WATER SUPPLY AND WASTEWATER DISPOSAL IN DEVELOPING COUNTRIES

Proceedings of a Water Supply and Sanitation Seminar
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EDITORIAL

The Water Supply and Sanitation Seminar was organized to complement an exhibition held at the U.S. Trade Center in Bangkok under the auspices of the U.S. Department of Commerce. One editor (Okun), as Director of the Seminar, took as his responsibility the creation of a professional seminar that would be of value to engineers, scientists, and government officials of the developing countries in the region and that would promote programs of community water supply and sanitation.

Participation in the program, and therefore in these Proceedings, was only by invitation. Manufacturers of equipment were invited because of the special contributions that such manufacturers make to water supply and sanitation projects. Moreover, proprietary items were not at all discussed in the Seminar.

The Seminar and these Proceedings cover the following subjects: The Importance of Water in Community Health and Economic Development; Water Supply and Sanitation Problems in Asian Communities, including problems typical of developing countries in Africa and Latin America as well; Planning Water Projects; Water Resources Development; Water Quality Management; Wastewater Management; Systems Operation and Management; and New Developments in Water Supply and Sanitation.

The responsibility for publishing the Proceedings volume was accepted by the Asian Institute of Technology (AIT) in the belief that it would become a valuable work of reference in developing countries. Contributors had attempted to present ideas in the context of developing countries and this orientation encouraged the editors to make the information available to a wider audience. Papers included are by authors from six countries as well as an international agency. Almost 500 people registered for the Seminar, including 99 from outside Thailand, representing in all fourteen nations.

The technology for implementation of water supply and sanitation programs in communities in developing countries is well developed, but implementation of programs for the construction of water supplies and wastewater collection systems has been slow. It is hoped that seminars and proceedings volumes such as this will help stimulate programs in water supply and sanitation for communities in developing countries throughout the world.

D.A. Okun & M.B. Pescod

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WATER SUPPLY AND SANITATION SEMINAR SUMMARY

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It is difficult, if not impossible, to present an adequate summary of the Seminar because of the broad spectrum of topics covered and the detail in which the papers were presented. Approximately forty speakers participated; their papers were of uniformly high quality and covered most aspects of the water resource, community water supply and waste disposal problem. The accumulated papers represent, in essence, a textbook on both present and future practice in the water supply and sanitation field.

In brief, the Conference was an exciting event marked by enthusiasm and sustained interest on the part of the five hundred participants. The Seminar marks, I believe, an important milestone in the economic and social development of Southeast Asia.

Perhaps the most significant feature of the Conference was that it was held at all; it was unique in its objectives (concentrating primarily on water supply and water pollution); it was truly regional in that sixteen nations from Southeast Asia participated; it was pioneering in that it represented the first meeting of its kind to be held in the region; and finally, it represented a truly cooperative undertaking on the part of manufacturers, consultants, academicians, government officials and students.

While it is impossible to adequately summarize the individual papers, there was general consensus among the participants on the following points:

1. Southeast Asia presents a unique environment which differs markedly from that of Africa, South America, Europe or North America. One of the features of the region is the general availability of water, and this, in turn, results in a uniformly high population.

2. One of the problems of the region is a lack of adequate data regarding water supply and sanitation, and this exists both in individual countries, the region, as well as between countries. Data is unavailable or inadequate regarding populations, stream flows, water consumption, sewage treatment, treatment standards, etc.

3. The region is marked by a high population density and a high rate of population increase. While the population is for the most part rural, increased agricultural efficiency will require fewer and fewer farmers and the present movement toward urban centers will increase markedly during the latter part of the Century.

4. Water is one of the region's most important resources. As such, its development must be planned on a multipurpose basis with long-range social and economic goals as primary objectives. Engineers must be prepared to provide leadership in this field and to plan for the rational conservation and utilization of water resources with community water supply and waste disposal as important but not exclusive factors.

5. Water resource development must be approached with an adequate knowledge of the experience which has been gained elsewhere; on this basis the most promising techniques should be adapted to local conditions in the full knowledge of both the successes as well as the failures which have taken place in other countries. It is essential that Southeast Asia avoid the mistakes of the past and not in effect "repeat the industrial revolution all over again."

6. A number of participants referred to the inferior status of the engineer engaged in public works, particularly in the water supply and waste disposal field. This is characterized by a generally low pay scale and difficulty in securing adequate appropriations for needed works. It was believed that this could best be remedied by a more statesmanlike attitude on the part of the engineer in adopting a systems approach to the conservation and development of the total water resources of a country for the long-range social and economic benefits of its inhabitants. The new World Health Organization concept of health—not merely the absence of disease or infirmity but the positive social, economic, mental wellbeing of man—could well serve as a guideline for future thinking in this regard.

7. For too long engineers have been underestimating the value of water as a commodity and should begin to recognize its vital importance together with the willingness of people to pay for it. If water prices were increased to more nearly represent the full cost of production and delivery, more capital and operating funds would become available for water supply projects.

8. One of the features of the Seminar was to recognize that all phases of water supply and pollution control are important and that none can be neglected. Papers were presented covering the following:

   Planning
   Design
   Finance
   Construction
   Management
   Operation

9. There is urgent need to develop unique criteria for all phases of water supply and waste disposal programs in Southeast Asia and this will require additional data for evaluation purposes. It was agreed that neither American standards nor those proposed by the World Health Organization necessarily apply directly to the region; with economy as an overriding factor, it was agreed that lower standards than those generally in world-wide use could be justified.

   A major consideration in plant and distribution design should be simplicity. This does not infer that advantage should not be taken of the latest and best techniques available anywhere but in labor intensive areas such as Southeast Asia there is little justification for excessive use of automation as compared to manual operation.

   Because of rapidly increasedp opulations, water consumption should be given the highest priority and every effort should be exerted to cut down on consumption consistent with health and sanitation. Many techniques are undoubtedly available to the imaginative engineer (such as cutting down the amount of water required by flush toilets, etc.) which have not been given a high priority by western engineers. There are also opportunities for producing minimum standards in pipe sizes and other appurtenances consistent with the Southeast Asian economy.

10. It was agreed that the continuous operation of water works plants should have the highest

priority. Part-time operation is inconsistent with safety and good management and should be avoided at all costs.

11 In the field of research and data collection, the engineering colleges of the region are a priceless asset and should be encouraged to participate, in fact, to take the leadership in developing design and operational criteria. Papers by representatives of the Asian Institute of Technology in Bangkok served as excellent examples of the types of investigations which are needed — each country represented has, however, schools which could make definite contributions as well.

12. Regardless of the social benefits of adequate water supply and waste disposal facilities the primary objective should still be the control of communicable disease; cholera, dysentery and other similar water-borne diseases are still epidemic in a large part of the region.

13. In the study and analysis of economic and social development, water resources are not always taken into account; economists and planners must be impressed with the important role which water plays in development and adequate investments must be provided for its development.

14. On a more limited basis, considering municipal water supply and sewerage projects, it was agreed that these must be adequately financed and operated on sound-business lines with sufficient revenues to fully cover capital costs and operation. There is no justification for having water supply and sewerage projects either inadequately financed, managed or operated.

15. A number of promising new techniques were reviewed, including the utilization of atomic energy and desalination. As was previously stated, there is nothing inconsistent with the utilization of new techniques in designing plants but having them as simple as possible to operate and maintain.

16. One of the primary benefits of the Conference was the opportunity which it provided for professionals from a variety of fields in the region to get together to discuss common problems. It was generally agreed that the impetus developed by the Conference should not be lost and that future meetings should be held within the region to further the objectives so clearly stated in this first meeting.

KEYNOTE – IMPORTANCE OF WATER

THE IMPORTANCE OF WATER IN COMMUNITY HEALTH AND ECONOMIC DEVELOPMENT

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The present era is one of development. The term development is widely used in connection with public as well as private undertakings. In the United Nations Organization alone, several of its agencies are concerned with development, namely, the International Bank for Reconstruction and Development, the International Development Association, the Inter-American Development Bank, the Asian Development Bank, and the Organization for Economic Co-operation and Development. The United Nations Organization also initiated the well-known "Development Decade", generally accepted by most of its member states.

According to the United Nations Administrative Committee on Co-ordination (ACC), "the essential purpose of development is to liberate mankind from poverty, squalor, disease, ignorance and exploitation, so as to permit the full evolution of human personality and dignity. This can be done; the human race now has the necessary knowledge and resources. What is needed is to mobilize our knowledge and resources for these purposes, and use them rightly."

"The First Development Decade" has just come to an end, and it has proved that it is possible to provide opportunities to the people for a better life. It has also been noted that although economic growth is an ultimate objective in development, nevertheless the essence of the development process is human development. We are now at the threshold of the "Second Development Decade." If the success of the First Development Decade is to continue, concerted effort must be made by all nations to create full international co-operation. With regard to its development policy, the ACC declared "Development policies and programmes must be oriented towards steady improvement in living standards of the masses, and the goal of balanced economic and social development, which is to serve man, should, in fact, be at the heart of the Second Development Decade."

Modern concepts of development closely interrelate economic and social activities; they are regarded as inseparable and of equal importance. Social development deals with education, health, welfare, public utilities, etc. Community health is one of the sectors which should receive close attention, and should be given high priority in a development programme.

WATER AND COMMUNITY HEALTH

Water is most essential to life and most human activities involve the use of water in one way or another. It is now universally accepted that by providing a community with safe water, epidemics of water-borne diseases such as cholera and typhoid fever can be prevented, and incidence of these diseases can often be considerably reduced. Other water-borne diseases include dysentery, paratyphoid fever, infectious hepatitis, hookworm, etc. By adding certain chemicals to the community's water supply, some diseases can be prevented.

WATER AND WASTES DISPOSAL

It was not until after the development of water supplies that the water-carried system of wastes disposal was made possible. This improvement, together with safer water supplies, resulted in a notable reduction in the incidence of water-borne diseases.

WATER FOR RECREATION

Swimming is a very healthy and invigorating form of recreation, which is now becoming very popular. A number of intestinal and respiratory diseases as well as skin infections can be transmitted by the water of a swimming pool. Close supervision of its sanitation, especially the bacteriological quality of the water, is imperative. Natural swimming and bathing places at the seashore and in lakes, rivers, and streams usually have plenty of water and seldom create serious health problems.

As society becomes more affluent, more and more people participate in water sports such as sailing, skiing, skin diving, surf board riding and fishing. There are no serious public health problems connected with these sports except when performed in sewage polluted waters.

WATER FOR PUBLIC USE

In communities where public water supply is plentiful and inexpensive, water is often used for flushing drains and sewers, for cleaning streets and pavements, for watering lawns, flower beds, trees, gardens and parks, and for drinking and ornamental fountains. It is generally accepted that the cleanliness, orderliness and environmental attractiveness of a community promote physical as well as mental wellbeing of its populace.

WATER SUPPLY—A VITAL REQUIREMENT FOR COMMUNITY GROWTH

A community with a restricted water supply is a community with restricted growth. Availability of water is most essential for the growth of population and its various activities. In the physical planning of a community, water supply plays an important role.

THE ROLE OF WATER SUPPLY IN ECONOMIC DEVELOPMENT

Water plays a very important role in economic development. In economic and social planning, the development of water resources is usually given a very high priority. Aside from public water supply and wastes disposal, the main uses of public waters include industrial water supply, agricultural use, hydroelectric power, and navigation, all of which are related to the economy of the community.

WATER SUPPLY AND INDUSTRIAL DEVELOPMENT

Most industries require water for their operation. The quantity and quality of water required for each industry vary. In most instances, it is neither economical nor practical for industrial establishments to provide their own water supply. Industries will usually locate in communities where ample water supplies of suitable quality are readily available and where sewerage systems already exist for the proper disposal of their wastes.

WATER FOR AGRICULTURAL USE

In regions where agriculture predominates, an adequate supply of water must be made available at appropriate periods in order to ensure maximun agricultural production. The largest single agricultural use of water is usually for irrigation, which is often the largest consumptive use. Other uses are for raising livestock and poultry, for processing farm products, and for other general purposes.

WATER FOR FIRE FIGHTING

Among the important benefits derived from a public water supply is fire protection. Each year the damage caused by fire, especially in underdeveloped areas, is still quite extensive, representing significant economic loss. In communities where public water supply is not available or adequate, fire insurance rates tend to be extremely high, a situation hardly conducive to commercial and industrial development.

WATER FOR FISHERY

From the viewpoint of water quality, fisheries may be treated separately from other industries. Water supply used for the propagation of aquatic life, such as fish, shellfish and waterfowl, is not required to be of the same quality as for manufacturing, for example. Nevertheless, where fishery produce forms a staple food of the population, and where fishery is a major industry, the cultivation of aquatic life becomes of paramount importance in the economy of the community. Water supply for such activity should be free from excessive toxic substances which may be derived from industrial wastes, agricultural poisons, domestic sewage, mining wastes, etc. Dissolved oxygen, turbidity, and pH values also affect aquatic life.

HYDROELECTRIC WATER POWER

Where rainfall is abundant and the terrain is favourable, hydroelectric power development is an undertaking of great economic importance. Hydroelectric power is often least expensive, and practically all water supply utilized for such purpose can be recovered for other uses. Furthermore, the quality of water is hardly of any significance, provided that large suspended matter is not present. Inexpensive sources of energy are most essential to the development of industry, transportation, public utility, and communications.

WATER FOR NAVIGATION

In spite of extensive road and railway systems, waterways still remain one of the cheapest and most common means of mass transport. In developing countries, where the economy does not permit intensive highway and railway construction, waterway systems can sometimes be developed faster and at less expense. For maintenance, they are cheaper and usually require less skill and supervision.

PROBLEMS IN WATER SUPPLY AND SANITATION DEVELOPMENT

In discussing economic development, it might not be entirely irrelevant to touch upon some of the problems and difficulties encountered in the development of water supply and sanitation, especially in developing countries. While most governments realize the importance of water supply and give it some support, other phases of sanitation such as wastes disposal, stream pollution and malaria eradication do not receive the attention they deserve.

In the field of water supply alone, innumerable obstacles have to be overcome. First and foremost is perhaps the lack of funds. The explosive growth of population coupled with unplanned urban migration render existing public water supplies of most cities inadequate. Their expansion becomes imperative, yet sources of financing are not readily available. In many instances suitable sources of supply do not exist, especially in coastal areas and other regions where both surface and ground water sources are brackish or contain excessive amounts of undesirable substances. Desalination, if inexpensive and not too complicated, would perhaps be a solution.

The paucity of trained personnel at all levels of local, municipal and central governments has often been the cause of inefficiency and delay in the development of water supply projects. Educational and training facilities should be developed and government salary scales should be revised so as to be comparable with current costs of living.

One of the main reasons for inadequacy of public water supplies is the old widespread belief, especially among the rural population, that water should be free or, at most, very cheap. Furthermore, in the development of rural water supply schemes, local participation is not easily achieved and sense of ownship rarely exists. Health education can perhaps bring improvement.

Prevalent in most developing countries is lack of maintenance. Constant surveillance and regular repair to maintain efficient and uninterrupted operation rarely exist. Breakdowns are frequent and regular and continuous service is well nigh impossible.

With the possible exception of water supply projects, most sanitation projects are usually given very low priority in development planning. This may be due in part to the public health authorities who frequently fail to present convincing and acceptable health and sanitation programmes, and often lack the capability of preparing them. Public health planning should therefore be strengthened and emphasized by training planning personnel and establishing planning units in public health departments.

In the planning and implementation of water supply and sanitation programmes, complicated and expensive installations and equipment are often used. Such practice is neither economical nor practical. Attempts should be made to employ design standards and construction procedures which make full use of materials and equipment which are locally available, inexpensive, and simple to operate and maintain. All installations should be suitable for local conditions.

Last but not least in importance is the lack of co-operation and co-ordination among the various government departments concerned, an obstacle not easy to overcome. Perhaps a solution would be the creation of a central agency vested with full financial and administrative authority in the planning, follow up, evaluation and revision of all programmes. Such practice has met with notable success in some countries in the Asian region.

THE IMPORTANCE OF WATER IN COMMUNITY HEALTH AND ECONOMIC DEVELOPMENT

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Much of the world is caught up in a rising tide of nationalism accompanied by an urgent desire for social and economic development. Because of the desire to shorten the time needed for development as compared to that taken by countries such as the United States, Canada and Australia, a great deal of attention is being paid to the selection of the most effective development investments among the many choices which are possible. The basic criterion is the economic return to the country concerned, and expenditures for services such as public health, malaria control, hospitals and water-resource development must compete for priority with many other investment opportunities in fields such as transportation, agriculture, education and industry.

If Asia is to avoid the mistakes which have been made in the growth of the industrialized nations of the world, its material resources (water, air, land and minerals) must be developed in a rational way. Water, for example, has a variety of uses: water supply, irrigation, waste disposal, transportation, recreation, fishing, aesthetics, industry, power, and the conservation of birds and wild animals; many of these uses are compatible, but in other cases a choice must be made as to the ultimate social and economic benefits. In the United States, because of an original failure to recognize water as a resource and a concomitant failure to plan its utilization on a multipurpose basis, we have glaring examples of gross pollution and the inability to develop important aspects of water use because of irreversible decisions made before priorities could be established. While it may be impractical to plan for the utlimate use of water in the detailed way in which this has been done, for example, in Israel, the establishment of a National Water Planning Board is inherent in the discussion which follows.

In the past, health services have been promoted on the basis of their social rather than their economic benefits. Recognizing the present emphasis that is being placed on economic development, the World Health Organization and the World Bank have accepted the impractability of financing public health projects on a wide-scale based on social benefits alone. However, in attempting to establish a relationship between health and economic development, they have found a serious lack of reliable information.

As a part of their public health planning, both the World Health Organization and the World Bank are now advocating a world-wide program for the construction of public water supplies "operated, managed and maintained on sound business lines." In order to win widespread acceptance for this program, they are faced with the problem of having to convince planners, economists and bankers that water-supply projects merit consideration as important factors in economic development (LOGAN, 1960). This is a matter of concern to anyone interested in the field of public health in Asia. It has been taken for granted that the control of disease, besides its basic humanitarian value, represented a sound investment in the future of the country concerned; this assumption is, in effect, being challenged, and unless a more effective case can be based on human values alone, further evidence must be sought to demonstrate the relationship between public water-supplies and social and economic development.

In accordance with modern theories of economic development, capital investment in public water supplies, like those for malaria eradication or public health in general, should be considered as a part of the social-overhead capital needed to develop and maintain a technologically-based society. Although public water supplies can have little economic justification in the so-called "traditional" economies (where the population is almost entirely rural and engaged in agriculture, public services are needed whenever industrial development begins.

The various states of industrial development have been delineated by W.W. Rostow of the University of Texas in a study which has attracted wide interest (ROSTOW, 1960). Rostow's thesis is that economic development upward from a primitive, traditional economy actually begins when a country decides that its physical environment need not be determined solely by Nature or by Providence, but that it can be an ordered world, manipulated in ways which yield productive change. In other words, in the traditional agricultural economies, life is unpredictable and fortuitous, dependent on factors such as disease, drought, famine, or flood, and man is, in effect, the slave of his physical environment. Planned progress begins only when he realizes that his environment can be controlled, and he decides to make use of science and technology for that purpose.

In the development upward from the traditional economies of countries such as those of South-East Asia to the mass consumption economies of Australia and Canada, Rostow categorized three states: (1) transition, (2) take-off, and (3) the maturing economy.

Social-overhead capital (the capital investment needed for projects of a public nature) is particularly important in the transition period, when a country makes its first conscious attempt to break away from an agricultural economy, and makes the changes in investment and labor necessary for the use of modern mass-production techniques. Social-overhead capital includes the investment needed for municipal water supplies, and also for other public-service facilities such as highways, power, railroads, irrigation, and police protection.

All of these services have both social and economic implications; investment in municipal water supply, for example, brings returns in comfort and convenience as well as economic growth. While it is difficult, if not impossible, to translate comfort and convenience into monetary terms, economic development is more amenable to evaluation in dollars and cents. It will be the purpose of this paper to indicate approaches to this latter problem.

In a developing economy, industrialization is both a means of development and an end in itself. Ways must be found to switch workers from agriculture to industry, and suitable facilities must be made available to permit industrialization to proceed. The determination of the precise role of municipal water supply in this transition is complicated; as with other social-overhead investments, there is no general agreement on measures of investment effectiveness, or on the importance of water as compared to other factors such as power or education. There is, however, a growing interest on the part of economists in development; it is now recognized as an important area of specialization, with a considerable volume of literature available. Because of their philosophy of a planned economy, Russian economists have been paying particular attention to economic development, but reports reaching the United States as late as 1958 (LESSER, 1958) show no agreement as to indices of effectiveness.

