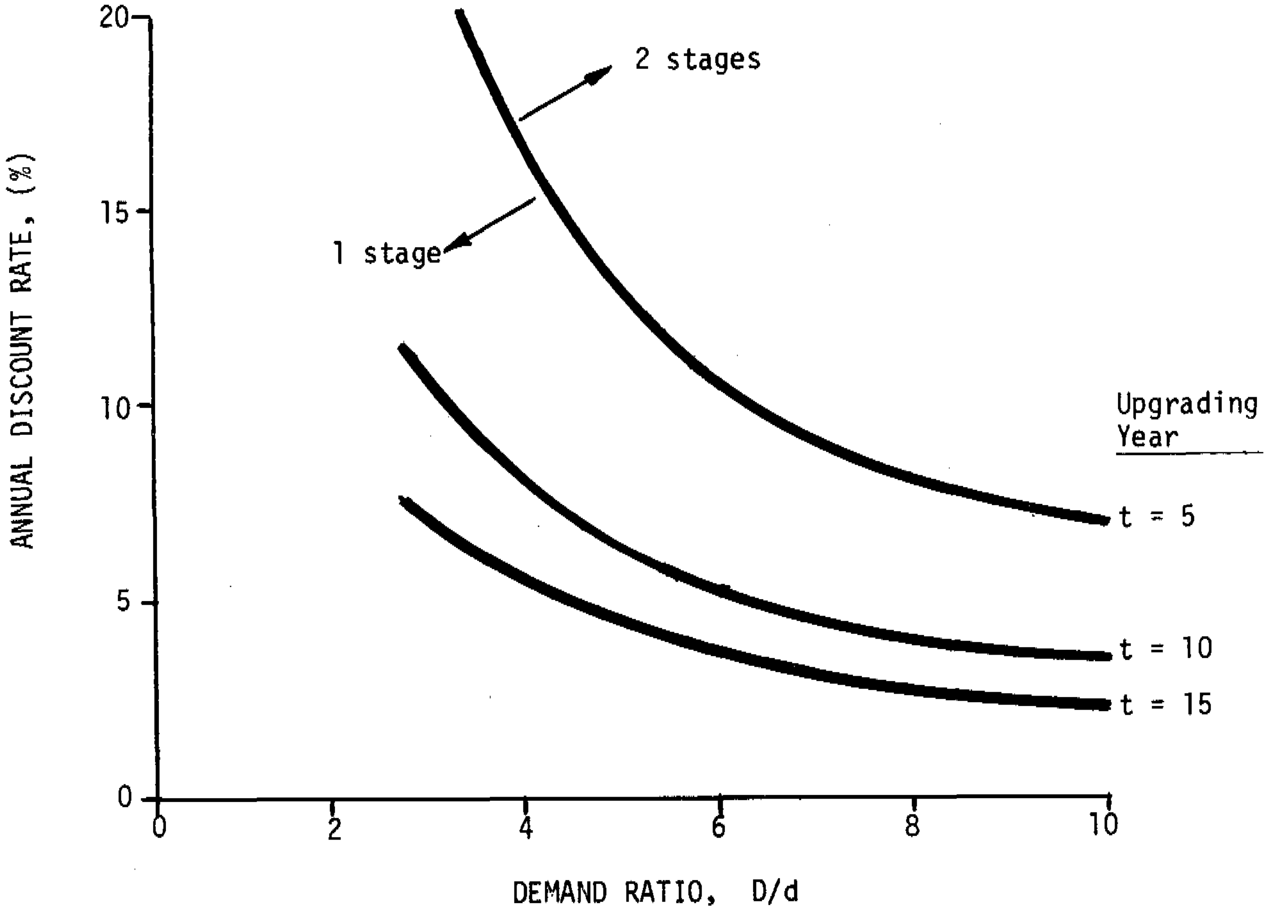

FIG 4 - BREAKEVEN ANALYSIS

Conclusions

1. Design guidelines and standards for appropriate technologies fall into two categories (i) levels of service and (ii) efficient engineering design. To focus on only one category and neglect the other may do little toward improving water supply and sanitation planning in developing countries. There is small advantage, for example, in producing an "optimal" design of a water network that provides house connections when standposts or yard taps are the better means of service; conversely a network with the incorrect amount of excess capacity that nevertheless provides the optimal level of service is wasteful of resources and has a cost that is too high. Optimal standards are therefore needed for both categories simultaneously.

2. The most promising approach for both selecting optimal levels of service and producing least-cost engineering designs is through use of the computer for planning. The computer enables quick investigation and assessment of numerous alternatives, thereby increasing the chances of finding a better plan than if only a few alternatives are checked, which is a limitation of hand calculations. In addition, the computer can increase the productivity of scarce engineering manpower and speed the planning process.

3. Branched networks of the type used with public standposts can be significantly less expensive than looped networks, mainly because the total length of pipe is less; they are also easier to design. Branched networks, however, are unsuitable where pipes are needed on most streets, as in the case of individual house connections. Also, they are less reliable than looped networks, a single break being able to disrupt service to many users.

4. If public standposts are used for water supply, the main decision variable is the number of persons per standpost (P/N), but if house connections are used, the main decision variable is design flow (Q/P), low values being associated with yard taps and high values with full plumbing. Assuming the values of P/N for standposts vary from, say, 20 to 500, per capita network costs from eq. 4 vary from about US$ 4 to US$ 2, assuming 25 lcd and 200 persons/ha. Assuming the values of Q/P for house connections vary from, say, 50 to 400 lcd, per capita network costs vary from about US$ 7 to US$ 22 assuming 10 persons/house and 200 persons/ha. Hence, decisions pertaining to house connections have greater effect on both the range and magnitude of network costs than decisions pertaining to the number and location of standposts, which indicates the relative importance of these two decision variables.

5. Network costs are quite sensitive to design flow, as indicated by the relatively large exponent of Q/P in eq. 4. Hence, costs can be kept low be designing for lower levels of service. If yard-tap or sanitary-core demands are used as the basis for network design, care must be taken to prevent ordinary house connections once pipes are laid in streets. If no assurance can be given, then networks may have to be designed for full-plumbing demands. This raises

questions about the need for improved demand studies, use of flow regulating devices, progressive tariffs, peak load pricing, and enforcement of house connection standards, particularly among those who can afford higher levels of service.

6. It has long been pointed out that proper water supply planning must take account of wastewater disposal. It is a serious mistake to ignore sanitation or relegate it to lower status or priority. Table 3 indicates that wastewater facilities account for about half the total cost of water and sanitation systems at all levels of service.

7. Table 2 shows nearly a doubling of cost from one service level to another; e.g. yard taps are about twice as expensive as standposts, and full plumbing costs about twice as much as a sanitary core. Water and sanitation costs are thus seen to be highly variable, which points up the importance of carefully selecting the service level. Too often, service level is taken as a given when in fact it is one of the most important decisions the engineer can make.

8. Table 3 shows that for all types of house connections, on-site water facilities represent a high proportion of total system cost. This underscores the need for studies, research and innovative approaches for reducing these costs, such as shared connections, meters and yard taps.

9. Fig. 4 shows that if upgrading is delayed at least 5 years after initial water system construction, it will usually be less expensive to build the initial water network in two stages, rather than provide full capacity to meet ultimate demands at the outset. If upgrading occurs before 5 years, not only will costs increase due to the higher level of service, but also the initial network should have capacity to meet demands to the end of the planning horizon because of economies of scale in piping. Where affordability is a problem, therefore, it would seem wise to use public standposts at the outset and wait at least 5 years before upgrading to a higher service level.

10. Table 4 shows that if a water system is to be upgraded to either yard taps or sanitary cores, the savings in present value costs obtained by delaying upgrading are quite modest: only about US$ 1/yr per capita for yard taps and US$ 2/yr per capita for sanitary cores. These rather small savings suggest that if the community can afford it, it might be best to provide the higher level of service at the outset and not bother with upgrading at all. Such is not the case, however, when full plumbing is the ultimate level of service and standposts are used initially. Here, the savings in present value cost obtained by delaying upgrading are on the order of US$ 3 to 5/year per capita. Hence, staged development is worthwhile and merits serious consideration to determine when such upgrading should occur.

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GUIDELINES FOR PROJECT MONITORING AND REAPPRAISAL

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ABSTRACT

Conventional engineering and financial approaches to project design and implementation have resulted in inefficient, inequitable or incomplete water supply and waste disposal systems or, at best, required extensive modifications prior or during implementation. These problems multiply as financial and other resources are diminished or the pace of project preparation and implementation accelerates during the International Drinking Water Supply and Sanitation Decade. The problem can be resolved by properly defining objectives and choosing the technology appropriate to achieve the objective at least cost, by making adequate institutional arrangements and by developing community participation, user knowledge and willingness to use and pay for services. The need for a modification in project development is discussed and guidelines for a different approach, valid not only for reappraisal but initial project preparation, are presented.