Lacking a generally recognized theory, it has been necessary to fall back on examples or statements which support the importance of water supply to industry, and economists have been willing to accept these as indicative or as illustrative. Typical of these is an advertisement of the New York State Department of Commerce which appeared in the WALL STREET JOURNAL (1959) entitled: "Now. . .Most Complete Report on Water Ever Assembled." The advertisement stresses the importance of water quality and quantity to plant location, the fact that New York State is uniquely endowed with water resources, and that it can meet any practical demand for either ground or surface supplies.

A UNITED NATIONS (1958) publication, *Water for Industrial Use*, states in part:

> "Water supply is gaining in importance as a location factor and is playing a decisive role in the location of an increasing number of new or expanding industries and even in the relocation of existing ones experiencing the problems of inadequate quantity or quality of water and rising costs... In the United States, by 1975, access to good water may become the most important factor in deciding where to locate industries ... Information (concerning water quantity and quality) ... may have important implications for the underdeveloped areas of the world now embarking on a program of industrial development."

In the United States, the Tennessee Valley Authority (TVA) has recognized the importance of municipal water supplies in the overall development of the Valley and has stressed the necessity of making adequate provision for industrial consumption in planning; a 1958 report states (TENNESSEE VALLEY AUTHORITY, 1958):

> "The use of water for municipal water supply directly affects more people in the Tennessee Valley than any other use. In addition to supplying water for domestic and commercial uses, these systems are used as primary sources of water for most small industries and many large industries ... The economic well-being of this region is, of course, directly related to continued industrial development in the area. The part that is played in this economic picture by water resources is being realized more each day .... New industries have an enviable opportunity in site planning as related to water supply. Among the variety of sites available can be found water tailored to meet any need .... Many industries use several sources of water. For instance, it is quite common in industry to obtain potable water from a nearby municipality, cooling water from an adjacent stream and process water from a well drilled on the plant grounds."

There is no lack of examples in the United States of how adequate, safe, economical, and reliable municipal supplies can attract industry. South Bend, Indiana, added 36 new industries and had an expansion of 26 old ones in the 3 years following the developments of its new supply (ANDRYSIAK, 1958). In the Simpsonville-Fountain Inn area in South Carolina (the so-called Golden Strip), a water district with a population of 1,290 people was organized for the primary purpose of attracting industry; a US$900,000 bond issue was approved by a ratio of 64:1. In 2 years, new industries alone provided employment for some 1,500 persons, and property values doubled, and in some cases trebled (AMERICAN WATER WORKS ASSOCIATION, 1956). Besides its importance as a prerequisite service to other industries, water can play an important role in stimulating the wide variety of industries which are needed for the water supply systems themselves; the manufacture of pipe, plumbing and bathroom fixtures, pumps, etc.

In a survey made in 1955 by the American Water Works Association (AWWA), of the 497 public-water-supply systems in the United States serving populations of 10,000 or more, it was found that slightly less than 50% of their revenue came from residential sales; about 19% was commercial and roughly 31% industrial (SEIDEL and BAUMANN, 1957). A study of industrial-water use made by the Bureau of the Census in 1954 (KOLLAR, 1960) indicates that manufacturers with a gross water intake of 20 million gallons per year and over (approximately 75,000 gallons per day), or 3.6% of 286, 817 manufacturers, use 97.4% of the total water used. Of this total, only 16.4% is from public supply.

Water is a unique commodity. Its role in industrial development is more that of a catalytic agent or a service than that of a raw material; only a relatively small amount of the water used by industry enters the final manufactured product. It must, however, be safe from a health point of view, it must meet minimum standards of quality, it must be available in adequate quantities, and it must be reliable. It must also be sold at a reasonable price, for although large industrial users can adjust the cost of water through the practice of conservation and reuse, small industries have very little scope for this practice.

The price of water depends on circumstances; if it is scarce it is priceless; on the other hand, in order to justify its use for the dilution of sewage, it has to be very cheap. Municipal water systems in the United States are able to deliver treated water for about ten cents per ton, and this is a reasonable guide for average costs anywhere.

Public water supply is "the foundation on which rests the health and economic progress of the community" (UNITED NATIONS, 1959). Its importance to public health varies, however, with individual communities and different countries, and must be evaluated on the basis of the prevalence and severity of water-borne and filth-borne disease. In attempting to establish the importance of municipal water supply to development from a public-health point of view, it is perhaps easiest to attempt an evaluation of the economic importance of public health, and then to determine what part of this is due to water. As an approach to the effectiveness of public health in Brazil, CAMPBELL and MOREHEAD (1952) suggested an analysis of the population distribution of the working population (men and women between the ages of 20 and 65) per million total population. They recognized that a comparison with the population distribution in more developed countries, such as the United States, would reveal a major difference; a higher percentage of working population in the developed areas and a higher percentage of dependents in the developing countries. The age group between 20 and 65 provides, in effect, the basic wealth which supports both the young (below 20) and the aged (over 65), and determines the standard of living of the country as a whole.

The high percentage of men and women in the productive age group in the United States (55%) at the present time is primarily the result of past investments which have been made in public health. In a comparison of the population of Columbia with that of the United States in Figure 1, it is evident that approximately 10% more of the

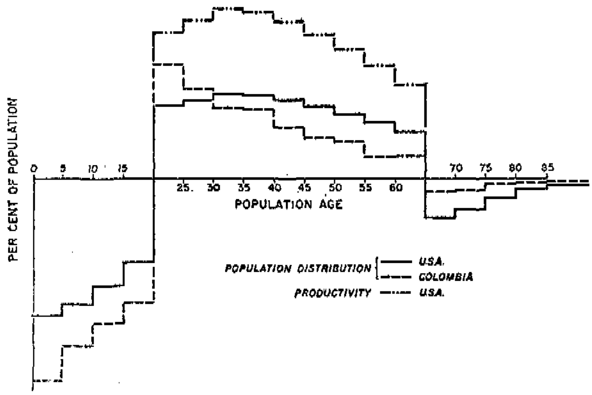

Fig. 1—Comparative productivity of working populations U.S.A. and Colombia per million people (1957). Population data from U.N. 1957 Demographic Yearbook, (1958), New York.

population of the U.S. (100,000 more per million) lies in the 20-65 age group than is the case in Colombia. On an annual basis, this means that the United States has 100,000 more man-years of productive potential per million people than Colombia.

In a comparison between working populations, efficiency must also be taken into consideration. United States workers are among the most productive in the world, partly, at least, because of their high standards of health and the absence of chronic debilitating disease such as malaria, enteritis, or schistosomiasis. For illustrative purposes, the efficiency factor has been estimated at 100% (U.S. workers are estimated to be twice as efficient as Colombians); this widens the margin between the two countries (the 100,000 difference per million is effectively 200,000). This manpower advantage is highly significant; if it is increased by the power (horsepower) available to individual workers in the United States and Colombia, the disparity in the potential productive power of the two countries is further evident.

Economists have been reluctant to recognize the importance of investments in health as a factor in capital development. Professor SCHULTZ (1959), of the University of Chicago has pointed out, however, that measures to increase the strength and energy of people and to improve their health and vitality should be considered as investments in human capital. In order to present a detailed analysis of the investment potential of public health projects, particularly of municipal water supplies, additional data are needed. These include accurate data on the capital investment required and a breakdown of the resulting effect on morbidity, mortality, and public health. However, there is no standard cost for the production of "units" of public health as there is, for example, in the production of power or irrigation. Some of the basic requirements for health in certain countries can be met very cheaply, for example, as low as five cents per capita for the eradication of yaws and two dollars per capita for the eradication of malaria. Overall public health expenditures in the United States are estimated at about $5.00 per capita per year, but this does not include the costs of water, sewerage or garbage disposal. Public water supplies require an annual expenditure in the order of from $8.00 to $30.00 per capita to cover both first cost and operations; the cost in developing countries is substantially lower.

The effect of water supply on morbidity and mortality has been amply demonstrated. Vital statistics are usually broken down into categories which make it possible to evaluate the importance of water-borne disease to death rates in any given country (mortality by age and sex for typhoid, cholera and dysentery; gastritis, duodentitis, enteritis, and colitis - International Categories B4, B5, B6 and B36). There are a number of excellent sources of information on the effect of water-borne disease on morbidity, such as VERHOESTRAETE and PUFFER (1958) and the WORLD HEALTH ORGANIZATION (1958).

The problem of translating the benefits of public health into dollars and cents has been explored by a number of economists, one of the most promising studies being that carried out by WEISBROD (1958). Using the stream-of-earnings method, based on the reported median income and median consumption of high-school graduates and their probability of life, he has obtained the present value of their net future earnings by age and sex, using discount rates of 4 and 10% (see Figure 2). Weisbrod's analysis is based on the thesis that,

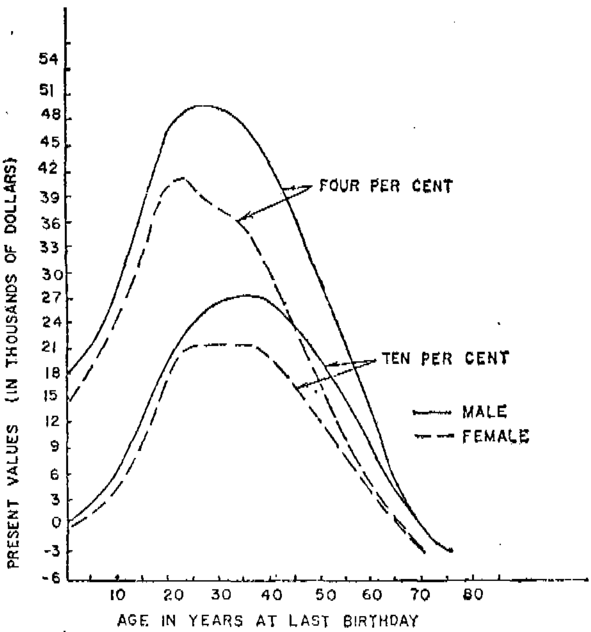

Fig. 2 — Present values of net future earnings, by age and sex, at 10 and at 4% discount rates. (Weisbrod, 1958.)

from an economic point of view, loss of life means the loss of a productive unit (and of a consuming unit as well). He assumes that earnings are a reasonably adequate measure of the value of the marginal product of a worker, but not of a housewife, whose measure is computed differently. Using this same approach Weisbrod states that it would be practical to obtain present-value curves for the developing countries and that these, in turn, could provide a basis for assessing the benefits of their public health programs, including the effect of municipal water supply.

A more direct approach to the economic justification of public water supplies was taken by WAGNER and WANNONI (1948) in Venezuela. They calculated that for an annual expenditure of approximately $6,500,000 to cover the amortization and operation of small municipal water supplies, Venezuela could obtain an annual return of some $50,000,000; a return of approximately 800% per year on the investment. These figures were based on the provision of safe water to an additional 2,000,000 people in the rural area of Venezuela (75 liters per capita per day); the economic benefits were calculated on the man-days of time which could be saved by avoiding premature death and sickness and by the savings in medicine and medical service. The calculations are said to be conservative.

Perhaps the economics of public health can be summed up best by a statement made by Dr. E. Ross JENNEY in his terminal report on leaving an ICA assignment in Brazil in 1959; Dr. Jenney wrote:

> "In the complicated network of economic deficiencies (in the underdeveloped areas), the improvement of a man's health is an achievement that will neither create a new need, nor in turn depend upon another capital investment for its success. It is unique in that it is a successful end in itself, economically basic, politically unquestionable, and in most cases technically negotiable. Sometimes, as in the eradication of a disease, it is a single investment, ended forever, a paid-up endowment for the infinite future. We (in the United States) are living on such an endowment; the underdeveloped areas are not, and this most acute difference is reflected in every facet of economic and cultural contrast."

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THE ASIAN SITUATION

WATER SUPPLY AND SANITATION PROBLEMS IN ASIAN COMMUNITIES

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For the purpose of this paper, problems are defined as those factors which inhibit the expansion and success of water and sanitation programs. These problems are not limited to engineering. In fact, most of the problems involve social, managerial, and economic aspects of engineering undertakings.

The U.S. Public Health Service has recently completed a study entitled, "Guidelines and Criteria for Community Water Supplies in the Developing Countries." This report prepared under A.I.D. auspices, is based on a worldwide evaluation of water supply projects and programs by teams of prominent sanitary engineers. The principal charge to the Public Health Service in the preparation of this report was: "Both those factors which contribute to a successful operation and those factors which limit success are to be determined." The major problems involve money, management, manpower, and motivation.

MONEY

Money is a universal problem recognized by all of us. However, there are probably considerable differences in our definitions of the problem. Loans from international lending agencies (both bilateral and multilateral) are being made for water supply projects in fairly substantial amounts each year, and most sound projects presented to these agencies have been financed to the extent of foreign exchange requirements. The present volume of finance of this type appears satisfactory for the present and I believe we can be optimistic in regard to the future. This, however, provides only a part of the initial capital for a project. The remainder must in most cases be obtained from within country sources. This is our real money problem, internal finance.

Most of the countries of Asia, as in the rest of the developing world, lack financial institutions willing and able to finance municipal undertakings. There is no established market where stocks and bonds may be freely traded, there are few commercial banks involved in long term lending, and no incentives such as tax exemptions to encourage purchases. Thus, the private sector is an unlikely source of finance for water supplies or other public works until substantial progress is made by the financial community. Such changes will require time in most developing countries. Without this private sector support the water supply industry will remain dependent upon the government for financing. This may be through grants or loans provided through the annual government budget, loans from development or other government banks, and loans from quasi-governmental agencies responsible for the management of social security, pensions or other trust funds. Again, our greatest problem with using these sources of finance is the lack of institutions, policies, and procedures for obtaining, administering and repaying loans. To date, little progress has been made in resolving the problems associated with finance. Therefore, considerable effort should be applied to the development of sound institutions, policies, and procedures for financing municipal works.

MANAGEMENT

Management of water supply enterprises has received considerable attention during the past ten years. However, much of the effort has been directed toward the management of individual systems. Water supplies in the United States and other developed countries are supported by a large infrastructure which provides supplemental services and, to some extent, supervision. State Health Departments establish and monitor water quality standards and provide technical advice. State and municipal agencies regulate borrowing by municipalities and often assist in financial arrangements. Manufacturers are at the end of a phone to provide information and service, as are consulting engineers who are often on a retainership basis, and so on.

Many of these sources of support are missing in most developing countries. We should not try to duplicate each of these "outside" agencies but we must find a way to efficiently and economically provide for the services. In larger water supplies it may be feasible to provide most of the services within the municipal organization, but smaller systems cannot afford the financial and human resources required. Therefore, I believe, we must develop water supply programs at a national or regional level capable of providing this support to the individual municipal projects if water is to be provided to large portions of the population.

MANPOWER

Manpower has been a recognized area of importance since the inception of international assistance and considerable progress is being made. At the professional level, early international programs depended exclusively on sending participants to developed countries for traditional advanced studies. Today this is changing. Participants still are coming to developed countries but more and more their curricula or programs are being tailored to their specific needs. An example of this is the International Program in Sanitary Engineering Design which has been developed by Dr. Daniel A. Okun and his staff at the University of North Carolina.

Another important improvement is the establishment of courses in developing country institutions at both the graduate and undergraduate levels to prepare men for the field of sanitary engineering. Progress has been most satisfactory, but greater effort is needed in both quantity and quality of graduates.

The training of middleman power—the operator, the foreman, and others essential to water supply operations—has not progressed as well. In fact, training techniques and curricula have not been developed which meet these needs. This shortage of middle-level personnel is our greatest manpower problem today and one which receives far less attention than it deserves. A concerted effort should be made to determine the skills required by these personnel, the training they need to acquire these skills, and the sound training techniques to be developed.

The utilization of human resources whether they be engineers, operators, administrators or other trained water supply personnel, is also a problem of some magnitude. When there is a shortage of skilled personnel, which is the situation in most developing countries, each man must be placed where he can be the most productive. This has not been the usual practice. There are many reasons but an important one is that personnel have personal preferences in regard to tasks. For instance, design is usually preferable to plant operation. There are also strong preferences in regard to location. Unfortunately, the large metropolitan area is the preference of most. Inadequate pay scales, lack of job incentives, and uncertain tenure play their part. However, the principal and basic cause is the lack of a well organized personnel system backed up by sound policies and procedures.

MOTIVATION

Motivation of a community to accept a water supply project is not difficult. In most cases, the population is quite willing to pay the necessary rates to operate the system and repay the capital cost of the project. However, this motivation is most often generated by convenience which does not require really first class service for satisfaction. Thus, many benefits which a water supply can provide are not exploited. Therefore, our problems of motivation are in the area of extended utilization and improved operations.

There is a need for Ministries of Health to take greater initiative in the development and supervision of water quality standards and in educating the public in the proper use of water for personal hygiene and household cleanliness. Agencies responsible for community development and housing must be encouraged to include public water supplies in their plans and, where economically feasible, water within the home. Long-term loans for home improvements, which include plumbing, are worthy of consideration.

Probably the most important and difficult task is to lead the public to *demand* a continuous supply of good quality water all day, every day of the year. The best way to accomplish this is by the water supply organization taking the responsibility for doing it.

WATER SUPPLY AND SANITATION PROBLEMS IN THE PHILIPPINES

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I can generalize, without fear of contradiction, that the one single problem — the most important problem — confronting developed, developing or underdeveloped nations narrows down to a minor thing called — money. A number of questions have come to my mind but, more for better organization than anything else, I have classified the myriad problems into six broad categories.

PROBLEMS OF THE ASIAN SANITARY ENGINEERING CONSULTANT

In the thirteen years that we have been practising as consulting sanitary engineers for both the government and private sector we have come to the conclusion that the problems facing the Filipino consultant are perhaps unique and unlike those in any other country. I refer particularly to the design of water and waste treatment plants, where our practice has been to bid out the supply of the treatment plant equipment first based on preliminary designs and sizing. After having selected and awarded the contract to an equipment supplier or group of suppliers we then, and only then, begin to design the civil, concrete, piping and electrical works to fit in the equipment chosen. This is later bidded out to select a general contractor who has to take care of the complete civil works which includes equipment installation and start-up. Rightly or wrongly, we try to limit bidding to selected equipment companies who are ably represented in our country. This measure is taken to assure owners of the ready availability of parts and service. In cases where we are forced to invite equipment suppliers not yet locally represented, bid price advantages would naturally be allowed to those with local representation and this is clearly spelled out in the bid documents.

Of late, a growing problem in consulting has been the competition offered by "turnkey" bids from Japanese trading companies or their liaison offices. This practice is quite prevalent in the Philippines and, we are sure, also in other Asian nations. When an industrialist or a government official is under pressure to deliver treatment plant facilities on a fixed budget and on a targeted completion date, the independent consultant who can guarantee neither the cost nor completion time will have to give way to the apparently more attractive "package deal".

To the American equipment supplier interested in extending and/or expanding their business to the developing countries of Asia, we suggest that tie-up agreements with reputable nationals or companies be seriously considered. The efforts of their sales engineers should be supplemented with technical support from practising consultants who are familiar with local problems and native solutions rather than putting complete reliance on company engineers 8,000 miles away.

One other significant problem facing consultants in Asia is the dearth of technical data and information originating within the region that could serve as guides for similar future projects. On this score, we have nothing but praise for our American counterparts who so freely and exhaustively discuss even mistakes that have been made in their lines of specialization. The ASCE Journal of the Sanitary Engineering Division (SED), the American Water Works Association Journal, and the Journal of the Water Pollution Control Federation are but three of the outstanding sanitary engineering publications in the United States. They are our only link with new developments in the environmental field and, as is to be expected, articles about Asian experience are few and far between.

In the many countries comprising South East Asia (save perhaps Thailand, because of the Asian Institute of Technology) laboratory and library facilities are sadly inadequate, research and development work is pitifully low, and there is little or no interest in highly qualified men to do basic or applied research. The government has not done much to improve the conditions either. We laud the efforts of the Asian Institute of Technology in training competent sanitary engineers and disseminating technical information through research reports, but we need more—much more of this. I just have a feeling that there is enough interest and enough material in this part of the world to support one sanitary engineering journal for all of Asia and hopefully even a federation of Asian Sanitary Engineering Societies.

WATER SOURCES

It is universally conceded that the rate of water demand in all countries, without exeption, is continually on the increase year after year. Total water use is a function of population and per capita water consumption rates. We cannot do much about the population explosion since family planning is, fortunately or unfortunately, not within our province. There is however increasing awareness of the consequences of a rapidly increasing population which, if not checked, will necessarily increase total water consumption.

Per capita water consumption figures are also forever increasing due to factors such as, but not limited to, the following:

Improving standards of living,
Use of water-using appliances, equipment and laborsaving devices,
Construction of efficient sewerage systems.

Of the many approaches that have intrigued us in attempts at conservation and the reduction of per capita water consumption rates, the following always stand out:

> We continue to use water closets that require about three (3) U.S. gallons of good clean water per flush. Some European countries have been able to develop water closets that will consume less than 1/2 of the generally accepted 3 gallons per flush.
>
> Water conservation measures in industrial plants can often be duplicated successfully in individual houses. One of the most fruitful is re-use of final rinse water in washing clothes and dishes for other less important domestic uses.
>
> We are glad to note that in the United States, most large cities have adopted regulatory measures for watercooled central air-conditioning systems. I am not aware of any Asian City, except perhaps Hongkong, that has tried control.

Considering that water demand is always increasing and that traditional surface and underground water sources are constantly drying up, the time has probably come for some Asian countries to look to desalination as a means for converting sea and / or brackish waters as alternate sources of community water supply.

WATER QUALITY AND TREATMENT

For quite some time, the USPHS Drinking Water Standards were used as yardsticks, as if they were our own. We are happy to note that WHO has come up with International Drinking Water Standards which are probably more suited to the needs and capabilities of smaller and poorer countries. Due to continued exposure, Orientals have developed some kind of immunity to common waterborne diseases. Because of these natural built-in safeguards and the hard facts of economics it is a matter of necessity that we thoroughly review and possibly adapt a further watered-down version of the WHO Standards for our local or regional drinking water requirements.

While we are on the subject of standards, environmental engineers in this region should be able to agree on the standardization of design concepts and criteria for water supply and sanitation facilities which will be more responsive and in keeping with our economic conditions, our culture, and our more tolerant attitudes. While we do look at American water and waste treatment plants with awe and admiration, let us not forget that for most of us our stage of development does not permit similar installations for our use. In the construction industry, we are told that American labor may account for up to 70% of the total construction cost of a project. This is the exact reverse of experience in the Philippines and, perhaps, for the rest of Asia. If American practice demands savings in labor costs, the less developed nations will naturally try to save on the more expensive component materials. In the choice of plant equipment therefore, we should tend to veer away from complete automation in favor of labor intensive systems and this should also help alleviate the growing unemployment problem.

WATER TRANSMISSION AND DISTRIBUTION

The dual system of water distribution has been advocated by many distinguished waterworks practitioners including the seminar director, Dr. Daniel Okun. In the United States, healthly discussions over the relative advantages and disadvantages of the controversial issue of dual systems have not died down. In spite of the reported higher first cost and other known disadvantages, we feel that the dual system could prove to be advantageous for some Asian communities. If the original proposers would accept suggestions for modifications of the dual system, we would urge that studies be initiated on the possible use of individual household water reservoirs for the potable water system. This can be somewhat akin to that of the tank in the water closet which can "float-on-line". Added advantages of this scheme would include (1) the use of very much smaller distribution and plumbing pipes that need not consider peak flows, (2) reduction in water main distribution pressures, and (3) making available emergency reserve storage.

We have always considered the Hardy-Cross method of pipe network analysis as a long and cumbersome series of approximations. In some of the more advanced countries, distribution network analysis has been successfully simulated on electrical networks through analogy. We have often wondered whether the electrical analogy cannot be extended to the design layout of water distribution systems. If I may refresh your memories, the electrical power distribution system is made up of primary and secondary lines separated by step down transformers. The overriding reason for the electrical set-up was to reduce the size and, necessarily, the cost of the primary cables by increasing line voltages and current flows. Could this scheme be adopted in the design of water distribution systems?

For peak flows, mentioned a little earlier, the universal practice has been for cautious engineers to design pipe sizes for the "worst probable conditions". This simply means an oversize of 2½ to as much as 5 times the capacity for something that would only provide the average normal water demand. Orientals are a patient lot and sizing pipe diameters to take care of average flows may produce slight inconveniences but it can definitely be tolerated. We might also consider doing away with the accepted practice of installing sectioning valves at every pipe crossing. Installation of 2 or 3 gate valves at pipe intersections is obviously aimed at limiting or containing disruption of water service for repairs and maintenance into smaller areas. Again, this can be considered a needless luxury for the bulk of Asian water consumers. A secondary purpose of these gate valves is to enable water works men to concentrate fire flows towards afflicted areas as a help in fire fighting. In our country (not necessarily the same as in other Asian countries), all fire fighting trucks are equipped with their own water tanks and pumps. Perhaps, on this score, we might explore the lowering of distributing water pressures to as low as 10 psi at the distribution mains. We might also correspondingly reduce the 6 in. minimum diameter water main requirement to allow for hydrant connections.

Exhaustive studies we have made on peak flow patterns of water consumption for typical Philippine Communities revealed interesting findings. The two peaks in the water use curve commonly assumed for American cities do not agree with the curve evolved from Philippine conditions, which has four instead of two pronounced peaks. After many sleepless nights trying to figure out the case of the two extra peaks, we finally accepted the logical explanation that the upturns are always associated with the preparation and eating of meals. We are not exactly proud to admit that Filipinos, in addition to 3 full and square meals a day, almost always partake of late afternoon snacks. Needless to say, this tends to increase our diversity factors in water use with consequent reduction in pipe and pump sizes.

WASTE COLLECTION

As a matter of practicability and economics, most sewers in this part of the world are made of concrete or vitrified clay pipes. Excessive infiltration, which may be partially attributable to high water tables and heavy rainfall, is still caused on the whole by defective sewer joints and fittings. We have seen and read about the many excellent water-tight sewers that use simple and inexpensive pre-molded plastic or rubber joints; we hope some enterprising American manufacturer will license Asian companies to make these available here.

While concrete is an economical and indigenous material in all of Asia, we are still quite worried about internal sulfate corrosion. Again, technical advances in certain types of sulfate resistant cements and plastic linings should be made use of by sewerage engineers in the Orient.

Much work has been done in the United States on the use of curved sewers for sewer systems which has resulted in meaningful savings on expensive manholes, particularly on modern subdivisions planned on the curvilinear instead of the conventional road grid system. This is a case where the straight line is not necessarily the shortest. We are anxious to use similar techniques but, except for larger diameter sewers which have been tried with some success, we lack performance data and other relevant design information to use curved sewers with confidence.

As a two pronged attack on the global worsening of water supply crises, we would like to see more technical articles about European, or other countries, development of the vacuum system of waste collection. The net effect will be reduction in water demands as well as waste treatment facilities for the spent water.

WASTE TREATMENT AND DISPOSAL

We have always been told that there are only three possible directions for disposal of liquid wastes, namely: disposal onto land, disposal into large and natural bodies of water, and disposal into the atmosphere. To a certain limited extent waste disposal onto land has long been practised in sewage irrigation, in sub-surface leaching systems for septic tanks, and in the percolation (no matter how insignificant) of sewage in oxidation ponds or sewage lagoons. The bulk of disposal of treated or untreated wastes has been *traditionally* a discharge to large natural bodies of water such as rivers, lakes, or the ocean. Disposal of wastes into the atmosphere has not been fully explored and exploited. Because of our intense and year-round sunlight we think that induced evaporation and possibly transpiration for the disposal of liquid wastes may prove to be technically and economically feasible in most Asian communities.

Despite the wealth of published knowledge on secondary waste treatment by biological means, we are a little disappointed to know that no new and innovative biological treatment method is being investigated outside of the three old reliables: (1) trickling filters, (2) activated sludge, and (3) oxidation ponds and their various modifications. Surely, there ought to be more.

We all know that the poorer a family is, the greater the number of its members. So is it with nations. When a country is poorer, the richer it is in population, and consequently the greater are its sanitary engineering problems. We can witness it in my country and I am sure you can also see it in the poorer sections of your country. If our western friends are thinking of television as a solution, we can tell them outright that this does not seem to work. The imbalance is oftentimes so acute that the sanitation problems of poorer families and communities demand more immediate attention. Of course, there are two alternatives, our expertise on one hand and that grim equalizer, nature, on the other. In this very seminar we are afforded the excellent opportunity for discovering answers.

As I was preparing for this seminar paper, I could not help but think that there could be Asian participants among us who have had broader experience in the fields I have discussed but who, through lack of a communicative vehicle, have not been able to disseminate their ideas. All of us are aware of the twin evils of lack of technical research communication and lack of motivation for further research. This gathering of experts suggests an awakening in technical co-operation between ourselves and our respective countries. It speaks also of the willingness of our western friends to help us forge ahead. We have made a first small step in this meeting. Let us take the second giant leap by writing. Not to one another alone but by interlinking our knowledge through one sanitary engineering journal and then further enhance our relationship in an Asian Federation of Sanitary Engineering Societies.

THE URBAN WATER SUPPLY IN INDONESIA

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THE LAND AND ITS PEOPLE

Geographical Situation

The Indonesian Archipelago is situated along either side of the equator, extending from 95° to 141° East Longitude (about 5,110 km or about 3,200 miles), and from 6° North to 11° South Latitude (about 1,888 km or about 1,100 miles). Eighty-four percent of Indonesia is water and the remaining 16 percent is land, consisting of more than 3,000 large and small islands. Among the large and important islands or groups of islands are:

Java and Madura	± 132,000	sq.km.
Sumatra	± 474,000	,,
Kalimantan (Borneo)	± 539,000	,,
Sulawesi (Celebes)	± 189,000	,,
Bali	± 5,600	,,
Lesser Sunda Islands	± 67,800	,,
Maluku Islands (Moluccas)	± 74,500	,,
West-Irian	± 422,000	,,

Three time tables are valid in Indonesia, the Western, Central, and Eastern Indonesian time zones, with a time difference of one hour between zones.

Climate and Temperature

Due to its position along the equator, and being surrounded by vast bulks of water, Indonesia is included in the tropical zone and monsoon region. The seasonal climate is influenced by the monsoons, in which the wind coming from the continents (Asian and Australian) circulate back and forth, each season lasting for about 6 months. In general, the west monsoon lasting from October to March carries more rain than the east monsoon. This is due to the fact that the west monsoon as it arrives in Indonesia has gone a longer distance, passing over the Indian Ocean.

The average rainfall throughout the country is about 2,000 mm (about 80 inches) per year. The highest rainfall is registered in Kranggan, at the foot of Mt. Slamet in Central Java, with 8,000 mm/year, and the lowest is in Palu, Sulawesi, with only 530 mm/year.

The average temperature at sea level is about 26° Centrigrade or about 79° Fahrenheit, but every 100 meters of elevation reduces this temperature by one degree Fahrenheit. The average maximum temperature is about 30°C or 86°F, whereas the average minimum is about 23°C or about 74°F. The difference in temperature between day and night is 5° Fahrenheit.

The relative humidity is generally high, with an average maximum of 90 % and an average minimum of 80 %.

Geological Features

In Sumatra the hills and mountains follow the west coast continuously; to the east the mountains level out to broad expanses of low land. In Java most of the hills and mountains are in the southern part of the island. They are less continuous than those of Sumatra, allowing frequent access from north to south and *vice versa*. In Kalimantan the mountains are mainly along the border of Sabah. The rest of the island consists of a vast lowland and swamps. Similarly, in other islands, such as Sulawesi, Bali, and Lombok, the lands are also hilly and mountainous. The peak of the highest mountain in the country, in West-Irian, is covered with snow the year round.

Indonesia is indeed one of the most volcanic regions in the world. It has more than 400 volcanoes, of which over 100 are still active. The volcanic ash enriches the soil and this is one of the reasons why most of the soil is fertile, particularly in places where active volcanoes are present, such as in Java and Bali.

Water Resources

The high rainfall and mountainous and heavily-forested land provide abundant water resources in Indonesia. Rivers and streams can be found flowing in most of the islands. Among the larger rivers are:

Sumatra:— Asahan
— Kampar
— Rokan
— Batanghari
— Musi

Java: — Tjiliwung
— Tjitandui
— Bengawan
— Solo
— Brantas

Borneo: — Kapuas
— Mahakam
— Kahajan

Celebes: — Maros
— Djeneberang

Generally, these rivers have an average discharge ranging from a minimum of 50 m^3 per second to a maximum of 3,000 m^3 per second. Discharge naturally changes over the year, depending on the season.

In addition to rivers, lakes exist in several of the islands, among which are:

Sumatra: — Lake Toba
Celebes: — Lake Poso
— Lake Towuti
— Lake Tondano

Ground water sources, such as springs, are abundant in mountain regions. These springs generally discharge an adequate supply of water of good quality. This is one of the reasons why water supply facilities in Indonesia mostly originated from spring water sources.

Population

The total population of Indonesia is about 120 millions and it ranks fifth in population in the world. The population is unevenly distributed throughout the country, 60 to 70% being concentrated on the islands of Java, Madura, and Bali, As these islands account for only 7% of the total land area of Indonesia, the population density of these islands is very high. The island of Java has, for instance, a population density of about 1,300 people per square mile and is probably the most densely populated in the world. On the other hand, West-Irian has only a population density of 4 people per square mile, whereas Sumatra, which is 4 times as large as Java, has only 16% of the total population, or about 90 people per square mile.

Fifteen to twenty percent of the total population are urban population and the rest are still living in rural areas. With an estimated population increase of 2.5% per annum, Indonesia's population will reach some 123 million in 1970, and approximately 210 million in the year 2000. This naturally constitutes a major problem for the economic development of the country, including development in the field of water supply and sewerage.

The Culture

There are many different ethnic groups in Indonesia, each having its own language and tribal customs. In the island of Java alone, there are 3 different ethnic groups—Sundanese, Javanese, and Maduranese. In all, throughout the country, there are approximately 200 different languages.

Considering this fact, special attention must be given in regard to modernization of any particular region so as not to interfere with the existing local customs. In this respect, the planning must be adjusted to local conditions. In Bali, for instance, spring water sources could not be tapped without considering their use for public bathing since it has been the local custom of the Hindu Balinese to bath in such places. If local customs and existing culture are considered, any plan of modernization will receive public support so that maximum benefits will be derived from such programs. In addition, existing culture could be preserved through the adjustment of the programs to fit into local conditions.

Brief History

Beginning in 1596, Indonesia, formerly known as the Netherland Indies, was colonized by the Dutch for more than three centuries. In March 1942, during World War II, Japanese forces conquered Indonesia and occupied the country until their capitulation in August 1945. Immediately after the Japanese capitulation, on August 17, 1945, the independence of the Republic of Indonesia was proclaimed in Djakarta, but it was not until December 1949 that the Dutch and their allies recognized its sovereignty. From August 1945 to December 1949 was a period of struggle between the Dutch and the Indonesians.

The Government

The Republic of Indonesia is a democratic and constitutional State. The Head of State is the President, who is elected by the people through the People's Assembly (Madjelis Permusjawaratan Rakjat), the highest policy-making body. In performing his duties, the President receives mandates, and is directly responsible to the People's Assembly. The cabinet ministers, who are appointed by the President, assist him in carrying out his executive duties. In addition, the policy set forth by the President is checked or controlled by the Parliament, a legislative body responsible for the formulation of legislative matters. Moreover, the President is assisted by advisory boards, consisting of the Financial Advisory Board, the Supreme Court, and the National Advisory Council.

ORGANIZATION OF THE DIRECTORATE OF SANITARY ENGINEERING

The Directorate of Sanitary Engineering is one of the technical organizations under the Directorate General of Planning and Construction belonging to the Department of Public Works and Electric Power and is responsible for the provision of water supply systems in Indonesia. The principal duties of the Directorate, among others, include:

Formulation of physical development planning that aims at the improvement of water supply and sewerage facilities, along with the provision of financial requirements based on the policy and guidelines defined by the Directorate General of Planning and Construction, Department of Public Works and Electric Power,

Proposing physical and financial programs through the Directorate General of Planning and Construction and the Department of Public Works and Electric Power, for submission to Bappenas for approval and ratification,

Determining the order of priority of proposed water supply and sewerage projects, based on the funds available,

Conducting periodic inspections on projects undertaken, including both financial and technical aspects, through field inspection or quarterly reports,

Formulation of a guiding policy along with provision for technical services for proper operation and management of the regional water works facilities, so as to improve their condition and to ensure proper management and operation of water systems.

In carrying out these duties, the Directorate of Sanitary Engineering operates under the organization shown in Figure 1.

Director	— Secretariat	— Administrative	— Finance
			— Personnel
			— General
	— Water Supply Division	— Ground Water Supply Section	
		— Surface Water Supply Section	
	— Drainage, Sewerage, & Refuse Disposal Division	— Drainage & Sewerage Section	
		— Refuse Disposal Section	
	— Survey, Planning, & Laboratory Division	— Design Section	
		— Laboratory Section	
		— Operation Section	
		— Survey & Planning Section	
	— Logistic Division	— Supply Section	
		— Equipment & Materials Section	

Fig. 1 — Organization of The Directorate of Sanitary Engineering.

URBAN WATER SUPPLY AND SEWERAGE IN INDONESIA

Present Condition

To be frank about the problems of urban water supply in Indonesia, it is necessary to say that conditions are far from satisfactory. From data available, there are approximately 183 urban water works facilities throughout Indonesia. Most of them were built during colonial times, and most today are in serious condition. Supply capacities are decreasing due to leakages in the main and distribution pipes and to improper functioning of very old equipment. This situation has arisen from the facts that rehabilitation work has not been undertaken at the proper times, and that facilities were maintained improperly.

The overall production capacity of all facilities is approximately 4,500 liters/sec. After achieving independence, the Government undertook improvement programs, in which several new water purification plants were built in cities having serious water problems. The cities are the following:

Djakarta: additional production capacity 2,000 liters/sec (1957), original capacity 600 liters/sec,

Bandung: additional production capacity 1,000 liters/sec (1959), original capacity 400 liters/sec,

Surabaja: additional production capacity 1,000 liters/sec (1964), original capacity 400 liters/sec,

Semarang: additional production capacity 500 liters/sec (1965), original capacity 200 liters/sec,

Pontianak: additional production capacity 110 liters/sec (1964), original capacity, nil,

Medan: additional production capacity 120 liters/sec (1967), original capacity 350 liters/sec,

and other smaller cities and towns.

Although this increase is approximately 100% more than overall existing capacity prior to World War II, the increase in production capacity is not as significant as the improvement indicates. In fact, the condition today is far worse than ever before. One of the reasons is that the improvement undertaken could not catch up with population growth, industrial development, urbanization, higher standards of living, and other water demands such as port and tourist facilities.

In this case, the metropolitan city of Djakarta may be taken as an example. Prior to World War II, the population of the city was about 600,000 people, and the production capacity of its water system was 600 liters/sec. Its supply was drawn from Tjiburial spring, located about 60 km south of Djakarta. This means that the consumption per capita at that time was 1 liter/sec per 1,000 people, or 86.4 liters/person per day, which was the minimum water standard requirement established by the colonial government. Within two decades, the city of Djakarta grew into a metropolitan city, its population increased from 600,000 to about 2,000,000 in 1957, and in 1969 its population had grown to 4,500,000. On the other hand, its water supply facilities produce only 2,300 liters/sec of which 2,000 liters/sec come from the newly-built water purification plant, and 300 liters/sec comes from the remainder of the original 600 liters/sec supplied from the Tjiburial water system (this decrease is due to leakage and illegal connections made along the transmission main to Djakarta). Thus, with the present population of 4,500,000 people, the water consumption per capita for Djakarta then becomes ± 50 liters/person/per day, which indicates a decrease in water consumption when compared with thirty years ago.

The condition of other water supply facilities is even worse, because of the decrease in water production due to lack of improvements and, on the other hand, because population and other water needs increase rapidly. From data available, the following figures are obtained:

The overall production capacity of all existing water supply facilities is approximately 9,000 liters/sec. Assuming that 20% of the total population of 120 millions, or about 24 millions, constitute the total urban population, then the consumption per capita will be approximately 32.4 liters/person per day. This very low figure indicates a grossly inadequate supply.

Proposed Programs

The proposed improvements of water supply facilities throughout Indonesia will be divided into two phases as follows:

In the first phase (First Five Year Plan 1969/1973), The aim will be to increase the overall average water production from 9,000 liters/sec to 17,000 liters/sec.

In the second phase (Second Five Year Plan 1974/1978), the aim will be to increase the production capacity from 17,000 liters/sec to 24,000 liters/sec.

In order to achieve the above objectives, the following two programs will be undertaken:

Intensification and rehabilitation program, and Expansion program.