I. INTRODUCTION

Developing countries generally follow the approach employed in industrialized nations to provide their population with drinking water supply and waste disposal services. This usually means first the construction of a multiple tap house connection water supply system, followed eventually by the installation of waterborne sewerage.

This appears to be the result of beliefs that imply: (i) developing countries must of necessity use the technologies applied in industrialized countries; (ii) benefits of these technologies will be equally available to all--industry, commerce, the well-to-do and the poor; (iii) water systems can be designed without considering the need to dispose of the wastewater generated; (iv) sanitary disposal of wastes is not of great importance;

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(v) waterborne waste disposal can be economically operated without due consideration of the cost of flushing water or its availability; and (vi) involvement of the user of water supply and sanitation facilities is not required to select acceptable solutions.

Unfortunately, conditions in developing countries are not similar to those in industrialized countries: (i) national and personal incomes are substantially lower, making technologies used in industrialized countries unaffordable to the majority of people in developing countries; (ii) there are far more people with low incomes in developing than in industrialized countries; they are unable to pay for high convenience service conventional technologies provide, thus often do not receive service at all; (iii) the introduction of large quantities of water, in the absence of sewerage, generates disposal problems, polluting both the local environment and downstream water sources; (iv) public health considerations are no longer a principal concern in industrialized countries, thus system are designed for convenience rather than health; in developing countries local health problems often require sanitary disposal of excreta as urgently as water supply; (v) waterborne sewerage is often not a possible solution because prospective users cannot afford the cost of connection, or flushing water, or do not even have a source of water; and (vi) users do not make use of facilities for socio-cultural reasons which were overlooked in the project design stage.

As a result, water supply and sanitation service in developing countries are dismally low, as is shown in table 1.

Table 1. ESTIMATED POPULATIONS1/ OF DEVELOPING COUNTRIES WITH REASONABLY ADEQUATE COMMUNITY WATER SUPPLY AND SANITTION SERVICES2/

	Total population (United Nations estimates)	Population served (from WHO survey)			
		Community water supply		Sanitation	
	in million	in million	%	in million	%
Urban	577	450	77	437	75
Rural	1,419	313	22	209	15
Total	1,996	763	38	646	33

1/ Not including the population of the People's Republic of China.

2/ From report on Community Water Supply (12) submitted by World Health Organization and the World Bank to the 1977 UN Water Conference.

That developing countries cannot afford the conventional solutions is amply demonstrated by these figures. If they had the funds, higher service levels would presumably have been acheived. This should not come as a surprise if it is remembered that the greatest progress in the provision of piped water supply and waterborne sewerage in industrialized countries was achieved during the period of greatest economic development (1, 9, 10). Today, during an economic slowdown, investments in pollution control quickly diminish. Therefore, if developing countries wish to accelerate progress in water supply and sanitation without waiting for substantial improvements in their economies, other than conventional approaches must be employed.

II. EXISTING APPROACH

The Masterplan

Customarily, the masterplan is the first step in the planning process for water supply and sewerage projects. Its objectives are to provide a long-range development program for of water supply and/or sewerage. Service standards are usually multiple tap house connections for the water system, waterborne sewerage for excreta disposal. Community health profiles, which would lead to the selection of technical alternatives suitable to overcome identified problems, are rarely available or prepared as part of the masterplan.

Alternatives are evaluated in water source development, transmission and distribution layouts and methods of water treatment. Similarly, alternative sewage collection, treatment and disosal systems are evaluated. Preliminary cost estimates are prepared, and stages of implementation proposed. It is not uncommon to find that neither the masterplan nor the subsequent feasibility report discusses institutional and manpower issues or socio-cultural aspects. Even rarer is the consideration of alternative technologies for those population groups which are not going to be served by he first stage project identified in the masterplan. As a consequence, service is rarely proposed to all area inhabitants, but almost always only to those who can afford it.

The Feasibility Report

Following the completion of the masterplan, a feasibility report providing details for the design, financing and implementation of the recommended first stage is usually completed. Pilot studies leading to the proper selection of water or waste treatment may be part of this study. Design criteria for subsequent detail design are usually determined at this stage.

Similar to the masterplan, the feasibility report does not usually consider technical alternatives or socio-cultural conditions, which can lead to the unsatisfactory results reported elesewhere (2, 11, 15). However, more attention is usually paid to institutional and financial arrangements for construction, operation and maintenance of the proposed facilities. The design is normally based on conventional practice, rather than being a response to existing health conditions.

III. DEVELOPING COUNTRY CONDITIONS

Health

The principal consequence of highly deficient water supply and waste disposal is a heavy burden of disease with consequent suffering and hardship, stunted human growth and development, and diminished productivity (13). Water and excreta are prominent factors in the transmission of most of the more serious diseases of the developing world (4). Gastrointestinal infections are the leading causes of both death and disability in most developing countries. In many areas diseases related to deficiencies in water supply and waste disposal are contributory causes of most infant deaths and account for a large proportion of adult sickness.

Studies made in recent years show clearly, however, that these problems can seldom be overcome by a single measure or remedy. A combined approach is usually required that includes ample water supplies, hygienic disposal of excreta, and education in water-use practices and household hygiene to change traditional beliefs and habits; improved garbage collection is sometimes also essential, particularly in densely populated, low-income areas. There is considerable evidence that the economic burden of disease and ill health that is in large part the result of deficiencies in water supply and waste disposal is very great in developing countries, particularly, for the poor. Anecdotal accounts and a handful of somall-scale studies that have been conducted suggested that about a tenth of each persons's productive time is sacrificed to disease in most developing countries. In addition, while it may not disrupt a person's activities totally, ill health reduces stamina and energy. Decisions regarding cropping patterns, the use of capital equipment, and the assumption of risk are affected adversely by high prospects of incapacitating disease. Malnutrition occasioned by gastrointestinal disease compromises the defenses of the body against infections and is therefore largely responsible for the diarrhea-measles-pneumonia complex that kills a fifth or more of the children born in many developing countries.

Socio-cultural Aspects

Appropriate technologies are capable of decreasing the prevalence of disease, improving the aesthetics of the environment and, in many instances, reducing the drudgery of collecting water or disposing of wastes. These benefits will only be realized, however, if the intended beneficiaries use the system properly and operate it correctly. Constraints on realization of the benefits of a project arise at four distinct points. First, the intended consumers may not be willing to accept the new technology. Second, local institutions and individuals may fail to operate the system as designed. Third, the skills and equipment necessary for maintenance and repair of equipment may not be available or forthcoming. Finally, improper water-use or waste-disposal behavior may undermine the effectiveness of even those systems that function as designed.

Acceptance of new water-supply and waste-disposal systems is often incomplete, reflecting the judgments of consumers as to their benefits and costs (3). Water-supply projects frequently provide water that is perceived to be inferior in taste, odor, or appearance to water from source previously used. Thus, in the absence of an understanding of the detrimental effects on health of polluted water, consumers may continue to rely upon contaminated sources. Even where the water is acceptable, public standpipes may be less convenient sources and thus may not be used consistently. Attention to the odor, taste, and appearance of water, the convenience of collecting it, and education in the dangers from unseen disease-producing organisms can increase acceptance.

Improper operation of water-supply systems may compromise the intended benefits or introduce risks. Lack of fuels and lubricants leading to failure of mechanically powered pumps will force consumers to return to traditional sources. Failure to close taps after use or to dispose of waste water as planned may increase operating costs, exhaust sources of supply, or create nuisance or hazards from stagnant waters. Failure to protect the area around a well from pollution by domestic animals may create additional health hazards from seepage of surface contaminants into the water source.

Problems of maintenance and repair afflict both sources of supply and distribution of water. The scarcity of qualified technicians and the ubiquitous problems of procuring spare parts argue against complex or sophisticated equipment. On the other hand, simple technologies such as hand pumps, are often likely to break down and are readily vandalized. It should also be noted that a system consisting of many independent, discrete parts--latrines, hand pumps, and so on--is inherently more stable than a single, large centralized system, especially where maintenance capacity is low. With the former, a failure deprives a few people of service; with the latter, an entire community is affected. The choice of a technology should reflect its maintenance requirements, the ease with which maintenance can be accomplished, and the potential effect of a failure on health and the environment.

Even water systems that function well will not have the anticipated effect on health if they are not accompanied by good water-handling practices and improved hygiene. Contamination of water may occur anywhere between the point of distribution and consumption. Soiled jars used for collection or storage of water and soiled dippers are common vehicles for contamination.

What has been said in the preceding paragraphs applies with perhaps greater force to waste disposal. Because most societies have ritualized disposal practices and have created taboos around defecation, changing patterns of behavior is difficult. Convincing consumers that the benefits of improved disposal of waste are indeed benefits may be particularly hard when the solution being advocated is confined, malodorous, or shared. Keeping community sanitation facilities clean is generally difficult, and failure to maintain water seals or vents or to relocate latrines as pits are filled may discourage use or render a given facility unsafe. Selecting a technology that is in harmony with traditional practices and limiting the number of persons that share a facility will minimize these problems.