In the intensification and rehabilitation program, the improvements to be carried out will be to rehabilitate the water supply facilities so that the overall production capacity will be increased to at least its optimum original capacity and, whenever possible, to increase the capacity by improving the system and building some additional construction works. Included in the rehabilitation program are the improvement of spring water sources, water treatment plants, and replacement and rehabilitation of distribution systems which are not operating at full capacity. In the expansion program, new construction of water supply systems for the extension of the existing water systems will be proposed to increase the present production capacity to conform with current water needs. The program is to be carried out particularly in large cities, where water demand (due to increase in population, industrial growth, etc.) has been increasing at a rapid rate.

The proposed improvements for both intensification and expansion programs are to be carried out in the following cities or towns:

— provincial cities
— port cities
— industrial or tourist cities
— other cities having economic potential.

Moreover, the order of priority for any given water supply project will be synchronized with other development projects of other Directorates and/or Departments so as to achieve full coordination in all sectors. Naturally, top priority in the First Five Year Plan, particularly in the field of water supply, will be given to the cities mentioned above, or to cities which satisfy most of the established requirements. In view of the above mentioned requirements, any improvement in the water supply for any given city will be directed simultaneously at the following water needs :

— domestic
— harbour or port facilities
— industrial establishments
— tourist facilities

In the First Five Year Plan, high priority is given to harbor or port cities. Since Indonesia consists of many islands, these cities play an important part in the economic progress of the country, in particular in sea transportation and interinsular activities. This is the reason why so many water supply projects are carried out in port cities.

To overcome water shortages, an immediate aim is to utilize fully the water resources originated from ground water (i.e. springs or wells). This approach is based on the following:

First, ground water generally requires no treatment, except chlorination. Further, a ground water system is easier to maintain, thus reducing operation cost.

Second, operation and maintenance of water treatment plants are generally more difficult because of the shortage of trained technicians. Thus, ground water systems will be suitable in regional areas, where skilled personnel are in short supply.

Finally, due to an abundance of spring water sources, of which many are not yet fully utilized, ground water will then be most advantageous.

The utilization of surface water (i.e. rivers or lakes) as a source of supply (complete with treatment units) will be considered only when the utilization of ground water sources (i.e. springs) is not both technically and economically justified.

In addition to the execution of the above mentioned programs which are the responsiblity of the Directorate of Sanitary Engineering, the proposed improvements in other sectors must be considered in order to strengthen the actual programs. Thus, to gain the above mentioned objectives, water supply development must be accompanied by other actions. These efforts, which are not necessarily the responsibility of the Directorate, can be summarized as follows:

Rules and regulations in the field of water supply, in which not only technical and sanitary requirements must be included, but also other aspects, such as water works management, so that the quality of water produced is properly maintained along with the operation of the system.

Regulations on forest conservation and protection of surface and ground waters that are potential sources of water supply, particularly spring water sources whose overflow is to be maintained at constant discharge. Further land use practices are to be encouraged so as to reduce erosion and flooding.

The establishment of local pipe and chemical industries for producing some materials required in the operation, rehabilitation, and maintenance of water works facilities. These materials, particularly pipes and fittings, are continuously in large demand. In view of the above needs, the establishment of local pipe manufacture certainly will contribute to the development in this field. Similarly, chemicals such as aluminum sulfate and calcium hyphochlorite are also continuously required for proper operation of water purification plants. Yearly demand for such chemicals is estimated at 10,000 tons of aluminum sulfate, and about 100 tons of calcium hyphochlorite. These chemicals, as well as piping materials, are presently imported from abroad. Further, the establishment of such local industries will also include the creation of employment and savings in foreign exchange.

The Role of the National Overall Development Planning Board

The National Overall Development Planning Board, or what we refer to as Bappenas, is one of the advisory boards of the President, having its principal duty to coordinate and formulate the national planning policy in all sectors in accordance with the decrees set forth by the People's Assembly. In carrying out its activities, Bappenas compiles proposed development programs submitted by the Departments concerned. Upon considering the funds, after the programs are reviewed and evaluated, Bappenas then decides or makes recommendations as to which projects (physical development programs) should be undertaken in the fiscal year concerned.

It is very clear, therefore, that any proposed physical development is expected to conform with the policy set forth by the Government. Further, since all of the development programs submitted by the Departments are coordinated through one advisory planning body, any duplication of efforts will be eliminated, and a broad synchronization of development activities will be attained in all sectors. Moreover, the financing of any project undertaken will be assured, since consultation in regard to funds will already have been made with the Department of Finance. In this case, there will be no stoppage of the projects undertaken because of local costs. For those projects which require foreign exchange, the financing is channelled through long or short term credits, for which Bappenas undertakes the details.

Further, for those projects whose planning, survey, and design require the services of foreign consultants, Bappenas acts as an intermediary in obtaining the services of foreign consultants, whose service fees are to be financed through technical aid assistance. In these efforts Bappenas is assisted by experts from the World Bank who act as advisers on financial and technical assistance from foreign countries.

At present Bappenas is making an effort to acquire technical aid for the study, survey, and planning of proposed water supply projects to be undertaken in 1970/1971 in several Indonesian cities having high priority, such as in Djakarta, Bogor, Palembang, Solo, and Denpasar. Through this assistance, it is expected that the possibility of having foreign contractors survey and design as well as supervise the construction itself, as previously happened, will be eliminated. Aside from this, it is expected that the shortage of trained personnel will be reduced to a low level so that the field of work for Indonesian engineers will be broadened. In addition, our young engineers could learn much from those experts.

Current Problems

1. The Problem of Finance

The major problem in the improvement programs of water supply in Indonesia is the failure to provide adequate financial support. Due to inefficient funds, the Directorate is compelled to undertake a tight selection as to which cities, all of which have the same urgency, high priority will be assigned. In determining the priority, the Directorate is often faced with various and complex problems. Aside from lack of local resources, foreign exchange coming from project aid credits are also insufficient. This is due to the following factors:

a. In the First Five Year Development Plan, high priorities are given to agricultural and industrial sectors. Most of the budget available is allocated for this purpose. In fact, in the present Five Year Plan, water supply is included in the social sector.

b. Another problem confronting the Government is the difficulty of acquiring enough foreign exchange for its water supply programs. Project aid credits coming from foreign countries could not be used for the procurement of piping materials. The reason is that donor countries are not interested in providing credits for such purpose. The credits are generally provided only for the construction of water purification plants. Pipes and fittings, however, are the most required materials in the rehabilitation and extension of water supply systems, whereas the construction of water purification plants themselves does not require much foreign exchange.

2. Management and Operational Problems

Improper management and operation of water works facilities also present major problems which often become an obstacle to the progress of the programs. Due to shortages of skilled and experienced personnel, the supervision and operation of water works facilities in regional areas are often handed over to unqualified persons. Similarly, management of water works is far from satisfactory. Further, water rates adopted by many regional water works are generally low. Revenues are insufficient to cover all costs of operation and maintenance. In fact, the operating revenues are often used for other purposes, since revenues received are passed to local authorities' treasuries. To meet operating and maintenance costs, water organizations generally seek relief from their respective regional or provincial governments, in which in some cases political elements determine the policy. These are the cases which often plague water works facilities, causing the degradation of the quality as well as the quantity of water produced. Thus, the benefits resulting from rehabilitation or extension of the works are hampered by the decrease of water supply capacity due to improper management and operation of the system.

3. Shortage of Experts and Skilled Technicians

Aside from lack of skilled personnel for the operation and maintenance of regional water works facilities, shortages of qualified and experienced personnel in the field of sanitary engineering also constitute problems in the Central Government (i.e. the Directorate). Thus, the scope of works which can be carried out in the improvement programs of water supply is also limited. Further, we confess that our experience in this field is not yet broad enough so improvement programs sometimes suffer from insufficient detailed studies due to lack of attention in this matter.

Considering the above facts, along with the absence of qualified local consulting engineering firms which specialize in work in this field, the Directorate is then compelled to utilize the services of foreign engineering consultants on the basis of a turnkey contract, in which the contractor not only serves as supervisor and supplier, but also conducts the survey and design of the construction works. This type of contract often creates an unfavourable situation and is disadvantageous, particularly in the utilization of foreign exchange.

Implementation of Proposed Programs of Improvement

In accordance with the funds available, and considering the present progress of the First Five Year Development Plan with regard to the execution of water supply projects, the Directorate then formulated programs of implementation of water supply projects, as follows:

1. Implementation of Expansion Program

In this program, priority is given to projects already under construction, whose construction was begun prior to the commencement of the Five Year Plan and, moreover, whose completion is expected within 1 or 2 more years. These projects are as follows:

a.	water	supply	project	Djakarta	production	capacity	3,000	liters/sec
b.	,,	,,	,,	Padang	,,	,,	250	,,
c.	,,	,,	,,	Menado (1st stage)	,,	,,	125	,,
d.	,,	,,	,,	Bandjarmasin (1st stage)	,,	,,	250	,,
e.	,,	,,	,,	Bogor	,,	,,	100	,,
f.	,,	,,	,,	Palembang	,,	,,	200	,,
g.	,,	,,	,,	Ambon	,,	,,	100	,,
h.	other smaller projects.							

Final completion of those projects with full capacity is expected by the ends of 1970 and 1971.

In addition to the above projects, there are also new projects whose construction was started at the beginning of the Five Year Plan. These projects are of high priority, and include the following cities:

i.	water	supply	project	Makassar	—	production	capacity	500	liters/sec
j.	,,	,,	,,	Solo	—	,,	,,	150	,,
k.	,,	,,	,,	Denpasar	—	,,	,,	100	,,
l.	,,	,,	,,	Sukabumi	—	,,	,,	100	,,

Other projects of high priority, whose execution is expected to commence within the First Five Year Plan among others, are the following:

m.	water	supply	project	Djambi	—	production	capacity	500	liters/sec
n.	,,	,,	,,	Pakandaru	—	,,	,,	250	,,
o.	,,	,,	,,	Jogjakarta	—	,,	,,	500	,,
p.	,,	,,	,,	Bitung	—	,,	,,	100	,,

The execution of the above projects, however, depends much on the foreign exchange or credits coming from donor countries (credit-offering countries).

2. Implementation of Rehabilitation Program

In this program, improvements are concentrated on those water facilities suffering from deterioration or in those cities suffering from acute water shortages. Priority in this case will be given first to cities having economic potential, such as port cities and/or provincial capital cities, like:

—Banda Atjeh
—Samarinda
—Singaradja
—Tandjung Xarang
—Kendari
—etc.

For this rehabilitation program, large sums of funds are generally required for the procurement of piping materials for the replacement of broken mains or rehabilitation of old pipes (ranging from 30 to 40 years old). Due to very limited funds, along with the vast number of water works facilities requiring considerable rehabilitation work, the Central Government (i.e. Directorate of Sanitary Engineering) has then undertaken a policy to confine the rehabilitation work to the sources of supply (i.e. spring watershed) and transmission mains of the system. Other works, such as the rehabilitation of water service meters and distribution mains are left, both in financial and technical matters, to the regional governments concerned.

Program of Finance

In the First Five Year Development Plan, funds appropriated for both water supply and sewerage projects amounted only to Rp. 7 billion. In the present budget foreign exchange for the procurement of piping materials and equipment, to be imported from abroad, is already included. On the basis of the above amount, the Directorate determined the proposed breakdown of budget as shown in Table 1. In the proposed list, the water supply projects Djambi and Pakanbaru are not yet included because these projects require considerable amounts of local and foreign exchange financing, whose execution can be carried out only when additional funds are made available. In fact, several of the projects listed still require considerable amounts of foreign exchange. For example, the Djakarta water supply project still requires another US $6,000,000 for the extension and rehabilitation of the distribution system, which eventually must meet the increase in supply from 2,000 liters/sec to 5,000 liters/sec. For those projects which fall in this situation, additional funds must be provided, The required additional increase of funds could be obtained, for instance, through other financial sources, or revision of State Annual Budget Appropriations. In such a case, revision of the Annual Budget is possible because of the fact that the State Budget in the First Five Year Plan is not fixed, both in its planning and financing. Since the development programs are based upon regular annual appropriations, the financing as well as the physical progress are therefore reviewed and adjusted to new developments so as to attain maximum benefits.

Table 1 — Summary of Budget Allocation for Water Supply and Sewage Development

Project	Construction Cost Rp.(1,000's)	Foreign Exchange US $ (1,000's)	Countervalue (US $ = Rp.350) Rp.(1,000's)	Total Cost Rp.(1,000's)
A. Expansion				
1. Ambon	77,500	150	52,500	130,000
2. Palambang	115,000	100	35,000	150,000
3. Sutabaia	10,000	-	-	10,000
4. Semarang	25,000	-	-	25,000
5. Padang	185,000	-	-	185,000
6. Bandjarmasin	550,000	-	-	550,000
7. Td. Uban	5,000	-	-	5,000
8. Bogor	130,000	200	70,000	200,000
9. Menado	330,000	200	70,000	400,000
10. Djakarta	950,000	-	-	950,000
11. Karawang	145,000	300	105,000	250,000
12. Makasar	1,000,000	2,200	770,000	1,770,000
13. Solo	125,000	500	175,000	300,000
14. Denpasar	150,000	1,000	350,000	500,000
15. Bitung	105,000	200	70,000	175,000
16. Jogja	162,500	250	87,000	250,000
17. Sukabumi	97,500	150	52,500	150,000
Sub-total	4,162,500	5,250	1,837,500	6,000,000
B. Rehabilitation				
Regional Water Works & Sewage Facilities	650,000	1,000	350,000	1,000,000
Sub-total	650,000	1,000	350,000	1,000,000
TOTAL	4,812,500	6,250	2,187,500	7,000,000

In the first year of the Five Year Plan(1969/1970), out of Rp. 7 billion provided, funds already allocated amounted to Rp. 1,770,000,000 as shown in Table 2, whereas in its second year, as much as Rp. 1,850,000,000 has already been approved by Bappenas. Aside from the funds provided for water supply and sewerage development, additional funds from other sectors (i.e.

rrigation) amounting to Rp. 500 million had been made available in the first fiscal year of the Five Year Plan. These funds are also used for the Djakarta water supply project.

Table 2 — Budget Allocation Water Supply for 1969/1970

Project	Construction Cost Rp.(1000's)	Foreign Exchange US $ (1000's)	Countervalue (US $1 = Rp.350) Rp. (1000's)	Total Cost Rp. (1000's)
A. Expansion				
1. Ambon	22,000	-	-	22,000
2. Palembang	35,000	-	-	30,000
3. Surabaja	10,000	-	-	10,000
4. Semarang	25,000	-	-	25,000
5. Padang	100,000	-	-	100,000
6. Bandjarmasin	275,000	-	-	275,000
7. Td. Uban	5,000	-	-	5,000
8. Bogor	75,000	200	70,000	145,000
9. Menado	150,000	-	-	150,000
10. Djakarta	25,000	-	-	25,000
11. Karawang	15,000	-	-	15,000
12. Makassar	90,000	1,250	437,000	527,000
13. Solo	40,000	430	150,500	190,000
14. Donpasar	50,000	320	112,000	162,000
15. Bitung	10,000	-	-	10,000
16. Sukabumi	10,000	-	-	10,000
Sub-total	932,000	2,200	770,000	1,702,000
B. Rehabilitation				
1. Banda Atjeh	5,000	-	-	5,000
2. Td. Karang	5,000	-	-	5,000
3. Kendari	5,000	-	-	5,000
4. Samarinda	5,000	-	-	5,000
5. Kupang	7,500	-	-	7,500
6. Purbolinggo	10,000	-	-	10,000
7. Singaradja	5,000	-	-	5,000
8. Pd. Pandjang	10,000	-	-	10,000
9. Bandung	2,500	-	-	2,500
10. Malang	1,000	-	-	1,000
11. Palangkaraya	5,000	-	-	5,000
12. Other cities	7,000	-	-	7,000
Sub-total	68,000	-	-	68,000
TOTAL	1,000,000	2,200	770,000	1,770,000

CONCLUSION

It was the intention of the writer to provide a general background of the water supply situation today in Indonesia in order to promote a general understanding of the problems confronting the Government. Further, it is hoped that the material presented here will be of value to other developing countries involved in water supply development.

WATER SUPPLY AND SEWERAGE IN DACCA, EAST PAKISTAN

M.J.R. KHAN
Chairman, Dacca Water Supply and Sewerage Authority, East Pakistan.

On June 1, 1961, the International Development Association approved allocations of 24 million dollars for the rehabilitation and extension of the Dacca Water and Sewerage Systems. Since partition of the Indian subcontinent in 1947, Dacca, then a comparatively small provincial university town in Bengal, has become the capital and largest city of East Pakistan, and the administrative and most important commercial center for a Provincial population of 51 million people. The large expansion of population, government agencies, educational facilities, business, and industry has developed in somewhat of a haphazard manner. At present the area is faced by a number of problems including a shortage of suitably located building land free from annual flooding, congestion in the old, central area of Dacca, an inadequate water supply system and very poor sewerage and drainage facilities, which are all being improved by the present systems now under construction.

The following diseases are presently a problem: cholera, typhoid, parasitic and dysenteric disorders. Principal contributory factors are the insanitary conditions in which the people live coupled with the peculiar environmental characteristics of the area, which are optimal for continuance and transmission of these diseases. Various studies and reports have generally indicated the widespread use of water from contaminated sources, insanitary disposal of human wastes, very low standards of personal hygiene, and contaminated food. Focal points in the transmission of these diseases are open bodies of water, especially hundreds of "tanks" (ponds resulting from excavation for land fill) which are used by a sizeable portion of the population of Dacca as sources of water and centers of social life. They are visited daily to wash clothes, for bathing and swimming, to collect drinking and cooking water and to wash livestock. These waters are grossly polluted by sewage and polluted surface drainage as well as by their heavy use.

At the time the Dacca Water and Sewerage Authority was established, there were 16 public water systems within Dacca. Five of the distribution systems were within the Municipality and administered by the Dacca Municipal Committee. Eleven of the public systems were in the suburbs and under the jurisdiction of the Directorate of Public Health Engineering (DPHE) of the Government of East Pakistan. In all, these systems include about 200 miles of distribution mains.

The Burhi Ganga river supply continues to serve a portion of Dacca Municipality. The river has proved to be a difficult and heavily polluted source of water. The river water obtained (maximum 3.0 IMGD) is pumped and treated at an antiquated plant which is in a poor state of repair and is very inefficient.

In addition to the public water systems, the Central and Provincial Governments operate a number of tubewells for the use of various government agencies and installations including the army cantonment and the Dacca airport. These government systems are not considered to be part of the public water supply facilities. A considerable number of small private wells serve individual residential buildings and at least 20 larger tubewells are used by private industries and institutions such as hospitals. A significant portion of the water used by the Dacca population in the lower income groups comes from rivers, canals, ponds and many "tanks".

Existing water pressures are too low to permit reliance on the public distribution systems as sources of water for fire fighting. Fire fighting apparatus makes use of self-contained tank trucks which must leave a fire to replenish their supplies from open bodies of water. Fire fighting is thus inefficient and difficult.

The Project consists of construction of new facilities and improvement of existing ones for the water supply and sewerage systems of metropolitan Dacca and development of an adequate organization for their efficient operation.

WATER SUPPLY AND DISTRIBUTION SYSTEM

New tubewells will be installed at various locations in Dacca, and worthwhile existing ones will be improved, to meet average water production requirements of about 30 IMGD (million imperial gallons per day) and maximum requirements of about 40 IMGD. All water production will be metered. New distribution mains and three 1.0 million imperial gallon elevated storage tanks will be constructed. Existing treatment, distribution and storage facilities will be improved to provide more effective service.

The Project includes new water service connections and a program of installing water meters on both new and existing connections. These elements of the Project will be adequate to provide on-premises water service for a total of about 400,000 people in the metropolitan area and at least 50% of the water connections will be metered by the end of the construction period. Existing street hydrants will be reconstructed and metered and new ones added for a total of about 1,500. There will be an experimental program of constructing and operating public sanitary structures.

SEWERAGE SYSTEM

Sewage disposal is an unusually severe public problem in Dacca. The soil is relatively impervious and the ground water level is generally close to the surface; both characteristics hinder or prevent effective underground disposal of sanitary wastes. Commonly, liquids from septic tanks or cesspools rise to the surface of the ground or pollute the limited water bearing sub-strata from which well waters are taken. The land topography is extremely flat. Polluted surface drainage and wastes are carried off very slowly or collect in depressions, "tanks", and other stagnant bodies of open water creating serious health hazards. The flatness of the land also works against sewer systems. Sewers, which must be installed with a pitch or slope to permit gravity flow, soon get quite deep in the ground or the flow must be lifted periodically to a higher elevation by pumps; both alternatives are expensive. The high ground water leaks into the sewers through defects and increases the volume of liquid flow in the system. Large bodies of water into which sewage from the sewer system could safely be dispersed are above the level of the sewer system during most of the year and the sewage can be discharged only by pumping. All of these factors combine to increase the importance of a piped system for sewage disposal in Dacca and to make such a system comparatively expensive to build and operate.