Institutions

Responsibility for water supply and waste disposal, services that by their nature cannot be delivered over a great distance, has traditionally grown up on a local basis. The adequacy of service has depended greatly on local initiative. In developing countries today large urban areas typically have one or several authorities, of varying capacities and strengths, responsible for different facets of the service or for supplying different parts of a metropolitan area, while in rural areas there is barely any formal organization except sometimes at the local level. Official responsibility for the rural areas is often in the hands of ministry of health or public works or agriculture, but actual operations are often limited to stop-and-go construction efforts, with limited permanent countrywide capacity. Yet critical to the efficient development of rural services are continuing technical support and supervision and good coordination among the various entities and agencies involved. Increasingly, developing countries have moved toward the establishment of regional or national entities, depending on the size of the country, with responsibility for both urban and rural areas, but here again effective fulfillment of the resonsibility so far has seldom extended beyond the towns.

Typically, entities in the water-supply and waste-disposal sector in developing countries suffer from a series of closely interrelated problems. First, they have a serious shortage of trained staff--especially technical and commercial staff--quite often combined with a great excess of politically imposed untrained staff. Second, they face constant financial difficulties, on the one hand because tariffs are too low or are not collected properly and on the other hand because metering and cost controls are deficient. Third, inadequate preventive maintenance leads to breakdown of pumps and meters, large losses of water between original sources and points of consumption, and sometimes, delivery of unsafe water. Fourth, planning is rarely undertaken on any regular basis, and systems for the collection of accurate data on demand and possible alternative sources of supply are nonexistent or unreliable, making it very difficult to carry expansion programs through efficiently. The natural consequence of these combined constraints is that whatever resources are available tend to become concentrated on maintenance of systems already existing in better-off quarters of cities and on limited expansion in a few areas.

A few institutional and policy principles that make for successful water-supply and waste-disposal programs are the following:

- A realistic sector strategy, to which the government and the beneficiaries are firmly committed, to cover a period of years;

- Stable and continuing institutions, with clear responsibilities and adequate management authority on staff appointments, selection of contractors and consultants, expenditure allocations, and so on;

- Steady adjustment of internal organization to growing responsibilities by clear delegation and decentralization, with effective management controls for monitoring and measuring performance;

- Policies in regard to the setting of tariffs and their collection that promote efficiently and equity and ensure, with whatever borrowing or othr outside support are warranted, a steady cash flow to enable proper operation and maintenance, adequate salaries, and expansion of the system;

- Personnel policies that reward merit, keep remuneration competitive, and ensure the existence of career opportunities, with emphasis on staff development and training programs adequate to compensate for inevitable losses of trained staff to other industries;

- Dynamic institutional attitudes toward the expansion of service to meet the needs of those not yet served, reshaping the service as necessary to their sociocultural backgrounds, stimulating their active participation, and helping them to adjust their behavior in such a way that they realize maximum benefits;

- Progressive engineering attitudes, oriented toward the gathering and exploiting of the lessons from past experience in maintenance of facilities and use of services, adapting technology to a variety of local conditions, and testing new solutions;

- Active cooperation, and timely coordination of activities, with departments, agencies, or ministries that are responsible for any of the essential complementary measures, such as waste disposal, garbage collection, training in personal hygiene, provision of health services, health monitoring, housing development, and bulk water planning, that are beyond the scope of the executing agency.

Financial Considerations

Conventional water supply and sewerage services require per capita investment which range from US$50 to US$150 for ater and US$150 to US$600 for sewerage, not including connection and in house plumbing costs. Obviously, less developed countries, 74 of which had 1978 annual GNP/capita of US$700 or less (36 had an average of US$210, 28 had an average of US$470), cannot afford such expenditures (14). The question to be asked, therefore, is whether these countries should consider multiple faucet house connection water systems and waterborne sewerage as the principal means of providing water supply and sanitation at a time of increasing scarcity and rising cost of resources in general and energy in particular. Of course, global figures provide no more than an indication what resource requirements are, because they are based on an average of per capita costs which vary widely from country to country. Nevertheless, a calculation of costs using different services standards, shown on Table 2, is revealing.

Table 2: INVESTMENT REQUIRED AT DIFFERENT SERVICE STANDARDS TO REACH INTERNATIONAL DRINKING WATER SUPPLY AND SANITATION DECADE TARGETS

		Unit costs	Case 1			Case 2 1/		
			Pop. served %	Pop. served (million)	Cost (billion)	Pop. served %	Pop. served (million)	Cost (billion)
Urban water supply								
	hc.	120	70	447	53.6	40	260	31.2
	stp.	40	30	191	7.6	40	260	10.4
Sanitation	sew.	250	40	260	65.0	25	163	40.8
	sept.	100	40	260	26.0	15	97	9.7
	lat.	30	20	131	3.9	40	260	7.8
Total urban					156.1			99.7
Rural water supply								
	hc.	150	20	335	50.2	10	167	25.0
	stp.	40	40	669	26.7	30	502	20.1
	hp.	25	40	669	16.7	40	669	16.7
Sanitation	sew.	250	20	335	83.8	10	167	41.8
	lat.	20	80	1338	26.8	70	1171	23.4
Total rural					204.2			127.0
Total Urban and Rural					360.3			226.9

1/ Assuming 80% of population will be served at adequate levels (short distance to water source, uncrowded public latrines at lowest standard).

hc. = house connection, stp. = standpipe, hp. = handpump, sew. = sewer, sept. = septic tank, lat. = latrine.

Serving the entire urban population by conventional water supply and sewerage would cost US$330 billion, which, together with the cost of rual services, would result in a total investment of US$534 billion. This compares to about US$360 billion in Case 1 and US$227 billion in Case 2. The calculations are important not because the amounts are accurate (they are not, because per capita costs vary widely and other scenarios could be devised which would result in different financial requirements), but because they demonstrate that success of the International Drinking Water Supply and Sanitation Decade will depend on the implementation of less costly appropriate technology, at the very least as a first step, often as permanent solution.

IV. ALTERNATIVES

Technical Options

The technologies used will have a signifcant effect on the pace at which adequate water supply and waste disposal can be provided. The convenience of conventional modern systems has promoted their almost universal acceptance, and it is often assumed that when improvements are made, especially in urban areas, these technologies must be used. But their expense, coupled with limited investment budgets, means that only a relatively small number of people can be served. The consequence, as shown by the figures for past trends, is that most people remain without service. Any sector plan should therefore start with a determination of service standards required to achieve global objectives--basic needs, health improvements, commercial/industrial service--followed by the selection of the technology best able to satisfy these standards. In practice, this will result in master plans for water supply and waste disposal which include a variety of technologies, designed to satisfy a specific service standard at least cost, affordable to the beneficiary to be served.

A major issue in urban water supply projects is the type of delivery system to be installed--that is, whether it should consist entirely of house connections or of some combination of house and patio connections and standpipes. Many developing countries want to copy the system now used in advanced, industrial nations. It is true that where people can afford such a system it can produce social and economic benefits, is convenient and, through its university of use, it can limit spread of disease. Also, meters can be used to levy a range of tariffs, which in turn can be used to produce a financially viable public undertaking, to discourage waste, and to assist in the making of investment decisions.

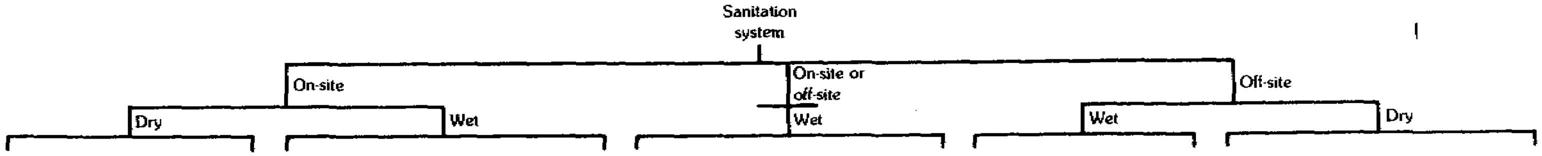
Nevertheless, there are several reasons that immediate implementation of full higher-grade delivery systems for all towns and cities in the developing countries is not possible: (i) many of the potential users are too poor to pay for the full cost of house connections and internal plumbing; (ii) the houses are often not suitably constructed for internal plumbing; (iii) the community is often unable to raise the capital required to construct the facilities and; (iv) the costs that the community would have to bear to dispose of the wastewater generated by consumers served exclusively through house connections would be high. Consequently, in spite of their shortcomings, public standpipes are recommended where water has to be distributed to a large number of people a minimum cost.

Waterborne sewerage provides not only benefits to health and the environment, but also very high convenience to consumers. As a consequence, there has been little interest in the identification of alternative technologies. Because of its cost, however, conventional waterborne sewerage offers little hope for improving waste-disposal services to either the urban or rural poor in developing countries. Sewerage also requires level of water use that cannot be achieved with standpipe service.

Methods exist for the disposal of excreta which can meet every public health test and which cost only a third to a tenth as much per household as conventional sewerage (5, 6, 7). It is important to note that a latrine properly located, properly constructed, and properly maintained, will meet all public health requirements for the sanitary disposal of human waste, whatever the design, be it a simple vault or borehole, one with a complex water seal, or a multiple-vault unit. No one design is better than another so far as public health is concerned; other things being equal, selection of one design over another is determined by a composite of cultural, aesthetic, social, and technological factors. The principal objective of conventional water-flush system is to provide a high level of convenience, not better health. Figure 1 shows schematically alternative technologies available. The technologies can be separated into three groupings according to cost, as shown in table 3 in which actual total costs from specific instances of the use of each technology are summarized.

Two variables that influence costs significantly--internal household plumbing and water for flushing--have often been ignored in engineering analyses. The former is important for all technologies and accounted for no less than 45 percent of total costs to households. The latter is most important for sewerage and septic tank system. Where the economic cost of water is high, the savings to be realized from designing systems with low requirements for flushing water are great; water-sealed pour-flush toilets require a minimum of water, while cistern-flush toilets use 50-100 liters of water per capita a day. These water requirements, moreover, imply that the corresponding technologies are feasibly only where water is available from house connections and where excess water can be

Figure 1 - Generic Classification of Sanitation Systems



Dry (on-site):

1. Overhung latrine
2. Trench latrine
3. Pit latrine
4. Reed Odorless Earth Closet
5. Ventilated improved pit latrine
6. Batch-composting latrine
7. Continuous-composting latrine

Wet (on-site):

8. Pour-flush latrine, soakaway
9. Pour-flush latrine, aquaprivy, soakaway
10. Pour-flush, septic tank, vault
11. Sullage-flush, aquaprivy, soakaway
12. Sullage-flush, septic tank, soakaway
13. Conventional septic tank

Wet (on-site or off-site):

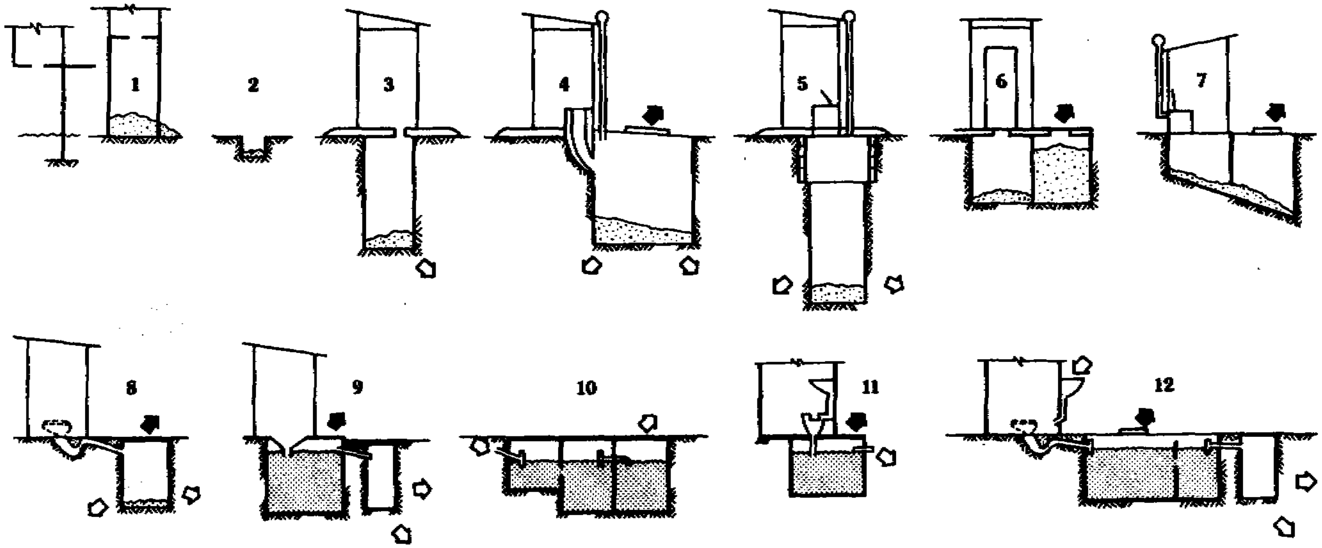
14. Low-volume cistern-flush, soakaway, or sewer
15. Low-volume cistern-flush, aquaprivy, soakaway, or sewer
16. Low-volume cistern-flush, septic tank, soakaway, or sewer

Wet (off-site):

17. Conventional sewerage

Dry (off-site):

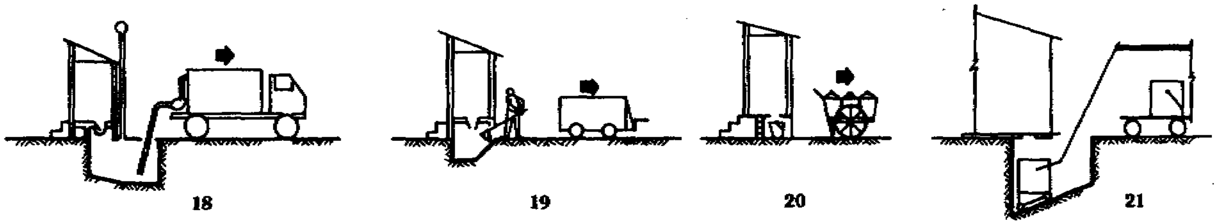
18. Vault and vacuum tank
19. Vault, manual removal, truck, or cart
20. Bucket latrine
21. Mechanical bucket latrine



13 Same as 12 except conventional cistern-flush.

14, 15, 16 Same as corresponding configuration in 8 to 12, except for elevated cistern with low volume-flush.

17 See standard manuals and texts.



Movement of liquids; movement of solids.

Source: The World Bank, Water Supply and Waste Disposal, Poverty and Basic Needs Series (Washington, D.C., September 1980).

Table 3: ALTERNATIVE SANITATION TECHNOLOGIES FINANCIAL REQUIREMENTS FOR INVESTMENT AND RECURRENT COST PER HOUSEHOLD (1978 U.S. DOLLARS)

ology	Total invest-ment cost a/	Monthly investment cost b/	Monthly recurrent cost	Monthly water cost	Hypothetical total monthly cost b/	% of income of average low-income house-hold c/
	1	2	3	4	5	6
ost						
flush toilet	70	1.5	0.2	0.3	2.0	2
atrine	125	2.6	-	-	2.6	3
nal toilet d/	355	7.4	0.3	0.6	8.3	9
m-truck cartage	105	2.2	1.6	-	3.8	4
ost septic anks	205	4.3	0.4	0.5	5.2	6
sting toilet	400	8.3	0.4	-	8.7	10
t cartage d/	190	4.0	2.3	-	6.3	7
m-cost						
ed aquaprivy	570	7.1	2.0	0.9	10.0	11
rivy	1,100	13.7	0.3	0.2	14.2	16
ese vacuum-ck cartage	710	8.8	5.0	-	13.8	15
cost						
c tanks	1,645	14.0	5.9	5.9	25.8	29
age	1,480	12.6	5.1	5.7	23.4	26

Including household plumbing as well as all other on-site and off-site system costs.

Assuming that investment cost is financed by loans at 8% over 5 years for the low-cost systems, 10 years for the medium-cost systems, and 20 years for the high-cost systems.

Assuming average annual income per capita of $180 and 6 persons per household.

Based on costs per capita scaled up to household costs to account for multiple household use in some of the case studies.

easily disposed of. Soil conditions and housing densities may preclude reliance on technologies that require soakaways; collecting systems, whether dry or waterborne, demand investment in off-site treatment facilities. Use of stones, maize cobs, and the like for anal cleansing may obstruct some systems. Facilities that call forthe simpler technologies can often be installed and maintained by homeowners, provided that they receive appropriate instruction, while waterborne sewerage demands skilled labor and professional engineering.

Technology Selection

Selection of the most suitable sanitation technology is site specific because the selection depends on sociocultural conditions, population density, soil conditions, the health profile and resources of the community. For water supply, the question is less one of technology--reduced in its simplest form to a choice between individual or communal wells and piped systems--than the selection of the service standard, standposts, patio hydrants, house connections, which are affordable to the user. For the selection of both the water supply and sanitation technology, the question often is reduced to: which is the least expensive, technically feasible technology the users will accept, can afford and maintain and the local authorities are able to operate.