A sanitary sewerage system for Dacca was started in 1923. At various times since 1931, the system has been expanded in the Municipality and extended to some adjacent urban areas, but at present most of Dacca is not served by sewers. The system is not extensively used in the Municipality, primarily because of the inadequate water supply and lack of sanitary plumbing in buildings. The existing system consists of four, small, intermediate pumping stations (two additional stations are under construction) and about 86 miles of sewers. About 50% of the sewers have been constructed in the last 4 years. Although intended only for sanitary wastes, the sewer system has a number of storm-water connections. These, and many leaks through which ground water enters, cause flows which exceed pipe and pumping capacities and overflows from the sewers to streets and ditches are common. The treatment plant is overloaded, in poor condition and generally ineffective.

New works for the sewerage system include major sewers, lateral sewers, intermediate pumping stations, a main pumping station, sewage treatment lagoons and an outfall sewer into the Burhi Ganga River. Existing sewerage facilities will be improved and modified to provide more effective service. New sewer service connections will be added so that when the Project is completed not less than 50 % of the buildings with water service connections will also have sewer service connections.

ORGANIZATION

An efficient organization will be developed for the Authority enabling it to operate efficiently in accordance with sound public utility practices. The Project includes management services and a training program. Repair and storage facilities and ancillary buildings will be erected and equipment and tools purchased as necessary for efficient operation. The Project is scheduled to be completed by June 30, 1971.

MUNICIPAL WATER SUPPLIES IN EAST PAKISTAN

JAMES ARBUTHNOT

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In 1964, Camp, Dresser & McKee (CDM) were employed as consultants by the provincial government of East Pakistan, one of the two provinces of Pakistan. Under the terms of the contract, Camp, Dresser & McKee became General Advisors in Public Health Engineering to the Government of East Pakistan. The foreign exchange for the contract was furnished by USAID as a loan. The purpose of the contract is "to provide general advisory services in public health engineering for the province of East Pakistan, with the ultimate goal of developing within East Pakistan the capacity to plan, design, install, manage, operate and maintain water and sewage systems." Camp, Dresser & McKee have had a team of 10 to 12 American engineers in East Pakistan assisting the government since 1964, and have necessarily developed considerable knowledge of municipal water supplies in East Pakistan.

EAST PAKISTAN

East Pakistan is the eastern-most province of Pakistan, and is separated by the width of India from the western province. East Pakistan is bounded by Burma on the east, by India on the north and west, and by the Bay of Bengal on the south. It has an area of approximately 55,000 square miles. The portion of East Pakistan which borders Burma is known as Chittagong, or Chittagong Hill Tracts, and has somewhat the same geographical character as that portion of Burma. Most of East Pakistan, however, is a large delta. Two great rivers, the Ganges and the Brahmaputra come together in East Pakistan, and discharge into the sea through East Pakistan. These rivers drain an area of approximately 600,000 square miles, some parts of which are reputed to have the highest rainfall in the world, 300 or even 400 inches a year. East Pakistan itself has an annual rainfall which varies from about 60 inches in the western part of the province to perhaps 140 inches in Sylhet. This rain comes generally in the monsoon season, in the six months from May to October. The rivers begin to rise in May after the rain has started in the hills and before there has been significant rain in East Pakistan itself. During the height of the monsoon much of the land is covered with water and a stranger approaching Dacca by air in the monsoon may wonder whether the plane can land. In the lower part of the delta during the flood period, at that time in the month when especially high tides occur, 80 or 90 percent of the land may be covered with water during the high tide period.

Geologically most of East Pakistan is, as has been stated, a large delta. Apparently in ancient times the center of what is now India was a relatively high plateau, and the area which is now East Pakistan was a deep gorge between this plateau and the Himalayan mountains. In the course of time this gorge has filled with sediment brought down by the Ganges and Brahmaputra rivers. Over much of East Pakistan this alluvial material is several thousand feet deep. The soil over the deltaic portion, the principal portion, of East Pakistan is clay silt and sand lying in irregular beds and lenses. It is relatively flat. Dacca, the capital, about 80 miles from the sea is about 20 feet above sea level The influence of the tide is felt even 100 miles from the sea and the river flow reverses for some hours in the day in many locations along tributaries or distributaries 50 miles from the sea. In many of these places the surface water is saline in the dry season. The alluvial sediments were of course laid down in the sea. In the upper delta these sediments have been flushed clear of salt by the flow of fresh water. In the lower delta where surface water is saline the coarser sediments 800 or 1,000 ft. below the land surface have also been flushed clean of salt by the flow of groundwater to the sea.

From what has been said it may be deduced that in the deltaic parts of East Pakistan, in most of the province, groundwater is abundant. In the northern part of the province, away from the sea, the groundwater is fresh though it sometimes contains iron. In the southern part of the province the groundwater quite near the surface will be fresh. The groundwater in the deeper layers will also be fresh here but intermediate finer layers may be saline.

East Pakistan is presently estimated to have a population of about 72 million persons. A portion of the lower delta is a so-called forest or jungle reserve known as the Sunderbans, where nobody lives. Excluding this portion and the Chittagong areas there may be 45,000 square miles in the province in which reside about 70 million people. This is a density in excess of 1,400 per square mile which is, as far as I know, the highest in the world for an area so large. The population is increasing at about 3% per year. One recent demographic study in a rural area indicates that half the population may be less than 15 years old. The great majority of the people live in rural areas. The largest city in the country has a population of about 1.2 million and the second largest 700,000. The four largest cities have a total population of about 2½ million. There are 17 cities in East Pakistan with a population greater than 50,000 people and 60 cities with a population greater than 10,000. Most families of East Pakistan support themselves by farming. The per capita income in East Pakistan was estimated at Rs. 315 per year, about US$ 66, in 1965.

East Pakistan is an endemic center for cholera, perhaps the worst endemic center in the world. In an official document accompanying the presentation of the 3rd Five-Year Plan the following sentences occur:

> "It is estimated that in East Pakistan nearly 50 percent of all illnesses are attributable to gastro-intestinal disorders like diarrhea, dysentery, worm infections, enteric fever and cholera, all of which thrive only in insanitary conditions. Protection against some of these diseases can be provided by inoculation, but permanent eradication requires arrangements for a proper disposal of sewage and the provision of safe drinking water."

In a survey made about ten years ago, all of 300 school children had one or more intestinal infections, having either protozoa or helminths or both. Conditions are believed to be unchanged at this time. Doctors frequently make the statement that a majority of the population (this refers to the rural, less healthy and less educated people) have *ascaris* or *trichuris* infections.

EXISTING WATER SUPPLIES

These health conditions indicate low sanitary standards in East Pakistan, and particularly lack of good water supply. A good water supply not only prevents the so-called water born diseases but also markedly decreases the diseases of insanitation generally. A good water supply induces cleanliness; cleanliness of people, of their hands, of their clothes, and of their utensils, and cleanliness prevents the diseases of insanitation. A good water supply, of course, is one that is conveniently supplied, and plentiful as well as safe to drink. The people in rural areas generally do not have access to piped water supply. Most of these people drink and bathe in surface water. Usually this water is taken from what is referred to in English as a tank, from a pond. The rural people also take water from canals and streams when they are convenient. In the past two or three decades a large number of hand pump, singletube, tubewells have been installed in rural areas of East Pakistan. There are now perhaps 140,000 of these small tubewells in good working order. These tubewells provide a good quality water, certainly the best available in the rural areas, and are much appreciated by the rural population.

When CDM began work in East Pakistan in 1964 there were 11 municipalities which could be said to have a municipal piped water supply, by our definition, which is that the pipes must provide a significant amount of water to a significant fraction of the population, to 25% or more of the people in the municipality. Even after five years in the country we continue to find small piped water supplies in various stages of repair serving a few people. This number of 11 excludes these small piped water supplies and excludes piped water systems installed by industry or the railway for their staff, though the eleven did include one system which was just barely worth counting.

The municipal water systems existing in 1964 were generally built long ago, perhaps fifty or seventy-five years ago, before the availability of groundwater was appreciated. Most obtained water from surface streams. Treatment was standard for those days, including coagulation, sedimentation and filtration. One slow sand filter system is still giving good service. These systems had not been significantly expanded in many years. In 1964 in these 11 municipalities a relatively small portion of the people were served with water, and the water supplied, at a guess, did not exceed 8 or 10 gallons per person per day. The custom was, and regrettably still is, to provide water in the pipes for only a few hours each day, perhaps 2 hours in the morning, and 2 or 3 hours again in the afternoon. Most of the people who use this piped water obtain it from public faucets in the street.

The public, in either rural or urban areas, values convenience more than any other attribute of a water supply. People generally will use the closest water, without reference to its quality, or at least without reference to its safety. Ground waters containing iron are disliked and people will walk past a public faucet or a handpump giving iron bearing water to take water from some open tank which appears to us to be heavily polluted. It is fair to say that the people generally do not put much value on a piped water supply and frequently indicate their unwillingness to pay much money for a piped water supply. The truth is of course that the piped water supply they know is not of much value.

The municipal governments as well as the public were accustomed to the shortcomings then existing. These governments would at times complain about shortages of water but they had no real intention of providing more or better water. Municipal water supplies generally were, and unfortunately still are, financed by a water rate, which is a tax on land and buildings. The tax was levied whether or not the building was provided with water though it might be levied at a higher rate when piped water was available to the property. The municipal water supplies existing in 1964 were old and had obviously deteriorated over the years. Generally, municipal financial accounting did not provide adequately even for operation and maintenance of these water supplies. If a pump broke down the custom was to make an emergency appropriation for repairs. There were no financial provisions for depreciation and replacement, or for accumulating money for extension and enlargement.

DIRECTORATE OF PUBLIC HEALTH ENGINEERING

The arm of the provincial government which looks after the municipal water supply is known as the Directorate of Public Health Engineering. This Directorate was created and given its functions before Pakistan was independent. About 75 years ago, a mechanical engineer was appointed in Bengal, which included what is now East Pakistan, to inspect and supervise piped water systems. It is clear from the instructions given to this engineer, and from the instructions given by him, that the government's principal interest at that time was in the maintenance and safety of operation of the steam boilers and pumps with which the town water systems were equipped. This mechanical engineer was made a part of the Public Health Engineering Directorate when it was established a little later, about the beginning of the 20th century. When Pakistan became independent the existing PHED continued to function in East Pakistan.

Unfortunately, however, the great majority of the professional staff in the PHED at the time of independence were not Moslems and did not become citizens of Pakistan. At the time of partition of British India into India and Pakistan then, although the organization existed, the level of experience of the staff was quite low. A man who had been an Assistant Engineer only two years before was made Chief Engineer of the Directorate, three ranks higher than an Assistant Engineer. Due to the shortage of engineers, men without full technical qualifications were brought into technical positions in the Directorate. Some of these men still hold high positions in the DPHE. Due to this shortage of technical staff and due even more to a shortage of money generally, municipal water supply conditions probably deteriorated for the first few years of Pakistan's independence, while cities grew.

Municipal water supply problems have always been recognized by the provincial government, and by the national government too. But Pakistan seems to have had its full share of the problems which regularly plague newly independent countries. Among all these problems, municipal water supply simply could not be given a high enough priority to get much money assigned to it until rather recently. About 1958 the provincial government planned a scheme to enlarge the sources and existing municipal water supplies by sinking a number of tubewells, equipping them with pumps, and connecting them to municipal water mains. This work began in 1959, and by 1967, 60 six-inch tubewells had been drilled and equipped. In 1958 also work began on plans for enlarging the water systems of the two largest cities in the province. The work then planned is now nearing completion with the aid of a World Bank loan and independent Water and Sewerage Authorities have been set up to execute the work and operate the systems. In 1961 the Nine Important Towns Scheme was begun. This scheme provided for increase to water supplies in six towns, and new supplies in three other towns. In 1962 the 21 Municipal Towns Water Supply Scheme provided for 18 new municipal supplies and enlargements to 3 existing ones. Except for the towns which received World Bank loans, all of these schemes were paid for entirely by the provincial government, i.e. the towns themselves paid nothing toward the capital cost of the water supplies.

In 1964, the provincial government hired CDM to assist it with these water supply schemes, and to train the DPHE. When CDM arrived, the Directorate had regular posts for 39 engineers; one chief engineer, 2 superintending engineers, 12 executive engineers, and 24 assistant engineers. Most of these men were stationed in various district headquarters throughout the province. During many of the years after independence, more money was available for rural water supply than for urban water, and much of the Directorate's efforts were aimed at construction or maintenance of the rural hand pump tubewells. The Chief Engineer's office itself had practically no professional or technical staff. Due to this shortage of technical staff it was very difficult to make proper investigations and engineering plans. When urban water supply work was done, it was the custom to ask contractors to do both the design and construction. Junior engineers, surveyors and draftsmen were not really proficient, due largely to lack of supervised practice.

One of the difficulties which I first observed in the operation of the DPHE was that the Chief Engineer was a part-time officer. He was considered an efficient officer by the government, and had therefore been given two other posts in addition to that of Chief Engineer. Both of these positions were considered senior in the government hierarchy to that of Chief Engineer, DPHE, and more important. The then Chief Engineer also taught at the University a few hours a week. This large number of other responsibilities inevitably resulted in his paying little attention to the DPHE, at a time when the Chief Engineer's staff consisted solely of a few clerks and when technical competence in the DPHE was generally low.

Although technical supervision of the DPHE's work was not what it should have been, financial supervision was strict. An Executive Engineer in

East Pakistan has lots of authority. He can let contracts and can pay contractors large amounts by cheques signed by himself drawn on the Government Treasuries. However, each Executive Engineer has an accountant, a representative of the provincial Accountant General, sitting at his side. Financial rules are therefore strictly followed. These rules require that money not used during a financial year must be surrendered at the end of that year, even though the money may not be allocated to the engineers who will spend it until 6 or 8 months of the working year have passed. This strict financial supervision was not sufficient to get good work done. To pick one example, an Executive Engineer can call for tenders for the installation of water pipes, accept the lowest tender, accurately measure the feet of pipe installed, and pay the proper rate, all in accord with financial regulations and the accountants' approval and still get bad work done if the pipe will not hold water. Water Engineers here will say the specifications were not right, or were not enforced, if the pipe would not hold water. But the pipe can be all right and still not hold water if the valves and fittings are not installed, and the accountant does not object to the valves and fittings being omitted, if they are not paid for. One consequence of the late allocation of money and strict enforcement of the surrender time was that the construction period was usually less than six months a year. Of course the engineers frequently compounded these financial handicaps by not preparing plans and specifications until they were told what money they could spend each year.

CDM ASSISTANCE

CDM began its work in East Pakistan in the manner that it considered a good consulting engineer should. It began by making surveys with the intention of writing reports, submitting these reports to the government, obtaining money for works more or less in accordance with the reports, developing design criteria, preparing detailed plans and specifications and after that supervising construction. We also knew that our contract required us to advise the DPHE generally, including giving advice on its own organization, develop commodities for water and sewage works, advise on necessary legislation, do research and development, and review engineering reports which were referred to us. We had problems with this work plan right from the start, although several reports were eventually submitted. The first problem observed was that the DPHE had only a few engineers in Dacca, where our office was, and these engineers considered they already had full-time jobs, and were not available to make surveys and write reports with CDM engineers. (All our work was supposed to be done jointly with the Government engineers.) After considerable insistence on our part, and I am sure the Government considered us a nuisance for our insistence, we got some DPHE engineers assigned to this work, made some surveys and wrote some reports. Detailed reports were written for three specific towns more or less as examples for the large number of reports intended to be written. One of these reports, after a delay of five years, has now served as a basis for financial approval for a large water supply for the town in question. When we found writing reports for specific towns to be difficult and thankless work, we wrote a general survey report for the province as a whole. A summary of this is reproduced here in Table 1, from our second annual report entitled "20 Year Public Health Engineering Program for East Pakistan". A crore is ten million, and Rs. 4.75 equals US$ 1.00, so that general report to the Government called for an expenditure of about US$ 2 billion. The standards on which these estimates were made were to our minds very meagre. Nevertheless, the amount requested was about six months' gross provincial product. I am sure that the government never seriously considered this report, and the DPHE engineers certainly did not take much interest in developing it.

While waiting for the Government to review our report, and to tell us how much of it could be executed, we adopted a somewhat different approach in our relations with the government and the DPHE. The essence of this approach was that we set out to be helpful. The basis of this approach

Table 1—20-Year Public Health Engineering Program For East Pakistan (1965 Estimate)

Item	Millions of Persons		Construction Costs Per Person Served in Rupees	Budgeted Cost Per Year in Crores of Rupees		Twenty-Year Costs in Crores of Rupees 1965-1985	
	1975	1985		1975	1985	Subtotals	Totals
I. Direct Construction Costs							
A. Water Supply Facilities							
1. Distribution System with house connections -	8.5	25.0	100	14.0	18.0	250.0	
2. Distribution System with Fordillas -	2.5	6.5	75	3.0	4.5	48.8	
3. Distribution System with street faucets -	8.0	12.5	40	5.6	1.6	50.0	
4. Hand pumps on tubewells-	64.0	62.0	8	7.2	7.0	49.6	
Subtotal:	83.0	106.0		29.8	31.1		398.4
B. Sanitation Facilities							
1. Sanitary sewers with house connections -	6.0	18.0	130	13.0	18.2	234.0	
2. Septic tank systems -	3.0	9.0	170	6.8	13.6	153.0	
3. Water-seal latrines -	65.0	79.0	5	4.0	4.0	39.5	
Subtotal:	74.0	106.0		23.8	35.8		426.5
II. Non-Construction Costs*							
A. Urban -	13.0	27.0		7.4	15.0	147	
B. Rural -	70.0	79.0		3.6	4.7	71	
Subtotal:	83.0	106.0		11.0	19.7		218.0
Totals	83.0	106.0		64.6	86.6		1,042.9

* Public Health Engineering Institute	- 5
Direct Public Health Engineering Payroll and Establishment Costs	- 6
Municipal Payroll, Establishment, Chemicals and Power Costs	- 187
Public Health Education Costs	- 20
TOTAL:	218

was that we took on the whole job. My personal philosophy, as an adviser, is that advice that is not accepted is not of much value, even if it is good advice. In regard to our work directly with the DPHE, we began to help them to plan, and to construct water supply facilities for which they had money. This was the work for which their engineers were responsible, and they were glad to find us helpful. Our work with the DPHE became easier as time passed and the DPHE engineers developed confidence in us. I am sure that many of them thought we caused them more trouble than the help we gave them was worth at the beginning. About this time also the government assigned a new Chief Engineer to the Directorate, full time. This man has gradually made it clear to the DPHE engineers that they were in trouble if their work was not physically well done, and done on time. This made them appreciate our assistance, and was a large step toward getting them to consider our help to be worthwhile. At the present time all plans and specifications prepared in the DPHE are reviewed by us before they are submitted to the Chief Engineer and usually before they are submitted to the Superintending Engineers. In the great majority of cases our criticisms are accepted and suggested changes are made as recommended. This relationship has not developed wholly because the DPHE has come to accept what we recommend. In part it has developed, I must admit, because we have come to recommend things which are practical under the circumstances. There has been some give on both sides.

DEVELOPMENT OF DPHE

We have seen a considerable improvement in the DPHE in our five years in East Pakistan. At this time there are regular posts for 53 engineers in the Directorate. This is a forty percent enlargement over 1964. One of the new posts is that of a Superintending Engineer in charge of a Central Technical Circle. This Central Technical Circle is intended to take over the work now performed by CDM. It includes 5 Executive Engineers, two of whom perform new functions.

One of the new functions is that of supervising a new groundwater division. Groundwater was very early found to be an important resource in East Pakistan about which very little was known. Certainly it was not realized how much groundwater was available, that for instance, it would be possible to furnish a million people in Dacca with water from groundwater alone. The importance of exploratory borings in advance of well construction was also not realized. The groundwater division is now providing expert supervision of all groundwater work of the DPHE, which includes the groundwater work done by municipalities and towns. It is also providing some expert assistance for other government agencies. The Division now has a staff of about 10 engineers and technicians, any one of whom can supervise a pumping test, and can perform routine chemical analyses of water in the field. Groundwater Division staff includes a groundwater geologist in a regular position. In the past, wells installed for municipal purposes have sometimes gone bad in two or three years because of faulty specifications. Some of the groundwaters are rather corrosive and the thin brass screens previously used have not lasted in these waters. Stainless steel screens are now being specified and installed in municipal wells and efforts are underway to obtain local manufacture of plastic screens.