Algorithms, developed by Dr. S. Duncan Mara, Professor of Civil Engineering, The University, Leeds, one of the principal researchers of a World Bank appropriate technology research project and co-author of several of the project publications (7, 8), are a guide to the types of questions to be asked in the selection of sanitation technologies. Although they are applicable to most situations encountered, there will always be the ocasional combination of circumstances for which the most appropriate option is not that suggested by the algorithm. Those shown on figures 2 to 4 should therefore not be used blindly in place of judgment, but as a tool in the decision-making process.

Upgrading Sequences

The selection of technologies should reflect both existing conditions and the future need for incremental improvements as the users' aspirtions and socioeconomic status rise. The design of sanitation upgrading sequences should reflect in particular incremental improvements in water supply because of the importance of water availability and cost in sanitation technology selection. Table 4 lists costs of water and sanitation services at different service standards in a Brazilian town.

Figure 2 – First-stage Algorithm for Selection of Sanitation Technology

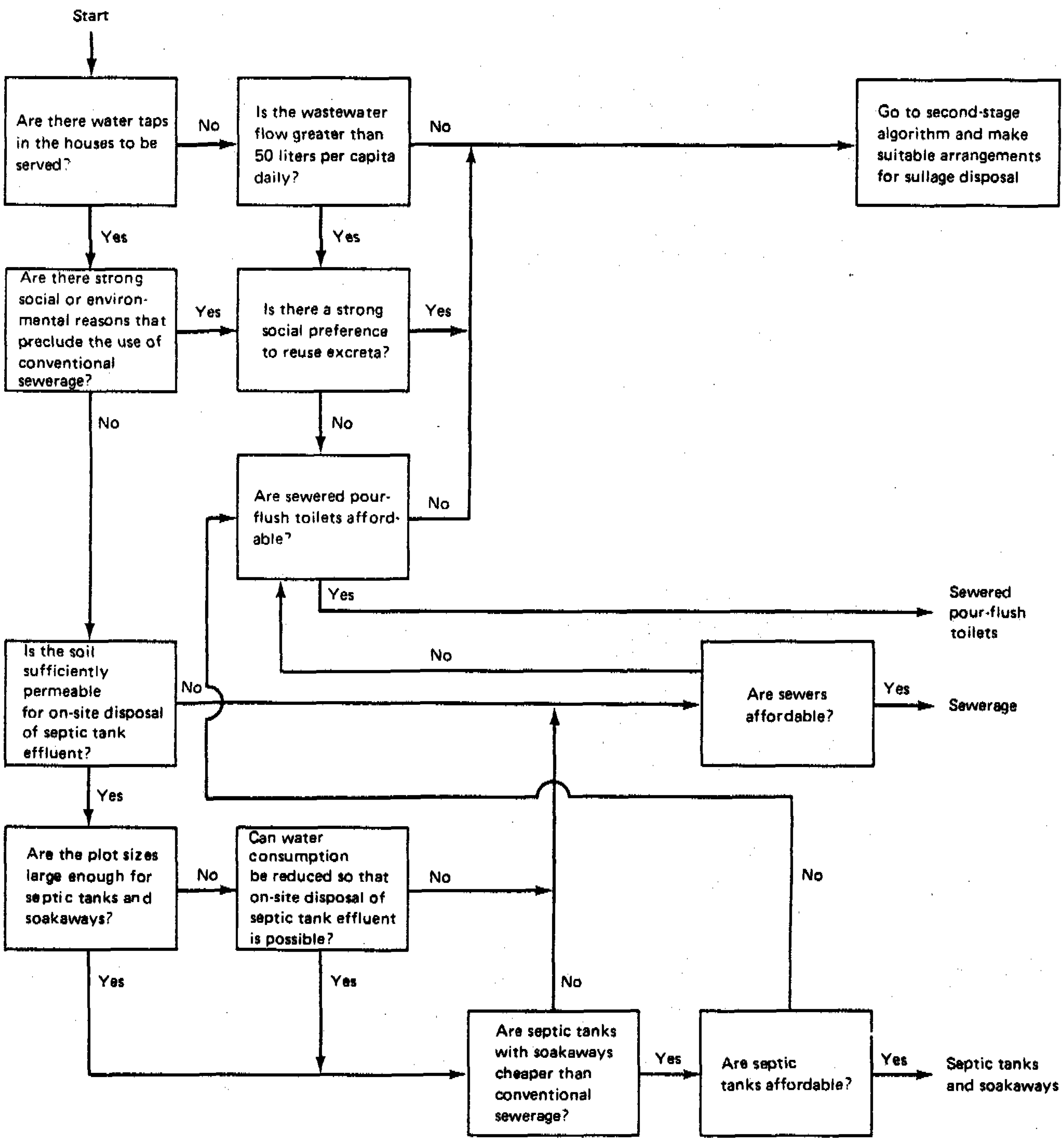


Figure 3 – Second-stage Algorithm for Selection of Sanitation Technology

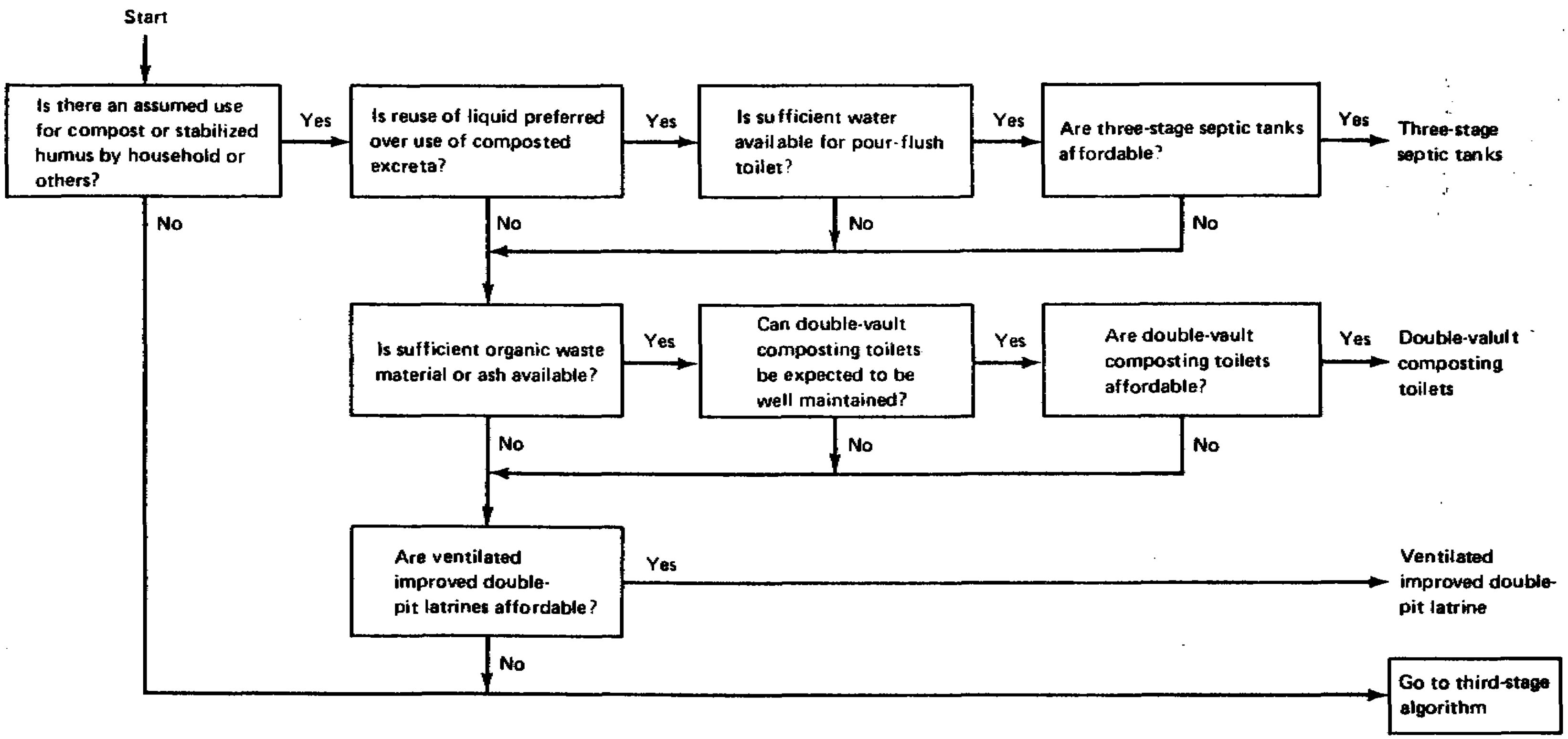


Figure 4 – Third-stage Algorithm for Selection of Sanitation Technology

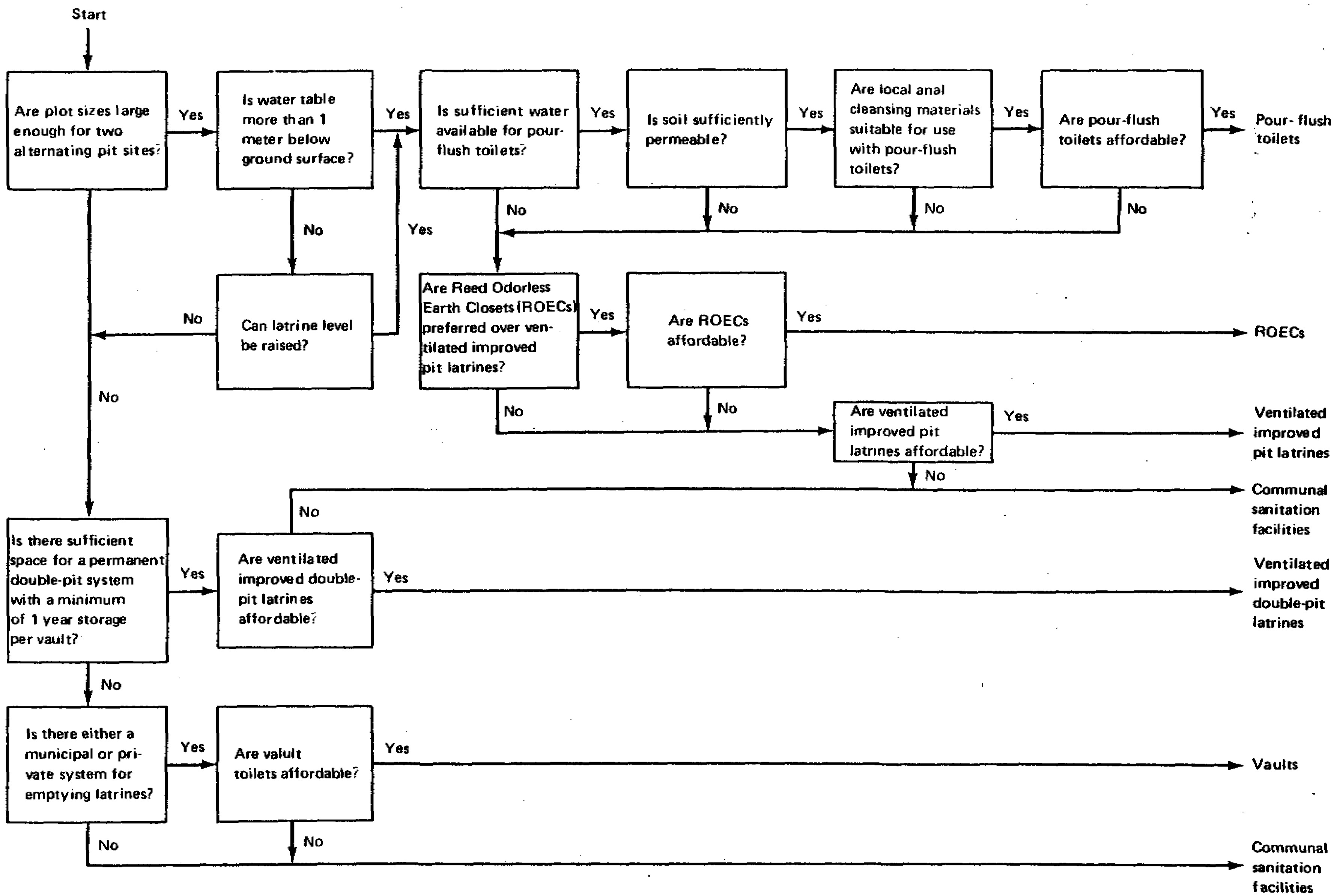


Table 4: DEPENDENCE OF SANITATION COSTS UPON WATER SUPPLY SERVICE LEVELS

Population per hectare	Water service level: lcd	Water service level: Average radius (in m) of area covered by standpipe	Average costs per household: Water supply 1/	Average costs per household: Sanitation	Average costs per household: Total
100	20	100 2/	52	70 4/	122
	20	50 2/	116	70 4/	186
	100	0 3/	425	1,500 5/	1,925
300	20	100	23	70	93
	20	50	51	350	401
	100	0 3/	310	1,500 5/	1,810
800	20	100	10	107	117
	20	50	25	355	380
	100	0 3/	178	1,500 5/	1,678

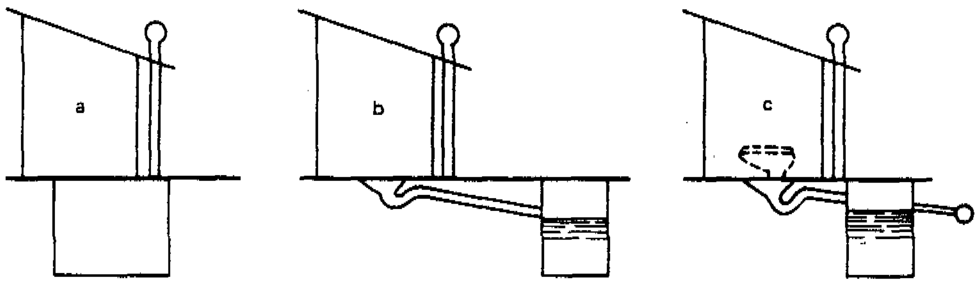
1/ Distribution costs only.
2/ Standpipe service.
3/ Houseconnections or patio hydrant service.
4/ Latrine.
5/ Gravity sewers, no rock excavation, minimum treatment and marginal costs of flushing water.

The Brazilian example clearly demonstrates the impact on cost of the change from pit latrines to waterborne sewerage required by the need to dispose of the greater amount of wastewater generated once water houseconnections are installed. Fortunately, a variety of sanitation improvements can be made which result a more gradual increase in standards and costs. One such scheme would start with a Ventilated Improved Pit (VIP) latrine, upgrade the latrine to a Pour Flush (PF) toilet after ten years and, with the installation of water supply houseconnections after another ten years, add small bore sewers to carry away excess wastewater which can no longer be disposed off by on-site drainfields.