A Design Division has also begun to function in the central technical staff. This Division is now designing water treatment works with CDM help and in one instance recently has done a complete design including structural design. This means that contractors are not asked to "design and build" and contracts can be let faster than before.

Another new function of the Central Technical Circle is that of the laboratory examination of water. Two laboratories have been set up; one in Chittagong, and one in Dacca. They are staffed completely by Pakistani chemists and technicians, and they function with only distant supervision from CDM. The laboratories are capable of performing several thousand determinations a month.

The Mechanical & Electrical Division of this Central Technical Circle existed before the Central Technical Circle was set up but it is now functioning in a very much improved fashion, doing more work in a month than it formerly did in a year. A workshop has been established for the Mechanical & Electrical Division. It was considered that the staff of the Division should perform a part of the repair and maintenance work themselves in order to be sure that they were capable of supervising properly that work which was performed by contractors. Services of the M. & E. Division are now demanded by municipalities throughout the province although these municipalities are not obliged to use DPHE services.

CDM gives training to the DPHE staff principally by working with them to execute the work for which they are responsible. CDM has also assisted with formal courses. 14 DPHE engineers have completed graduate study in the States and five more are now studying in the U.S. Six of these engineers have spent more than a year in CDM's head office in Boston, U.S.A. Others have spent several months in other consulting engineers' offices in the U.S.A. Three courses for Water Superintendents have been given by DPHE and CDM since 1965. These courses have averaged six months duration, exclusive of practical experience, and a total of about 160 men have completed them. We were recently pleased to learn that the government has officially listed these courses as a qualification for permanent appointment as Municipal Water Superintendent. Courses have also been given for Overseers, who are engineering technicians, and for Pump Drivers. We have also written an Engineers' Notebook, about 3 inches thick, which includes many standard specifications. The Chief Engineer has distributed the Engineers' Notebook to the DPHE engineers. We continue to add to it.

DEVELOPMENT OF WATER SUPPLIES

I have mentioned some of the defects we observed in the municipal water systems in East Pakistan. First, the public generally did not want to pay for water service. Second was the fact that the service really wasn't worth paying for either. Maintenance was poor. There were very many leaks, and frequent breakdowns of pumps. The municipal governments did not want responsibility for water systems, at least in the new systems, and frequently refused to take over new systems when the provincial government completed them. The municipal governments had little money for maintenance, and certainly had no money for expansion or enlargements. In summary, these municipal systems provided from 2 to 10 gallons of water per person per day; there was pressure in the pipes for only 4 or 5 hours a day and considerable waste.

To an American water engineer, this all may seem pretty senseless, but the first thing to be realized is that there were reasons for this system of municipal water supply operation. It actually was a system. For instance, in the matter of supplying water under pressure for only 2 hours in the morning, and 2 hours in the evening, the first hour water was supplied there was absolutely no wastage. At all the public taps in the streets many people were waiting to get water and although the tap was running free (and probably could not be closed,) still demand was such that there was no wastage. Similarly, in the connections to houses or buildings the water discharged into reservoirs, on the ground or on the top of the house. During the first hour the reservoirs were empty and filling, and there was no wastage. During the second hour that there was pressure in the pipes, some of the time no one would be waiting at the street taps and water would be running to waste through the open tap. Also in the second hour, some of the reservoirs in private homes become full and overflowed to waste. During the second hour of supply there was wastage, and if water had been provided during a third consecutive hour there would have been considerable wastage. You see it was a system, and you had to begin to improve all parts of it at once.

One of the big breakthroughs we made was a decision by the Chief Engineer, DPHE, that the provincial government could pay for supply pipes to private houses. In the past the provincial government had provided the source and principal mains of 8 in. or more and had left it to the municipal government to distribute water to the public. The municipal government often failed to arrange this, and frequently the public got little benefit from the sources of water provided by the provincial government money. We were therefore very pleased when the Chief Engineer agreed to the principle of spending provincial money for pipes for private use, as an example, if we could find a cheap way to do it. We had early recommended provision of more individual services to individual houses. Objections to this were that the municipal government would want a fee of perhaps Rs. 500.00 (about US$ 100.00) for the connection; that the people would waste a great deal of water if they had individual water taps; that the house connections would cost too much; and that the people would not pay a monthly fee for water anyway even if they had a private tap. We arranged a test installation and DPHE installed about 50 self-closing valves in the front of houses in the poorer part of the town of Comilla. We had early decided that self-closing faucets in yards would be unsatisfactory to the people unless the pressure was on for 24-hours a day, and we had a hard time finding any place in the province where we could arrange 24 hour pressure. During the trial it was found that the people used only about 4 gallons per person per day, and that they valued the service considerably. As regards costs, the Fordilla self-closing faucets were estimated to cost 10 or 12 dollars each delivered to the home with customs and freight paid. This was indeed too much for East Pakistan. Eventually we worked out a system for providing faucets in the yard of individual homes at a total cost including labour and all materials of Rs. 70/-, (about $15) each where the mains already exist in the street. About 3,000 such have now been installed and another 2,000 are to be installed in the remainder of this fiscal year. The faucets are not nearly so good as the Fordilla but water wastage is not high. When the water flows out in a private yard and the yard is not paved or drained, people do not want to waste water. We have successfully got the public to pay a small portion of this first installation cost, Rs. 10/- each, and to pay Rs. 3/- per month for the water service. This Rs. 3/- per month for each connection is an income for the municipality and a start on sound finances. Several municipalities refused at first to waive their usual connection fee for such yard faucets but others did agree to waive it and DPHE installed faucets where the municipality was cooperative. These yard faucets have been a big success. People apply to the municipality for more faucets than the provincial government has money for and, in some instances, the municipality itself is now finding the capital to construct more yard faucets. We are also very pleased that in the last six months one town has set up a sensible set of accounts for the water system money. All money collected for the water system goes into this set of accounts. Operation money is obtained and a depreciation fund is developing. We will publicize the success of this town with its accounts and expect others to follow the example.

As of the end of 1969 there were 26 operating water systems in East Pakistan, which is more than double the number in 1964. The municipalities which already had water systems in 1964 now generally have more water. An Organization and Management Manual has been written for water utilities and in at least one instance its principles are being followed. Of these 26 operating water systems two are operated by their own water authorities, and are not the direct responsibility of DPHE (or CDM). Of the others, there are only five where the municipality has not taken over responsibility for operation. Out of these five in only one instance has the municipality refused to take over and operate the system built by the provincial government. The other municipalities who have not taken over proclaim good intentions.

Municipal water supply problems are far from solved in East Pakistan. But a start has been made. A number of good examples are there for others to see and we believe progress will continue. Camp, Dresser & McKee do not claim responsibility for this progress. We have tried to be helpful and the government has told us we have been helpful. Nevertheless, the principal credit for any improvements which have occurred is due to the present Chief Engineer, DPHE, Mr. Latifar Rahman, who has provided and continues to provide the authority and drive to make things go.

FOREIGN AID, THE WORLD BANK AND FINANCING OF WATER SUPPLY AND SEWERAGE PROJECTS

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INTRODUCTION

The subject of this paper was originally limited to "The World Bank's Criteria for Financing Water Supply and Sewerage Projects." It is worthwhile to first present a few facts and considerations, related to "foreign aid" and to the World Bank, and to multilateral and bilateral financing, in general. This paper is drawn from many contributions by others on what has become a complex subject: the relationship between foreign aid, the World Bank and sanitary engineering projects.

BILATERAL AND MULTILATERAL AID

Reference should first be made to an important recent analysis on foreign aid, the so-called "Pearson Report" which had been commissioned and sponsored by, but carried out independently from, the World Bank (COMMISSION ON INTERNATIONAL DEVELOPMENT, 1969). Table 1 shows the total annual average and the regional distribution of "Net Official Assistance" from bilateral and multilateral sources. Attention is drawn to the following highlights:

1. Multilateral aid represents only 14 percent of the total.
2. The U.S. has contributed more than half (53 percent); France, U.K., Germany, Japan and Canada together have provided more that a quarter (28 percent), and the remaining donor countries (Belgium, Netherlands, Italy, Australia, Sweden, Austria, Denmark and Switzerland) about 5 percent, of the total.
3. The U.S. is the most important donor in all regions, except in Africa, where France has been contributing slightly more.
4. Most donor countries have allocated the largest share of their aid to Asia (highest Japan with 98 percent), but a few have given more to Africa, especially Belgium (99 percent) and France (92 percent).
5. Of the *multilateral* aid, 43 percent has been for Asia, 32 percent for the Western Hemisphere and 25 percent for Africa. The comparatively high proportion for the Western Hemisphere reflects the important contribution of the Inter-American Development Bank to this region.

Concerning the role of the *multilateral agencies* the Report States:

> "Since some bilateral donors will continue to give high priority to political, humanitarian and cultural considerations, distribution of additional aid primarily according to performance can be ensured only if multilateral agencies try to fill gaps left by bilateral preferences. This is one of the strongest arguments which developing countries have been making over the past two decades in favor of expansion of multilateral aid ..... The most important advantage of multilateral process is the fact that it is mutual. It gives

Table 1—Regional Annual Distribution of Net Official Assistance[1]
From Bilateral (DAC) and Multilateral Agencies
1964-1967 Average
(amounts in million US$ and percentages)[2]

	Africa		Asia		Western Hemisphere		Total		% of Total Bilateral & Multilateral
US	418		2,009	(66)	576		3,003		53
FRANCE	445	(92)	28		15		488		9
UK	198	(50)	175	(44)	23		396		7
GERMANY	94		232	(63)	38		364		6
JAPAN	1		221	(98)	6		228		4
CANADA	14		106	(80)	11		131		2
Others[3]	178	(62)	92		16		286		5
Total Bilateral	1,348	(28)	2,863	(58)	685	(14)	4,896	(100)	86
Total Multilateral	194	(25)	334	(43)	256	(32)	784	(100)	14
Total Bilateral and Multilateral	1,542	(27)	3,197	(56)	941	(17)	5,680	(100)	100

Source : "PEARSON REPORT" (1969).

1 Includes only assistance with concessional terms, e.g. IDA but not IBRD.

2 Figures in parentheses are percentages of country's total official assistance.

3 Others :

	Total
Belgium	77
Netherlands	70
Italy	51
Australia	33
Sweden	22
Austria	18
Denmark	6
Switzerland	5
	286

recipients an opportunity to monitor donors and donors to monitor other donors, as to the performance of their commitments, the quality and terms of proffered aid, the criteria of performance, and the ties and strings attached to aid."

On "foreign aid" in general, the Pearson Report states:

"The real economic burden of foreign aid to wealthy nations is often considerably exaggerated. It is not uncommon to hear the total flow of resources to developing countries referred to as something which the rich countries "give" to the poor. Nothing could be further from the truth, or more misleading .... The flow of private capital and official credits undertaken for commercial reasons have no more the character of "aid", when they flow to developing countries than when they flow between industrialized countries.... If there is reason to believe that goods devoted to foreign aid would otherwise have gone to waste, their real cost to the supplier would be nil.... In view of the fact that most bilateral aid is tied to purchases in the supplying country and helps to promote more production and exports, the real burden of aid must be less than the face value of the resources which are transferred.... It is doubtful whether transfers directed primarily to military purposes and only secondarily to long term developments, should be thought of as an aid burden at all. In the same vein, suppliers who expect economic returns from general aid programs in terms of a foothold in future markets can hardly maintain that aid is a burden equal to its face amount. In short, the real burden of aid clearly runs below the dollar value of all resources transferred from the developed to the developing countries. This fact deserves to be more widely known."

Obviously, the Pearson Report does not want to minimize the importance of commercial foreign aid programs, but it wants to stress that foreign aid should be considered under a new light and that the developed and the developing countries should become more aware of their common role: to be "Partners in Development", as is the appropriate title of the Report. In this respect, multilateral agencies, such as the World Bank in which both "donors" and "recipients" are represented, are probably the best vehicle to promote this partnership, and to make it operative.

Table 2 — Gross Disbursements By Multilateral Agencies to Less-Developed Countries, 1960-68 (amounts in million US$)

Agency	1960	1961	1962	1963	1964	1965	1966	1967	1968	%	Total 1960-68	%
World Bank (IBRD)	341	321	409	462	464	474	564	561	605	39	4,201	43
Internatl. Dev. Association (IDA)	-	1	25	105	148	277	273	368	215	14	1,412	16
Internatl. Finance Corporation (IFC)	13	8	18	12	16	19	30	26	31	2	173	2
Sub-total World Bank Group	354	330	452	579	628	770	867	955	851	55	5,786	61
Inter-American Dev. Bank	-	5	37	75	131	109	142	183	233	15	915	10
Asian Dev. Bank	-	-	-	-	-	-	-	-	20	1	20	-
African Dev. Bank	-	-	-	-	-	-	-	-	2	-	2	-
European Eco. Comm-European Dev. Fund	4	17	54	67	85	104	112	105	121	8	669	7
European Eco. Comm-European Invest. Bank	-	-	-	-	6	12	28	39	10	1	95	1
U.N. Institutions	125	197	182	229	263	252	272	207	300	20	2,027	21
Total[1]	483	549	725	950	1,113	1,247	1,421	1,489	1,537	100	9,514	100

Source : "PEARSON REPORT" (1969).

[1] This total should not be confused with the flow of multilateral "development assistance". These figures include, in addition to official contributions ($661 million), funds raised on private capital markets and repayments on previous loans which are lent at near commercial terms.

MULTILATERAL AID AND THE WORLD BANK GROUP

Table 2 illustrates the amount of lending by the different multilateral agencies for each year from 1960 to 1968. During this period, the number of multilateral agencies has increased from 4 to 9. While the World Bank (IBRD) is still the largest among these agencies, its share in the total multilateral operations (which has tripled) has decreased from 70 to 40 percent. The International Development Association (IDA) and the Inter-American Development Bank (IDB), which were founded in 1960 and 1961 respectively, have provided an increasing share of the total, reaching 14 and 15 percent respectively in 1968. The share of the UN institutions, which have mainly financed project preparation, not implementation, has been fairly uniform with 20 to 25 percent. The new regional development banks, namely the Asian Development Bank (ADB) and the African Development Bank (AfDB) have started operations only in 1968, but are expected to quickly accelerate their lending volume in the coming years.

The World Bank Group (IBRD, IDA, IFC) will probably continue to be the leader among the multilateral agencies. Furthermore, although the volume of multilateral aid will probably always remain small compared with the volume of bilateral aid, the World Bank has an important role as coordinator of multilateral and bilateral aid through the increasing number of consultative groups for specific countries of regions, and through joint financing arrangements.

THE WORLD BANK GROUP — ORIGIN, NATURE AND FUNCTIONS

The World Bank Group consists of three international financial institutions, the World Bank itself, formally the International Bank for Reconstruction and Development (IBRD or, in short, Bank) and two affiliates, the International Development Association (IDA) and the International Finance Corporation (IFC). Each has its own special function, but all are devoted to the same general objective—the promotion of economic development. The Bank, the senior institution of the three, was established in 1944 together with the International Monetary Fund. It makes loans to governments, or with a government guarantee, at conventional rates of interest. By June 30, 1969, the Bank had 110 members and had lent a total of nearly US$ 12,600 million to 85 countries[1].

The International Development Association (IDA) was created in 1960 and has 102 members (only a few Bank members are not members of IDA). It finances the same general type of projects as the Bank, selected according to the same standards, but on terms which place a much lighter burden on the balance of payments of the borrowing country. Its assistance, in the main, has been confined to countries where per capita incomes are exceptionally low (currently, a GNP of US $ 300 per capita or less determines the eligibility of a country for IDA funds) and which cannot meet all their external capital requirements on the basis of borrowing on conventional terms. At the end of June 1969, credits amounting to about U S$ 2,170 million had been extended by IDA to 51 countries.

The International Finance Corporation (IFC), founded in 1956, supplements the activities of the Bank by making and encouraging investments on commercial terms in productive private enterprises in developing member countries. By December 31, 1968 IFC had 90 members and has made net commitments totaling US$ 289 million to private companies in 39 countries. (For the purpose of this paper, the operations of IFC are irrelevant and will not be further mentioned.)

In most major respects the operating policies of the Bank and IDA are identical. Both institutions lend only for projects or programs which are of high priority for the borrowing country's economic development, which are economically and technically sound, and which have satisfactory prospects of being carried out and operated successfully. The two institutions apply the same methods and

1 A substantial portion of Bank loans (US $ 2,300 million) has been sold to participating banks, investment companies, etc.

standards in determining for what purposes loans or credits should be extended and in deciding what conditions need to be established to assure that these purposes will be achieved. The interrelationship between the Bank and IDA can be seen from the fact that of the 51 countries which have been receiving IDA funds, 32 have also received Bank loans. Some of these countries received these loans before IDA was established in 1960 and others became eligible for IDA funds as a result of a deterioration in their economic situation after that date; nevertheless, there are quite a few countries which have been and are receiving a "blend" of Bank loans and IDA credits.

Sources of Funds

The fundamental differences between the Bank and IDA are in the sources of their funds, which in turn have a bearing on the terms under which these funds are being relent. The *Bank* started its operations with a paid-in portion of 10 percent of the subscriptions of its member countries amounting to about US $ 2,300 million. However, the most important source of its funds has become borrowing in the international capital markets (total outstanding US$ 4,300 million), mainly the U.S. (outstanding US$ 2,800 million) and Europe, especially Germany (outstanding US$ 1,100 million). The Bank's bond issues are secured by the total uncalled capital (90 percent of the members' subscriptions), which is worth US$ 20,700 million. It is partly because of this large security—and partly because of the Bank's general credit rating as an efficient and profitable organization—that it has been able to borrow, and consequently relend funds at premium terms. For the borrowing countries, this is the most apparent tangible benefit from the Bank, namely, that it can provide funds at better terms than they would normally be able to obtain by borrowing directly in the same capital markets. Because of the increasing cost of the Bank's own borrowing and in spite of its desire to hold its interest rates as low as possible, these rates have increased from less than 4 percent in the first years of Bank operations, to at present 7 percent.

In contrast, *ICA* credits (the terms "loan" for Bank and "credit" for IDA are normally used to make a distinction between the two operations) are interest free, and carry only a low service charge of currently 3/4 percent. The repayment period is much longer, normally 50 years, compared with 15 to 25 years for Bank loans. These favorable terms are possible only because the major source of funds for IDA credits are grants or interest free loans from in total 18 (the so-called part I countries), of the Bank and IDA members. The original contributions to IDA in 1960 totalled US$ 780 million; since then they have been twice replenished, in amounts of US$ 750 million and US$ 1,190 million respectively. Also, the Bank has transferred US$ 385 million from its net earnings to IDA. However, it has been far more difficult for IDA to assure adequate and timely replenishment of its resources than for the Bank to obtain additional funds through borrowing in the capital markets.

Purpose of Bank Loans and IDA Credits (Tables 3 & 4)

In the past, Bank loans have mainly been made for Electric Power (33 percent) Transportation (31 percent) and Industry (15 percent); whereas IDA credits have mainly been for Transportation (34 percent), General Development Programs (25 percent) and Agriculture (18 percent). Water Supply and Sewerage Projects account for only a small fraction (less than 1 percent of Bank loans and less than 2 percent of IDA credits) of the Bank Group's operations.

GENERAL CRITERIA FOR PROJECT APPRAISAL BY THE BANK AND IDA

Before any particular project is appraised, which has been presented to the Bank or IDA for financing, the "creditworthiness" of the country is being assessed to ensure, in the interest of not only the Bank/IDA but of the prospective borrowing country, that the terms and amounts of the loan (or credit) are within the limits which the country can reasonably be expected to service, taking into account all existing and prospective future foreign

Table 3 — IBRD Loans and IDA Credits by Purposes and Regions
As of June 30, 1969
(amounts in million US$)

	Africa	Asia & Middle East	Europe	Western Hemisphere	IFC	Total
Electric Power	515	1,064	667	2,033	-	4,279
Transportation	952	2,140	546	963		4,601
Industry	224	1,032	552	170		1,978
Agriculture	215	735	132	426		1,508
General Development	40	992	100	-		1,132
Reconstruction	-	-	497	-		497
Communications	28	177	-	95		300
WATER SUPPLY	21	75	4	43		143
Education	123	65	-	55		243
Project Preparation & Technical Assistance	3	9	-	-		12
International Finance Corporation	-	-	-	-	100	100
Total	2,121	6,289[1]	2,498	3,795	100	14,739
IBRD	1,734	4,730	2,405	3,653	100	12,623
IDA	387	1,559	93	132	-	2,170
In % *Total*	14.3	42.5	16.9	25.6	0.7	100
IBRD	13.7	37.5	19.1	28.9	0.8	100
IDA	17.8	71.8	4.3	6.1	-	100
Number of Countries Having Received						
IBRD Loans only	11	12	17	10		50
IBRD Loans and IDA Credits	17	6	1	11		35
IDA Credits only	11	5	-	-		16
	39	23	18	21		101

Source: WORLD BANK/INTERNATIONAL DEVELOPMENT ASSOCIATION (1969) *Annual Report*.
[1] Including Australia (US$ 417 million) and New Zealand (US$ 97 million).