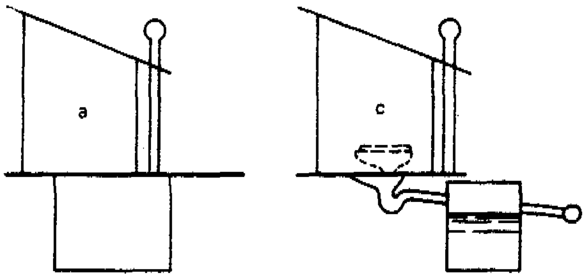
The present value of the total cost per household of this three-stage scheme over a 30-year period is $354 including the salvage value of the sewerage system, which is assumed to have a 40-year life. A variation, a two-stage scheme that moves directly from the VIP (installed in year 1) to small-bore sewers in year 11, has a present value cost per household over 30 years of $1,111. A third alternative is the installation of a small-bore sewerage system in year 1. This would have a total present value cost of $1,519 per household over 30 years. A final alternative,

Figure 5 — Sample Sanitation Sequences
(cost data in 1978 U.S. dollars)

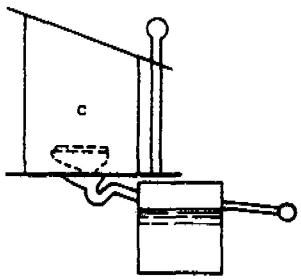
Item	Year 1	Year 10	Year 20	Year 30	Total economic cost per household 30-year period
Scheme 1					



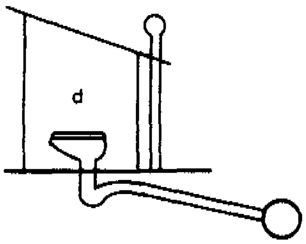
Item	Year 1	Year 10	Year 20	Year 30	Total economic cost per household 30-year period
Construction cost	108	65	905		354
Scheme 2					



Item	Year 1	Year 10	Year 20	Year 30	Total economic cost per household 30-year period
Construction cost	108	915			1,111
Scheme 3					



Item	Year 1	Year 10	Year 20	Year 30	Total economic cost per household 30-year period
Construction cost	960				1,519
Scheme 4					



Item	Year 1	Year 10	Year 20	Year 30	Total economic cost per household 30-year period
Construction cost	978				3,000

a, Ventilated improved pit latrine; b, pour-flush toilet with soakaway; c, pour-flush toilet with small-bore sewer (with optional bowl and seat); d, conventional sewerage.

calculated in the same way and with data from the same city as the sewered PF for purposes of comparison, is the immediate construction of a conventional sewerage system (CS). A 5-year construction period is assumed. The facility is assumed to be two-thirds utilized upon completion and fully utilized 10 years after completion. Based on these assumptions the present value cost per household over 30 years is $3,000. This includes the cost of flushing water and all regular operating and maintenance costs (as do the costs of the other alternatives). It is nearly ten times as high as the cost of the three-stage scheme and almost twice that of the one-stage sewered PF alternative. The schemes are shown schemetically in Figure 5, where both construction cost and present value are listed for each scheme.