Table 4 — IBRD Loans and IDA Credits by Purposes
As of November 30, 1969
(amounts in million US$)[1]

	IBRD		IDA		IBRD+IDA	
	amount	%	amount	%	amount	%
Electric Power	4,234	32.9	143	6.2	4,377	28.9
Transportation	3,993	31.1	784	34.2	4,777	31.5
Industry	1,964	15.3	46	2.0	2,010	13.3
Agriculture	1,216	9.5	406	17.7	1,622	10.7
General Development and Program	552	4.3	580	25.3	1,132	7.5
Reconstruction	497	3.9	-	-	497	3.3
Communications	187	1.5	120	5.2	307	2.0
WATER SUPPLY	109	.8	38	1.7	147	1.0
Education	97	.7	162	7.1	259	1.7
Project Preparation & Technical Assistance	1	-	12	.5	13	.1
Subtotal	12,850	100.0	2,291	100.0	15,141	100.0
International Finance Corporation	100				100	
TOTAL	12,950				15,241	

Source: IBRD/IDA INFORMATION AND PUBLIC AFFAIRS DEPARTMENT (1969) *Facts about the World Bank and the International Development Association*, November 30.

[1]Net of cancellations, terminations and refunds.

debts. The appraisal of the project itself usually involves six different aspects: economic, technical, commercial, financial, institutional, organizational and managerial aspects.

The objectives of the appraisal of the *economic* aspects are to determine whether the sector involved is of priority for the economic development of the country concerned, *and* whether the project is of sufficiently high priority in this sector to justify investment in it. The relative financial return of different projects is frequently not a sufficient test of their relative contribution to a country's development. In many cases basic investments are required before other investments in more immediately profitable activities can be undertaken. The benefits properly attributable to these basic investments may be very great even though the direct earnings, at least in the short run, are not high or may even be non-existent.

The economic appraisal involves an investigation of the demand for the goods or services which the project is expected to produce. This study may be of varying scope, ranging from a narrowly localized study, as in the case of a municipal water supply project, to one that is nationwide, as in the case of a national railway project.

The appraisal of the *technical* aspects of a project involves an investigation of the detailed engineering plan for its construction and operation, including the proposed scale of the project, the types of process or equipment to be used, the location, layout and design. The technical staff available to the borrower, both for carrying out the project and for operating it, is evaluated and a judgment is reached whether outside help is required. When, in the Bank's opinion, consulting engineers or other experts should be brought in, the Bank often assists the borrower to prepare terms of reference. The choice of consultant is made by the borrower, but the Bank satisfies itself that the consultant chosen is suitably qualified; it believes that a selection should be made on the basis of qualification to perform the work, not on price.

An important part of the technical appraisal of a project is an investigation of the assumptions on which the cost estimates have been calculated. Cost estimates should include adequate contingencies and provisions for interest during construction, and for initial working capital.

The *commercial* aspects of project appraisal entail a review of all arrangements for buying and selling. In the construction phase, this involves the arrangements for buying the materials needed to construct the project. The Bank is concerned that the borrower shall obtain the best value for the money spent—an objective normally attained by requiring international competitive bidding. For the operating phase, it involves the proposed arrangements for obtaining the raw materials, power and labor needed to operate the project, and for marketing its product.

The appraisal of the *financial* aspects of a project usually falls into two sections: that concerned with the amount of money required to bring the project into operation and with the sources from which it is to be obtained, and that concerned with operating costs and revenue and prospective liquidity in the operating phase.

Since the Bank and IDA finance only a part of the project cost, it is necessary to ensure that funds from other sources are available on reasonable terms to meet the balance. Financial projections must also be calculated for the operating period and are necessary, for example, for a revenue-earning project to estimate the financial return on the investment and to determine whether the borrower is likely to have sufficient working capital. In the light of these projections, a judgement has to be made about the soundness of the financing plan.

The institutions are also concerned with the *organization* proposed for the execution of a project, both during the construction and operating phases. In the case of some projects, the Bank has conditioned its assistance upon the creation of an autonomous operating authority insulated from political pressures and rigidities of government administrative procedures.

The Bank and IDA place particular stress upon the assurance of adequate *management* for a project. In cases where adequate local management is not available, the borrowing country, or the enterprise, concerned is asked to look for organizations or individuals qualified to assist in running the enterprise, at least during the initial stages, and to provide appropriate management training to local personnel.

It would seem that all these criteria are reasonable and ought to be applied not only by a lending-institution such as the Bank or IDA, but by *any* authority which is involved in programming, preparing or implementing a project, regardless whether it is located in a developing or in a developed country, and regardless whether outside financing is involved or not. However, the conclusion to be reached is not that the requirements are too rigid, but that most of the developing countries need assistance in meeting—gradually—these requirements. This distinguishes the Bank Group (and the other multilateral agencies) from most normal lending institutions: It acts increasingly as advisor and counsel for its poorer members and not as a lender who is only interested in protecting its investment. The key question and the area of potential controversy is, of course, how the Bank and IDA apply their general policies in specific cases. In the following chapters, I shall try to describe and explain this with respect to water supply and sewerage projects, and to add some general comments, where this appears useful or where the Bank's criteria are commonly misunderstood.

FINANCING OF WATER SUPPLY AND SEWERAGE PROJECTS

Background

The World Bank is not a prime lender for water supply and sewerage (henceforth WS&S) projects, nor does it claim to be an authority in financing such projects. A comparison between the operations of IDB and the World Bank with respect to WS&S project lending is interesting (Table 5). Two points should be highlighted:

1. Compared with only 1 to 2 percent of all Bank/IDA lending the IDB lending for WS&S projects was almost 20 percent.

2. The average Bank/IDA loan for WS&S projects was about US$7 million (Bank US$10 million and IDA US$3 million) which is somewhat higher than the average IDB loan for WS&S of US$5 million. However, while the IDB average is clearly in line with the average of all its loans, the overall average of Bank loans (US$20

Table 5 — Comparison Between the Interamerican Development Bank and the World Bank with Respect to Financing of Water Supply and Sewerage Projects (amounts in million US$)

	All Loans	Loans for WS&S	% of all Loans
IDB (as of December 1966)			
Number	387	68	18
Amount - Total	1,915	353	18
- Average	4.9	5.2	-
IBRD (Bank) (as of June 1969)			
Number	636	11	2
Amount - Total	12,622	107	1
- Average	19.8	9.7	-
IDA (as of June 1969)			
Number	165	8	5
Amount - Total	2,170	24[1]	1
- Average	13.2	3.0	-
Bank and IDA (as of June 1969)			
Number	821	19	1
Amount - Total	14,792	131	1
- Average	18.0	6.9	-

Source: IDB (1967) *Financing Water Projects in Latin America* and WORLD BANK (1969) *Annual Report.*

[1] Net of cancellations.

million) and IDA credits (US$13 million) is considerably higher than the respective average for WS&S projects.

These facts have no special significance as such but they give some indication of the different type and scale of operations. But WS&S is not the only area of Bank/IDA lending where the average loan amount is usually below "normal"; for example, the same is true for Education Projects. Also, the number of loans made in the past and their size are by no means an indication of the current, nor of the expected future, preference of the Bank Group for specific types and sizes of projects, nor is there a "bias" against WS&S projects. This is demonstrated in the Bank's Annual Report 1969:

> "Water Supply and Sewerage is a relatively new area of Bank Operations, and the Bank Group expects to expand its lending for water supply and sewerage during the next five years. Borrowers frequently need special help in the implementation of these projects; this may include assistance in institution building and detailed supervision of operations for some time after the completion of the physical construction work involved. As a result each loan takes up a proportionately greater amount of time than it might in a sector where the borrower is more experienced. Project identification and preparation in this field also present special problems."

Hence, the problem is mainly that—except in Latin America, which is relatively well assisted by the IDB and others, including the Bank Group—there are not enough suitable WS&S projects ready for financing. In many countries, Water Supply and Sewerage is not even recognized as a matter of national concern. Consequently, the investment programs prepared by the national planning offices of these countries have often no, or only inadequate, provisions for this sector. Usually only the capital cities are able to attract sufficient attention to their needs in water supply and sewerage. In fact, with a few exceptions, most Bank-IDA lending for WS&S has been for capital cities. Of course, there are also strong economic arguments for placing a high priority on WS&S projects in large urban areas (there the greatest number of people can benefit from the minimum expenditure of money, manpower and other resources), compared with smaller cities and rural areas. But the Bank Group is aware that, so far, the projects for which financing has been requested and was provided, were more selected by "default" than based on sound, balanced and comprehensive country-wide sector studies. This leads to the basic question of the "economic justification" for WS&S projects in general.

Economic Aspects

One of the elements on which the economic appraisal of a WS&S project is based, is demand projections. These should be as detailed as possible and should take into account not only projected population growth, increase in per-capita demand, different requirements and consumption patterns of different consumer groups (domestic commercial, industrial, public), but also the "elasticity" of water demand as, for example, affected by price, rate structure and metering. Textbooks are not always the best guide in establishing demand estimates, and the per-capita consumption in some developed countries is more an example for water waste than an indication of high economic development. Most important is a realistic estimate of the amount of unaccounted water, or more general "water losses", which in many cases have been found to be far above any acceptable level, sometimes unknown even to the engineers responsible for the system.

The techniques to analyse projects from an economic point of view, and to quantify the merits of different projects, can only briefly be mentioned here, they are: Cost-Benefit Analysis, Internal (or incremental) Rate of Return Calculations, Discounted Cash Flow, Present Worth Analysis, etc. In all these different but interrelated types of analysis, the sources and terms of financing are immaterial. In other words, the results are the same if a project is financed without, with limited or with a large amount of foreign funds; nor are they affected by the proportion between borrowed funds, funds generated from operations and others. Economically, all these funds are capital, which has a "price", also called the "opportunity cost of capital". This cost is different from country to country, but is always above the actual lending rates: Nobody would borrow money unless he expects to earn from investing it more than the amount needed to service his debt. Similarly, any country should be careful in investing its scarce financial resources (whether owned or borrowed) in projects which have an economic return below the respective "opportunity cost of capital".

Accordingly, the key factor in analysing the economic efficiency of any project is the measurement of cost and benefits in economic, not financial terms. While the "cost" of WS&S projects can normally be defined without too many difficulties, there is considerable discussion among economists what should be considered the "benefits". The easiest solution would be to define such benefits as the "maximum consumers would be prepared to pay for successive quantities of water or for successively better sewerage service." There are, however, two more types of benefits, normally referred to as "social benefits", which are *above* those realized by individual consumers. The first is related to the collective nature of water use like, for instance, street cleaning and public gardens watering, in short, the contribution to the aesthetics of urban life; the second—more important—are the "external" effects of water use, namely eradication or reduction of water-borne diseases, resulting in reduced disability, morbidity and death rates, in lower medical expenses and in increased productivity of the labor force. Further benefits are reduced fire losses, and, in turn, sometimes a reduction in fire insurance premiums.

The World Bank is increasingly aware of urban problems and the deteriorating conditions in many cities in the developing world. Mr. McNamara said in 1969:

"The phenomenon of urban decay is a plague creeping over every continent, but its corrosive effects are critical in the poorer nations. The resources required to provide minimal services and infrastructure for urban populations, which in the year 2000 may be 500% higher than today, are staggering. Our knowledge of how to best deal with the whole issue of urbanization remains primitive. But one point is clear: the problem must be dealt with on a comprehensive national basis."

With these remarks from the President of the World Bank Group, we are back at the fundamental obstacle for more WS&S project lending: The lack of sound national investment programs and sector studies for water supply and sewerage, which analyse the present situation, realistically estimate future requirements, and define priorities.

Technical Aspects

As pointed out earlier, preparation for Bank lending for WS&S projects has required proportionately much time and effort. The reasons are not so much deficiencies in detailed engineering but unsatisfactory planning. This refers to the identification and analysis of alternative ways of staging long range master plans, and of alternative schemes for the proposed initial stage; obviously these tasks are closely related with the economic analysis and justification of projects. In most cases, when the Bank/IDA eventually approved the loan, the project was very different from the time when it had first been presented for financing; changes had been made (i) in the scale of the project (and contrary to some beliefs, there are also cases where the Bank encouraged much larger schemes than had been proposed), (ii) in the basic supply alternative (e.g. groundwater instead of surface water and *vice versa)*, or (iii) in the emphasis on various project elements (often the possibilities of reducing water losses by rehabilitating the distribution system are not sufficiently explored; sometimes additional supply would mostly feed water leaks, and be lost for actual consumption, especially where supply had been intermittent and supply hours increase as a result of the project). Of particular concern in preparing WS&S projects in developing countries are the design criteria. Criteria, which have proven to be adequate or may even be prescribed in "rich" countries with a shortage of labor and with a sophisticated technology, should be carefully reviewed, and if necessary modified, before applying them to projects under different climatological, social and economic environments. In preparing specifications for bidding, engineers should leave as wide a range of options as possible for different, but equivalent equipment (e.g. pipe materials, pump sizes, meter types) unless there are justified constraints, such as a reasonable degree of standardization; this can result in important savings in cost.

In summary, based on the Bank's past experience with WS&S projects, it must be said that there is much room for improvement in the approach to, and in the preparation of these projects, from the preliminary feasibility study to the detailed bidding documents. Not only planning engineers from the developing countries, but especially the consulting engineers from the developed countries assisting them in project preparation, should be aware of the fact that the product of their work is in competition with many other proposals for investment in the countries concerned and that it depends, among other things, on the quality of this product whether or not more WS&S projects will be implemented in the future. Professional enthusiasm alone is not sufficient, and the desire to design a technically perfect scheme, using the most advanced techniques and employing sophisticated devices, normally leads into the wrong direction.

Commercial Aspects

Under "General Criteria for Project Appraisal" it was stated that these aspects refer to all arrangements for buying and selling, not only during the construction but also during the operating phase. The "selling" aspect is often neglected by agencies responsible for WS&S services; this is understandable, because in most cases the backlog and shortages are so great that it seems hardly possible that there would ever be a need to "advertise" for customers. Nevertheless, in cases, where a project provides new facilities in an area which had previously no community WS&S service, or where this service was only available to certain sections of the community (and where consequently the public was forced and able, and later accustomed, to use their own facilities) it has sometimes proven difficult to attract and to connect the projected number of customers to the new facilities. Special legislation may be needed, but may not be easy to obtain, to ensure an adequate support of the new system.

Naturally, during the stage of project preparation and implementation the "buying" aspect is of much more immediate concern. The Bank/IDA has issued "Procurement Guidelines", which normally become part of its agreements with the borrowers. These Guidelines explain specific steps to be followed by the project authority with respect to advertising, preparing specifications, and other bidding documents, bid opening and evaluation procedures, and to general contract provisions. The basic requirement is that—with a few exceptions—borrowers are expected to open procurement for all contracts related to the project to "international competitive bidding". The term "international" is qualified in the sense that, while bidding should be open to all Bank member countries (and Switzerland, which is not a member but has a special relationship with the Bank), no procurement should be made from non-member countries. When, in exceptional cases, the Bank agrees to reserve certain contracts to local procurement, these contracts are normally excluded from the package of works regarded as the "Project" financed under the loan; this has no implications when the loan is only made for foreign exchange expenditures, but it may be important if the loan amount is determined as a percentage of the total "project" cost.

The requirement of international competitive bidding is accepted by all Bank borrowers without difficulty, when procurement is for goods for which there is no competition from within the borrowing country. There is overwhelming, and sometimes dramatic, evidence from thousands of contracts procured under Bank/IDA financing, that such competition results in substantial savings, compared, for example, with "tied aid" as related to many of the bilateral assistance programs. However, international competition is more controversial when the goods and services involved are also available from within the borrowing country. The Bank Group's two basic objectives, namely (i) to ensure—through wide competition—that borrowers obtain the best value for their money and that all member countries have the opportunity to participate in such bidding, and (ii) to provide a reasonable degree of protection to the domestic industry of developing countries, thereby stimulating industrialization and economic growth, seem to be difficult to reconcile. In practice, the question is, of course, how to compare bids from foreign and from local suppliers, and how to determine the "lowest evaluated bidder" to whom the contract should be awarded. In the past, the Bank has in appropriate cases and at the request of the borrowers agreed to a certain degree of "preference" for local suppliers (normally 15%, or the amount of custom duties on the CIF price of the lowest foreign bidder, whatever is lower). Obviously, such an across-the-board formula is simple but, depending on each case, it may or may not provide an acceptable and adequate degree of protection for local suppliers. This is especially true if the locally produced goods themselves have a large import component. Therefore, from an economic point of view a formula based on "value added" (to the import component) would be preferable, but such a formula is more difficult to design and more so to apply.

With respect to WS&S projects, as in most other projects, the ability of local firms to compete with foreign suppliers varies from country to country. In general, however, it is for civil works, later in the manufacture of pipes (especially concrete pipes), and then in the production of mechanical equipment (pumps, motors, and sometimes water meters), where local firms become increasingly competitive in the various stages of economic development of the respective country.

Financial Aspects

The need to have sufficient funds available to cover the cost of a proposed project would seem to be a generally accepted fact. It is all the more surprising that there are cases, as in a number of the Bank/IDA's WS&S projects, where it has taken a long time, after the Bank/IDA loan was in principle assured, to obtain evidence that the balance of the funds was available from local sources (the project authority itself, the Government, local financing agencies or others).

However, it is with respect to the financial criteria for the "operating", not for the "project construction" phase, where the Bank/IDA is most commonly criticized as being too rigid and following a hard line. The principal scape-goat is the concept of the "financial rate of return", or more general "profit", which the Bank applies to all revenue earning projects, and specifically to public utility projects (electric power, telephones, water supply). The financial rate of return is defined as the "Net Income" *plus* Financing Charges (Interest but *not* Amortization) expressed as a percentage of the "Net Fixed Assets in Operation" (Rate Base). "Net Income" means Gross Income (from water sales, sewerage service charges, etc.) *minus* the sum of (i) Operating Costs (salaries, supplies, etc.), (ii) the amount added to the reserve for Depreciation and (iii) Financing Charges. "Net Fixed Assets in Operation" or "Rate Base" means the realistic (if necessary revalued) present value of all fixed assets (plants, pipelines, reservoirs, distribution system — but *not* inventories and other current assets), except work in progress, *minus* accumulated depreciation (which in turn must be based on a realistic present value of these assets). It is important to stress that for the purpose of calculating the Net Income, amortization is not a cost; it is, of course, an expenditure to be taken into account in income statements and cash flow forecasts. "Capitalized" Operating Costs (e.g. salaries of staff directly engaged in project preparation and supervision) and Capitalized Interest (interest or loans for projects during the construction period of such projects) have to be deducted from the totals before entering the amounts into the calculation; these capitalized costs become, of course, part of the project cost and thus of the "rate base".

Arguments brought forward against the "rate of return concept" are both "qualitative" (namely on the principle of using this concept for WS & S projects) and "quantitative" (on the size of the return requested by the Bank). As to the *concept*, which in simple terms requires a WS&S company to earn enough money to cover not only its current expenditures but to accumulate certain amounts for future expenditures, I would like to quote from Barbara Ward, the well-known British economist, who can hardly be accused of being a "capitalist". She wrote, in 1962:

> "A developing government should aim its policies at ensuring the quickest rates of capital accumulation. Profits should be strongly encouraged, in public as in private enterprise, and tax systems arranged so that all the incentives are towards their reinvestment. This does not always arouse much enthusiasm among planners brought up to believe in the inherent immorality of profits and ready to run essential public services on a 'no profit, no loss' basis. But profits are one of the chief means by which resources can be put at the disposal of society, and, as is little known, are a major source of investment in Soviet Russia."

As to the *size* of the return, the Bank is aware of the fact that water supply companies and even more so sewerage services, have normally to recover from a substantial backlog in investments and cannot be expected to generate immediately as high returns as would be desirable. Therefore, as is reflected in most of the Bank/IDA loan agreements for WS&S projects, borrowers are given a certain period of initially low, but increasing, returns to achieve the desirable target; the target itself depends on the situation, but is normally around 8 percent to 10 percent. In practical terms, the rate of return concept, coupled with the projections on actual cash requirements (which sometimes demonstrate the need for more funds than would be necessary to achieve the agreed-upon rate of return), has a direct bearing on the charges which have to be levied on the water and sewerage customers. It is here where economic and financial "theory" ends, and where practical and pragmatic, and too often political, considerations begin.