V. GUIDELINES

Reappraisal

To achieve the objectives of water supply and sanitation investment in developing countries, to provide the largest number of people with services at least cost in addition to serving commercial and industrial needs, a plannig approach different from the one heretofore used has to be applied. Rather than to transfer technologies from industrialized countries with few or no changes to reflect the environment in developing countries, technologies must be selected and adapted to specifically fit that environment. The methods of project development must be reappraised. The initial step is the redefinition of the plannig process:

i) Environmental Health Impact Analysis:

Market studies and demand projections usually are based on historical demands which, in industrialized countries, reflect demand for convenience, even luxury service levels, rather than basic needs and health requirements of people not yet served. Sociocultural aspects are frequently neglected, as is the fact that health improvements do not depend merely on the availability of the services, but the user's perception of their importance, his health profile and hygiene habits. The initial step in project planning should include an analysis of existing diseases, hygiene habits, nutritional status and environmental conditions in the project area in addition to the traditional demand analysis. The project should then be designed on the basis of this Environmental Health Impact Analysis (EHIA). The project as defined here would include direct health related interventions, such as health/hygiene education, before, during or after the construction of water supply and sanitation facilities. The EHIA would also provide information useful for the selection of technologies and the determination of priority areas for their installation.

ii) Master Plans

If real progress is to be made, less costly technologies must be used for those who cannot afford conventional service. The master plan should therefore include an evaluation of consumer ability to pay. From this background, a comprehensive plan can be developed which specifies a variety of technologies for different districts of the project area and recommends interventions needed to successfully achieve the intended benefits. The master plan should explicitly state the options available, their benefits and their costs so a decision-maker can choose whether to attempt to serve many people at lower standards, few at high standards, or any combination thereof his budget permits.

iii) Community Particiption

Successful planning, implementation and operation of appropriate technology projects requires the participation of the community, in contrast to the design and opertion of highly centralized, high-level technology projects where the individual has little impact on system performance or choice in service standards. Most appropriate technologies require some degree of user operation or maintenance and facilities often are built by the owner. Therefore, the user determines success or failure and experience shows that users who have not participated in the planning do not pay much attention to operation and maintenance. Consequently, an evaluation of user willingness and ability to assist in the planning, construction and operation of the facilities has to be an integral part of project development.

There are many other important aspects in the process of providing better water supply and sanitation services to those in less developed countries now lacking these services. Some of these issues have been mentioned earlier, some are covered in the publication listed among the references. The three points raised here: (i) Environmental Health Impact Analysis; (ii) Master Planning; and (iii) Community Participation, require for their implementtion a reorienttion of planners, designers, and implementers, rather than vast amounts of money or new laws. They also represent initial steps leading to improvements in the sector as a whole. As a consequence, public health and sanitary engineers, together with the behavioral scientists, must provide the leadership in the planning and implementation of measures which will dramatically increase drinking water supply and sanitation services to the less well-off in developing countries.

The logical consequence of the reappraisal of existing project development methods is the addition of certain design considerations and alternatives to masterplan and feasibility studies. As discussed in earlier papers (5, 6, 7), many projects are in fact undergoing review and redesign to reflect these considerations, and future projects should consider them from their inception. A brief project development guideline reflecting the special needs of water supply and sanitation projects in developing countries, in which aspects often ignored are emphasized, follows below. This guideline is not intended to be comprehensive or replae detailed masterplan or feasibility study terms of reference. Rather it list specific requirements of such studies for developing country communities.

Project Development

Technical alternatives for providing water supply and sanitation services should be evaluated and non-engineering aspects (capacity for operation and maintenance, need for health education, etc.) of various alternatives assessed.

Objectives

Objectives intended to be achieved in the project area including, for example, regional development, health improvement, pollution abatement, job creation, etc. should be clearly stated. These objectives should be quantified to the extent practicable and based on a analysis of existing health and environmental conditions and service demand. In particular, people to be served, service standards and target dates should be identified.

Service Standards

Description of alternative feasible service standards and explantion of implications of providing services at these various standards should be discussed. For water supply, this could include individual point sources (wells or rainwater catchments) or communal facilities with alternative distribution standards such as public standpipes, courtyard connections or private connections to each building. The distance to water points is a matter of convenience which directly affects water use habits.

The range of consumption levels associated with each standard should be assessed, as well as prospects for upgrading over time. Particular reference should be made to linkages between service standards for water supply and the related standards for disposal of wastewater and human wastes.

The range of service standards for sanitation which should be considered includes flush toilets in the house, individual latrines inside or outside the house, or communal toilets.

Options for Water Supply

In the light of a range of average and peak demands, considertion of feasible components of possible future water supply systems, should be evaluated. Particular attention should be paid to opertion and maintenance capacity and remedial measures recommended for the reduction of customarily high unaccounted-for water levels.

Options for Sanitation

A wide range of sanittion systems merit consideration, from simple latrines to conventional sewerage. The ultimate disposal of the wastes, and the associated environmental impact, merit more attention for communal and waterborne systems of sanittion than for individual on-site systems. In all cases, however, the health impact on local groundwater supplies merits particular study.

Determination of Priorities

Implementation priorities should be evaluated using criteria such as:

- need for services based on the analysis of existing conditions in the project area, helth problems, access to water, commercial and industrial needs, etc.;
- per capita costs of alternative standards of service;
- possible capital constraints which could provide a budget ceiling for program implementation;
- implementation capability of agency or agencies with role in delivering of services;
- willingness of local communities to designate leadership and participate in system implementation;
- delivery systems for supporting programs (software);
- political priorities on regional, state or district basis;
- other factors of local significance.

Alternative System Developments

A range of alternative development programs for water supply and sanitation systems throughout the planning period should be postulated and evaluated. A screening process should reduce the alterntives to a small number, perhaps four or five, which would be described and presented in some detail. For each of these programs, the services to be provided in each year should be estimated in terms of the standard of service and the number of people to benefit. Funding requirements for new works and operating cost of existing facilities should also be estimated for each year.

Each sanitation program should be rationally consistent with the complementary water supply program in terms of priority areas, standards of service, etc.

Various possibilities for staging the development of major systems should be investigated. Also, the possibility of upgrading the system over time should be explored.

Cost Effectiveness and Affordability

Each alternative development program will probably have different costs and benefits. Judgments will have to be made of the more attractive options in economic and financial terms.

Costs should be presented both in economic terms (constant prices, free of inflation and transfer payments such as taxes) and in financial terms.

The cost effectiveness of each alternative program need to be assessed and compared to the others. Examination of the per capita costs (capital plus recurrent) for the various standards of service can be helpful in this regard.

For any programs which have comparable benefits (the same people receiving comparable standards of service), the more attractive alternative would clearly be the one with least costs. Future capital and operating costs for each program should be discounted to determine the total present value of each program.

Another test of the merit of alternative development programs is their affordability in terms of the user group. Assumptions should be made on cost recovery policies (consistent assumptions for each case) and the resulting per capita costs to pay for alternative programs should be estimated. These selling prices for sector services should then be compared to per capita income levels in the project area to determine whether or not the people are likely to be able to afford to pay for the program.

Health and Environmental Aspects

Each different program will have different impacts on the public health of people, and more generally on the environment, in the project area. Such impacts should be estimated, in qualitative more than in quantitative terms, and contrasted between alternatives. The relative impact and differences between the different programs should be compared and evaluated.

Recommended System Development

A preferred development program for sector systems should be presented, along with the justification for the recommended program.

A thorough description of all components should be provided, with information including:

- location map;
- technical features of each major component;
- proposed staging of construction;
- costs, by years, for construction and operation of all program components;
- implementation schedule with realistic allowances for all steps up to initial operation of each component;

Supporting Programs

Implementation of system facilities will not, in itself, meet the sectoral objectives. Complementary non-engineering activities should also be planned to support the use of the physical facilities. Components of such supporting programs, which also merit considerable attention and consideration of alternatives, should include:

- development of awareness among project area residents about the linkages between water, sanitation and disease;

- training local residents to assist in the construction and opertion of system components;

- training of the staff of various agencies involved in sector developments.

Preliminary estimates should be provided of the magnitude and cost of suitable supporting programs, along with a timetable.

Recomended First Stage Project

The first stage project would consist of:

a) primary components of the recomended system development which could be built within the near term, say within the next three to four years, or components most urgently needed to alleviate serious problems;
b) rehabilitation of existing system facilities;

c) supporting programs for people in the project area, engineering organizations and other organizations, all of whose inputs would be essential for a comprehensive water supply and sanitation project. Each component of the so-called software package (community motivation, education, manpower development, etc.) should be included.

All project components should be described and costed, with sufficient allowance for contingencies. Provision should also be made for price increases.

A complete implementation schedule should be provided, showing all subsequent actions required to make the project operational.

Institutional Aspects

Each agency or group (government or non-government) whose involvement is desirable in subsequent stages, should be identified. Their role in each future stage should be defined and an estimate made of the resources they require (personnel and financial) to provide the necessary outputs. A lead agency should be identified as having overall responsibility for each future stage.

Institutional constraints should be identified. If no suitable organization exists to manage the overall project or components thereof, suitable recommendations should be made. Correctible weakness in existing organizations should also be analyzed and improvements suggested.

Particular attention should be focussed on manpower requirements at all skill levels and in all groups, government and private, expected to be involved in project implementtion and operation. These requirements should be compared to the available manpower supply in order to determine the shortfalls and need for various training programs.

Financial Aspects

Tentative sources of finance should be suggested to provide all funds required to construct the project. All local sources of capital should be explored, including banks, pension or life insurance funds, other credit institutions and government budgets and potential international sources of capital should identified.

Total capital requirements for all programs of the agency or agencies responsible for the project should be estimated, along with a tentative financing plan for these total programs, includig the project.

The recurrent expenditures associated with the operation and maintenance of the project should be estimated for future years. Alternative methods of financing these recurrent expenditures should be considered, including various methods of recovering costs from the users for the services provided. A reommended policy and program should be provided concerning recurrent revenues and expenditures.

Issues

Possible special issues which might arise should be identified and evaluted, such as:

- boundary questions for project area or involved agencies;

- water availability and possible need for cooperation with adjacent regions in sharing resources;

- availability of land for project facilities;

- difficulty in planning water supply and sanitation services at same time because of different institutional responsibilities;

- problems in coordinating health and engineering inputs in project development;

- unwillingness of local leaders to consider alterntive standards of service or legal/administrative difficulties associated with alterntive technologies;

- possible need to change policies for charging for sector services;

- shortage of labor or materials for project construction; of trained local personnel for community motivation or hygiene education.

Uncertainties and Sensitivity

The degree to which conclusions are sensitive to basic assumptions and data limitations should be explained, at least in qualitative terms. For example, when alternative contending projects are being compared, there should be an indication of what conditions would have to change in order for the second best project to become the preferred project; and vice versa.

Monitoring

The reappraisal/appraisal guidelines suggested above do not involve new technologies or fundamental changes--except that they provide for service at an affordable price to all by means of a careful selection of service standards and the technology appropriate to them and insist that projects should be designed on the basis of an analysis of local needs (health, environment, etc.) with solutions the local community can operate and maintain. These ideas are not new, in fact, to those who work for any length of time in developing countries, they appear to be no more than good common sense. Why then suffer so many people from inadequte services, either because only part of the community has access to them, or because the facilities are in such a state of disrepair that service is deficient?

Some of the principal causes, such as use of the wrong technologies, lack of staff development, etc. are discussed in this and other papers. These papers indicate improved project design requires policy-makers and engineers to learn from past experience and modify their approach accordingly. That projects continue to reflect industrialized country solutions rather than local conditions, is at least partially, if not principally, a lack of systematic, continuous monitoring of project performance and project impact. If decade objectives are to be accomplished, i.e., permanent improvements achieved, project designs should include the establishment of a permanent monitoring system which allows those reponsible for operation and maintenance to verify system performance and those resonsible for policies and financing to ascertain that project objectives are being achieved.

The monitoring indicators should be selected to verify: (i) the accuracy of key assumptions and forecasts on which project design is based, and, (ii) achievement of objetives. Obviously, the monitoring system has to be designed to reflect project conditions as no universally valid set of indicators exist. Monitoring projet performance and impact with selected indicators will permit modifications to the project being monitored to improve its performane and provide information to improve the design of future projets. Monitoring indictors commonly used are listed below:

A. WATER

Staffing

Number of permanent employees against targets (can be total or broken down by category such as: production/treatement, meter reading, billing and collecting, engineers, accountants, etc.).

Employees per 1,000 connections or similar parameter (excluding construction labor).

Employees per mgd produced, or sold or other parameters.

Number of people trained per year in agreed program (actual vs. agreed or other measure).

System Opeprations:

m^3 of water produced.

m^3 of water sold.

$$\frac{\text{Water Produced - Water Billed}}{\text{Water Produced}} \times 100 = \text{\% of unaccounted-for water}$$

Total number of connections.

Number of metered connections.

Number of connections by category and % metered, i.e. residential, industrial, etc.

Number of public standpipes, number of standpipes metered.

Number of new connections (total or by category).

Number of people benefited directly.

Water billed/capita in area.

Water billed/connections (and/or by type of connection).

Peak day production.

Number and length of periods of no pressure or reduced pressure (separte for system as a whole, and specific parts).

Average daily hours of service, if intermittent.

Pressure range on system.

Number of system leaks repaired.

Number of meters repaired/replaced.

Number of meters installed (on new or on unmetered services).

For National or Specific Area Programs

Percentage or number of cities with public water service.

Percentage of people in urban population served by water from public system (house connections or house and hydrants).

Percentge or number of villages without access to safe water.

Percentage of village populations having reasonable access to safe water (specify distance to define reasonable).

(a) Number of systems completed during period (urban or rural).

(b) Number of people benefited.

B. SANITATION

Remark: Many indicators shown for water are applicable with slight modifications (e.g. water distributed/treated becomes sewage collected/treated). Specific sanitation oriented indicators are given below.

Water sold and sewage produced.

Water sold and sewage treated.

Sewer connections and water connections.

New sewer connections/year/1,000 population.

Number or percentage population served by direct sewer connections system.

Number or percentage of population served by onsite excreta disposal.

Number or percentage of population served by communal toilets (septic tanks, latrines).

Number of people per communal toilet.

Number or percentage without access to excreta disposal service.

Cost/kilo (or other unit) of BOD removed.

Sewer investment/1,000 population.

Actual and potential house connections.

Total annual cost and per capita costs for service to onsite disosal systems (pit emptying, etc.).

Total annual cost and per capita costs for sewage collection and treatment.

C. FINANCIAL INDICATORS (WATER AND/OR SEWERAGE)

Net plant investment
  for water per average mgd produced
  for sewerage, per connection or per capita

Average depreciation rate (annual deprecition charge average gross plant excluding work in progress).

Operating revenue per unit of value of gross plant.

Operating revenue per connection.

Average revenue per m^3 or 1,000 gal, sold/collected (total and by consumer class).

Cash operating expense per unit of value of gross plant (exclude depreciation).

Total operating expense per 1,000 gals, or m^3 sold.

Numner of average days bills outstanding (by customer category if possible).

Revenue effectiveness index :

$$\frac{\text{Revenue Collected: gross } m^3 \text{ (or 1,000 gal) produced}}{\text{Average Revenue Billed per } m^3 \text{ (or 1,000 gal)}}$$

D. HEALTH AND SOCIAL INDICATORS

Incidence of principal water/sanitation related diseases such as:

Gastroenteric diseases

Ascaris

Hookworms

Other parasites

Other diseases

Schistosomiasis

Pneumonia

Tuberculosis

Number of people per:

physician

nurse

hospital bed

Child mortality rates (1-5 years)

Life expectancy

Per capita income poverty threshold

Number of people below threshold

Percentage of income (based on minimum legal wages or poverty level income) spent for:

Medical care/and medication

Fuel for cooking and heating

Housing

Food

Clothing

Water

Sanitation

Population density (people per ha)

Average size of household

Although this list is fairly comprehensive (especially for revenue earning public utilities), there are probably other indicators more suitable for any given project. Whatever indicators are chosen, three to five per category (i.e., a total of not more than 15) should be sufficient to properly monitor the project while keeping the task of data collection and analysis at manageable levels.

VI. CONCLUDING REMARKS

A review of the design and impact of water supply and sanitation projects in developing countries reveals that many, if not most, fall short of reaching their objectives. They frequently do not respond to local conditions, do not reflect the intended beneficiaries' perception of their needs and exceed the communities' competence to operate and maintain the facilities. Project designs are not improved because there is no systematic process of feedback to the policy maker or designer.

If the Interntional Drinking Water Supply and Sanitation Decade is to be more than a slogan, everyone involved in the planning and implementation of water supply and sanitation projects must reappraise the approach used in the past and emphasize environmental health considerations, affordability, community participation and appropriate technology selection in project design. Projects which do not attempt to serve all members of a community, albeit at different service standards, and do not ensure permanent and adequate operation by local organizations, are not responsive to the needs of developing countries and are doomed to partial or total failure. The task requires less the infusion of large accounts of money but rather the imagination and expertise of water and sanitation professionals to make projects--and thus investments--more effective and improvements andpermanent. In short, what is needed is not new inventions and scientific breakthroughs, but the innovative use and implementation of the tools already available.

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