In this connection, it is sometimes argued that it is irrelevant, and the Bank should not be concerned about, how the total amount of the necessary funds is being generated. However, in the Bank's view, the most equitable way of charging for water, and the least conducive to waste, is to relate water charges as closely as possible to actual consumption; this requires, of course, metering of all connections, and can normally only be achieved in stages. Nevertheless, in the financial appraisal the Bank/IDA is concerned about any proposal, and wishes to be satisfied about the need, for charging for water on any other basis than consumption (e.g. property value, fixed amounts with minimum consumption allowance) or for giving water "free" to certain consumer groups (hospitals, schools, government). It is, however, accepted in certain cases that the Government or the municipality pay or subsidises payment for water consumption of a consumer group which they wish to assist.

Financial management of a WS & S company, or of any other public utility, requires an efficient business-like accounting system. Accounts should regularly be audited by independent auditors. Billing and collection, budget control and budget programming are important areas of financial management. The quality and effectiveness of a public utility company, as of any other business or government, can always best be assessed from the way it is handling its financial affairs.

Institutional, Organizational and Managerial Aspects

It has sometimes been said that if there is a single most important objective of the Bank Group's operations, besides providing funds for financing projects and programs, it is to help the developing countries building institutions which provide the necessary organizational and adminstrative framework for planning and implementing public and private investments. The need for such assistance is especially great in the WS&S sector and involves the institutional set-up at the national government level, the local organizations responsible for constructing and operating WS&S schemes, and the recruitment of competent managers, experienced professionals and skilled labor to staff such organizations. Unfortunately, there are no textbooks or formulas which provide a tool for defining or for measuring the best solution in a given case. Neither does the Bank have a ready-made solution. WS&S have some peculiar features. On one hand, and in physical terms, WS&S services are mostly "local", seldom regional, and almost never national (in the sense of nationally interconnected systems of roads, railways, or electric power lines). On the other hand, while the supply of good and sufficient water is essential for almost any economic activity, the demand for industrial, and even less for potable, water represents normally but a small percentage of all available water resources in a country and normally most of these resources are used for other purposes (especially hydropower generation and irrigation).

Not surprisingly, therefore, one can find a variety of ways how different countries have assigned the responsiblity for WS&S and for "water" in general to various departments at the national government level. For the purpose of water resources allocation and from the point of view of WS&S most of these arrangements can be adequate, as long as it is assured that sufficient quantities of water are reserved for water supply. However, in spite—or possibly because—of the proportionately small quantities of water involved, this requirement is sometimes overlooked and in some national water programs there is "no water left" for community water supply.

More important from an institutional point of view, is the question how to organize and exercise at the national government level *regulatory functions* related to WS&S services, such as developing and administering rate policies, monitoring financial performance, setting technical standards, etc. Considering the difficulties of most WS&S services in developing countries, the need for such coordination and central assistance is obvious. Therefore, while the Bank does not necessarily suggest or support the establishment of a national water authority, it strongly recommends instituting and enforcing sound national public utility policies (not limited to WS&S) and giving support to the operating agencies in following such policies.

As to the responsibility for *constructing* and even more for *operating* WS&S services, the Bank/IDA's experience indicates that this should normally be left, or delegated, as close as possible to the local level. However, regardless of whether the operating authority is established at the municipal, regional or national level, it should be organized and operated as a revenue-earning utility, should be separated from normal government bureaucracy, and should not be subject to political interference in its normal affairs. For example, it should be able to independently set water rates in accordance with sound financial criteria and within the limits of generally accepted rate policies in the country. It is in this respect that the Bank/IDA is sometimes requiring the setting-up of a new autonomous authority (before approving a loan for a public utility project). This authority may be fully or partly owned by the public and may have a board in which the political councils are represented.

Even where such an autonomous authority cannot, or not immediately, be established the Bank/IDA expects that the WS&S service is organized as a separate department within the general structure of the respective local or national government. This refers especially to keeping WS&S accounts separate from the general books in order to clearly allocate income and expenditures, and determine the financial performance, of the WS&S service.

The *organizational structure* of a WS&S service should be functional and should define lines of responsibility in such a way that management can effectively delegate authority without losing control over the operations. This requires the installation of effective management reporting systems and of general communications systems within the organizations. In this respect, a WS&S service should not be different from any other commercial firm. Experience shows, however, that the principle of operating revenue-earning public enterprises in a business-like manner, is least developed at the municipal level and, in turn, seldom adopted for WS&S services.

The best institutional framework and the most perfect organizational structure are useless if there are no men to staff the key positions on the top and at the supporting levels of these organizations. Without any doubt, and this is the case not only in many developing but also in a number of developed countries, WS&S companies are not very glamorous; they have usually great difficulties to attract qualified staff, and even to compete with other public enterprises in recruiting competent people, especially for the top management position. In many countries, where career opportunities for engineers in top government positions are scarce, management of WS&S companies is usually "reserved" for civil or public health engineers. While there may be many good reasons for this policy, it fails to recognize that management is an art on its own, and no professional group — engineers, accountants, lawyers, etc.—can claim to offer the best or exclusive qualification for management.

In a number of countries, there is not only a scarcity of good managers, but also of engineers with sufficient experience and expertise in the specific technical aspects of a WS&S service. In these cases, scholarships for training in well-established foreign water authorities or for graduate studies at specialized foreign universities may provide a solution, although not for the immediate future. Once a certain amount of experience has been accumulated in the country itself, and this process normally starts at the WS&S services of the larger cities, specialized courses at local universities and national training programs should be established. In this way experience can be handed down to the smaller cities and to the rural areas. This is a long process, and the absence of sufficient and sufficiently trained staff can be the strongest argument in favor of establishing a national water authority responsible for all aspects of WS&S, including operating the systems, where the local authorities cannot provide the necessary support of personnel.

LOAN ADMINISTRATION AND PROJECT SUPERVISION

Project preparation and appraisal is only one step in the Bank/IDA's involvement with a specific project. It is normally preceded by a history of Bank/IDA lending for other projects, and of continuous review of the economic situation in the country. Once a project has been appraised and in principle accepted by the "Loan Committee" in the Bank/IDA, representatives of the respective government, the borrower, and of the project authority (which may be identical) are invited for negotiations. After negotiations the legal documents are finalized and the loan-credit proposal is presented to the Bank/IDA's Board of Executive Directors, which represent the member countries. After the Board's approval, the loan is signed and, provided certain steps are taken by the borrower, becomes effective.

It is at that time when the second major phase of the Bank/IDA's involvement with a particular project begins: Supervision. On the average, each "active" project is visited at least once ("problem" projects more often) per year. The great importance which the Bank/IDA attaches to project supervision can be seen from the fact that there are as many supervision missions every year as there are project identification, preparation or appraisal missions. In addition, the Bank requests its borrowers to prepare and submit periodic progress reports (monthly, quarterly, annual), covering all important aspects of project construction and of operations. These progress reports are designed not only to provide the Bank with information, but to serve as part of the borrower's internal management reporting system.

CONCLUSIONS AND OUTLOOK

Water Supply and Sewerage (WS&S) projects have required a much greater amount of time and effort, for preparation, appraisal and supervision, than is reflected in the relatively small amount of Bank/IDA lending for, or in the number of, such projects (for details of Bank/IDA lending for WS&S projects see Table 6). Certainly the Bank/IDA's experience

Table 6 — IBRD Loans and IDA Credits for Water Supply and Sewerage Projects As of November 30, 1969 (amounts in million US $)

Fiscal Year	Country	City	WS[1] or S	Total Project Cost	Foreign Financing: IBRD	Foreign Financing: IDA	Foreign Financing: Joint Loans	% of Total Project Cost	Cancellation and Refunding	% Disbursed
1962	CHINA	Taipei	WS	9.7	-	4.4	-	45	.4	100
	ICELAND	Reykjavik (hot)	WS	6.2	2.0	-	-	32	-	100
	JORDAN	Amman	WS	2.9	-	2.0	-	69	.5	100
				18.8	2.0	6.4	-		.9	
1963	NICARAGUA	Managua	WS	4.8	-	3.0	-		-	100
1964	PAKISTAN	Dacca	WS&S	50.1	-	26.0	-	52	12.8	16[2]
	PAKISTAN	Chittagong	WS&S	43.0	-	24.0	-	56	17.0	30[2]
	JORDAN	Various Cities	WS	5.0	-	3.5	-	70	1.0	100
				98.1	-	53.5	-		30.8	
1965	PHILIPPINES	Manila	WS	48.2	20.2	-	-	42		86
	SINGAPORE	I	WS	13.7	6.8	-	-	50		100
				61.9	27.0	-	-			
1966	BURUNDI	Bujumbura	WS	1.6	-	1.1		69		68
	VENEZUELA	Caracas	WS	54.1	21.3	-		39		79
				55.7	21.3	1.1				
1967	PAKISTAN	Lahore	WS&S	5.6	-	1.8	1.7 (Sweden)			35
1968	SINGAPORE	II	WS	16.0	8.0	-		50		43
	COLOMBIA	Bogota	WS	35.3	14.0	-	3.0 (US & Germany)	48		33
	JAMAICA	Kingston	WS	9.1	5.0	-	-	55		1
				60.4	27.0	-	3.0			
1969	SINGAPORE		S	22.4	6.0	-	-	27		10
	MALAYSIA	Kuala Lumpur	WS	7.7	3.6	-	-	47		2
	TUNISIA	Tunis & Others	WS	32.8	15.0	-	5.0 (Sweden)	61		1
	CAMEROUN	Yaounde Duala	WS	6.7	5.0	-	1.4 (France)	96		-
				69.6	29.6	-	6.4			
1970	GHANA	Accra-Tema	WS&S	5.9	-	3.5	-	59		-
	TOTAL (As of November 30, 1969)		15 WS 4 WS&S 1 S	380.8	106.9	59.3	11.1	49		
					(11 Loans)	(9 Credits)				

1 WS = Water Supply
S = Sewerage

2 Of remaining credit after partial cancellation.

with, and its interest in, such projects is considerably larger than what the past record would suggest. For example, the number of WS&S projects which are currently under consideration by the Bank/IDA and are expected to result in actual loans or credits within the next two years is almost twice as large as the number of projects financed since the early sixties, when the Bank/IDA started lending for WS&S.

In general, it is expected that the Bank will become more and more involved in financing not only large and "easy" projects, like for electric power and transportation, but projects in more "difficult" sectors like agriculture, education, population planning, and — last but not least — urban development. It is with respect to this last point that I foresee, especially in the long run, a substantial increase in financing of water supply and sewerage projects, not in isolation, but as an integral part of comprehensive urban development plans, which in turn are based on balanced nation-wide economic programs.

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EXIMBANK AND WATER RESOURCES

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Impure or polluted water — in these days of worldwide population explosion and unprecedented industrial growth — is rapidly becoming the number one health problem of advanced as well as emerging nations. Not only does the small village in the back country have its own particular problems of supplying its inhabitants with adequate potable water, but so do the great metropolitan areas. New York, Tokyo and Hongkong, for example, are running into terrific shortages of this essential ingredient to life, both as to quantity and quality.

Governments everywhere, representing both developed and developing peoples, today are confronted with the increasing need for improved water management. In the United States of America, for example, we spend annually some $2.7 billion for water systems. And still, the demands for an end to water pollution and the calls for pure water persist. The allocation of financial resources to meet these demands, aligned with the similar demands for improved housing, decreased air pollution, better transportation, higher education, and less crime, presents a challenge in determining money priorities which tests the wisdom of the most prudent fiscal experts. Meeting this test, however, President Nixon on January 1, in his first official act of the 1970's, declared that he is convinced that restoring the cleanliness of the water is a "now or never" task for the new decade.

We all know the calls for pure water are not based simply on aesthetic or culinary tastes. Water is fundamental to life. Every schoolboy learns that 60 percent of the human body consists of water. When that water is impure, disease is inevitable. And, the toll of disease on economic growth is severe.

The distinguished Chairman of this Seminar, Dr. Okun, has previously stated that "the food intake of worm infested children may contribute more to the nourishment of the worms than the children." He has observed also that the cost of health care associated with disease management is one more economic liability attributable to inadequate water supply.

Endemic disease hardly creates the environment necessary for attracting tourists from abroad. And we know that a prospering tourism industry is the chief source of foreign exchange for several countries. Prospects for industrialization are not enhanced by poor water. Many manufacturing processes depend on clean water. The low productivity of sick managers and workers must affect adversely the profitability of the enterprise. Children's learning capacities are degraded by disease, preventing them from maturing to positions of leadership in industry, government and agriculture.

The singular solution of many planners to this toll is an adequate community water supply. Yet, experience in the United States at least has shown beyond doubt that proper emphasis on sanitation is a key corollary to disease control. And beyond the question of human waste disposal is the question of control over industrial effluents and the run-off of fertilizers and pest-control chemicals from agricultural lands. As recognized in a recent World Health Organization report, once a water supply system is installed, a crucial need for its continued safe maintenance is the availability of local engineering and technical staff. Any water supply plan which omits provisions for maintenance personnel is incomplete.

Thus, the solution to the toll of disease caused by inadequate water must lie in the development of comprehensive water management. Unfortunately, comprehensive water management cannot be bought cheaply. The cost will run into the billions of dollars. One group estimates the cost for urban Asia alone could exceed 600 billion baht, or nearly 10 trillion yen. Our research staff at Eximbank believes these estimates may be exaggerated, but they will agree that the cost extends beyond normal money comprehension.

The financing of these requirements, whatever the ultimate total may be, will present a gigantic burden to both those expected to provide the funds and those expected to service the debt. Since much of the financing requires investment in infrastructure, it is proper that those agencies commonly associated with the development of infrastructure play a major role in the financing — the International Bank for Reconstruction and Development, the Asian Development Bank, and the aid agencies of the various industrialized countries. In this regard, it might be noted that the United States Agency for International Development, and its predecessor agencies, already have participated significantly in Asian water management improvement projects, extending some $30 million in loans and grants for this purpose to Taiwan, Korea, the Philippines, and Thailand. An important part of this financing has been for water resources surveys which are basic to the orderly planning of projects and expenditures.

It is also proper for the Export-Import Bank to finance the export of United States goods and services which may contribute to meeting Asia's water management development requirements. Unlike the World Bank, Asian Development Bank, and the development assistance agencies, the chief function of the Export-Import Bank is to promote and assist in the financing of United States exports. Eximbank serves this purpose by guaranteeing loans made by others and by making loans directly to overseas buyers of U.S. goods and services, by guaranteeing and insuring short and medium-term transactions, and by loaning against debt obligations held by United States commercial banks. Each of these export financing techniques has some applicability to the needs of Asia for improved water management.

First, for the major projects involving capital equipment purchases, such as sanitation, desalting, water supply and water treatment plants, Eximbank can extend an unconditional guarantee to cover loans made by either U.S. or non-U.S. financial institutions to government and private buyers alike for an amount up to 100 percent of the value of U.S. goods and services involved in the project. Further, Eximbank can participate in the financing of such projects by making a direct loan to the buyer for a portion of the value of the U.S. goods and services involved. And, moreover, as necessary to counter third-country competition, Eximbank may guarantee a loan by others to cover local costs of the project up to 15 percent of the value of the U.S. goods and services purchased by the buyer in the particular transaction. There is no standard application form for these financial guarantees and direct loans. Our procedures have been greatly simplified in recent weeks to allow speedier processing of cases. We have prepared a short ten-point outline of the kinds of information we need for reaching a decision on any case, and the applicant is free to provide this information in any form he believes will enhance the attractiveness of his loan or guarantee request.

It should be clear that U.S. services associated with major projects and equipment purchases are eligible for these guarantees and direct loans. In this latter regard, the Bank has initiated a new program for financing the participation of U.S. firms in the early planning stages of major projects. Through financial guarantees and direct loans, Eximbank will finance up to 100 percent of the dollar costs involved in engineering, planning and feasibility studies.

Second, since the Export-Import Bank, by law, must supplement and not compete with private sources of financing — hence, one reason why we insist upon private participation in even those large-scale projects just mentioned — we ask that U.S. suppliers and their customers abroad attempt to obtain financing for their export sales from private banks or other financial institutions. This generally places no imposition on the customer because he has access, of course, to his own banking system and, often, to the overseas branches of U.S. commercial banks. Loans made by U.S. commercial banks, with maturities of one year or longer, may be eligible for Eximbank's discount loan facility. Under this program, a U.S. commercial bank extending a loan to support an export sale may then borrow from Eximbank an equal amount of money on the same length of term granted the original borrower. The loans thus "discounted" may, but not necessarily, be insured or guaranteed by Eximbank. The discount loan program is designed, and works effectively, to encourage private financing of U.S. exports, particularly in periods of restricted liquidity.

Third, for a wide variety of equipment purchases, requiring terms of 180 days to five years, such as meters, pumps, controls, centrifuges, industrial purification and demineralizing equipment, and water drilling and monitoring devices, Eximbank has two programs of interest to purchasers — the medium-term bank guarantee and insurance obtainable through the Foreign Credit Insurance Association. Usually, financing under these programs is arranged by the exporter, who works closely with his commercial bank and insurance agent. Nevertheless, it is to our mutual advantage if prospective overseas purchasers of our goods and services are knowledgeable of the procedures of these programs, and we are attempting to make this kind of information available to all through our embassies, consulates, and trade centers. Again, it should be clear that the medium-term guarantee and insurance programs will cover also the purchases of U.S. services, including the training of personnel. And, as appropriate, these facilities can be used for the financing of engineering, planning and feasibility studies.

Fourth, for follow-on orders of spare parts and lower unit value equipment and services which do not require terms in excess of 180 days, Eximbank offers short-term comprehensive, short-term political, and combined short-term insurance policies through the Foreign Credit Insurance Association program. These policies usually are arranged by the U.S. exporter, although larger numbers of prospective buyers are becoming better acquainted with the availabilities of Eximbank facilities.

Fifth, for the purchases by smaller industrial and agricultural buyers of water and sanitation equipment, Eximbank can offer its re-lending program. Under this program, Eximbank extends direct credits to foreign financial institutions on a selective basis for re-lending to small and medium-sized private enterprises.

Finally, there is one other program area which merits attention. Many countries necessarily must rely heavily upon the more developed countries for the supply of much of the research and engineering, systems management, training, equipment, and spares required for water and sewerage projects. To the extent that there is this dependence, we want to recommend U.S. goods and services, and we at Eximbank want to support the sales of these items by our suppliers. However, sustained borrowing to finance imports which themselves will not generate foreign exchange earnings could seriously aggravate the debt-servicing capacity of countless countries. Thus, consideration might be given to local manufacture. Eximbank is prepared through any one of its programs, where appropriate, to support purchases from the United States of production plant and equipment needed to establish local industries.

Eximbank has a large number of other programs. The five general program areas described are those which appear to have more immediate application. It is recognized that these short explanations will not answer the questions of those who are seriously considering the use of Eximbank facilities. In addition, it is understood that for many the availability and desirability of United States goods and services must first be established.

THE EVOLUTION OF A MASTER PLAN

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This paper is a review of the manner of selection of professional engineering services for the preparation of a Master Plan of Sewerage, Drainage and Flood Protection Systems in Bangkok and Thonburi, Thailand.

BACKGROUND

On February 3, 1965, the Council of Ministers of the Government of Thailand appointed the Bangkok Drainage and Sewerage Planning Committee to review all matters pertaining to the problems of sewerage, drainage and flood control and to recommend solutions to these problems and means of financing the improvements required for the solutions of these problems. The Committee's assignment also included the selection of, and recommendation for employment of, professional services for the preparation of a comprehensive master plan of sewerage, drainage and flood protection, and the supervision of the work of Consultants so selected.

Three previous reports had been presented, dealing in part or in whole with the sewerage, drainage and flood protection problems, but none of these appeared to the Committee to be wholly adequate or sufficiently comprehensive. A previous Committee, appointed by the Council of Ministers to consider problems of housing, roads and bridges as well as sewerage and drainage had reviewed these reports and conducted hearings on the matters presented therein.

At the request of the Ministry of Finance, the World Bank sent two representatives from its Projects Department to Bangkok for a brief period from October 22 to November 6, 1963. The World Bank Mission reported its findings on February 17, 1964. While not endorsing, in full, the recommendations of any one of the previous reports, the principal findings of the World Bank were:

1. Bangkok needed a more adequate sewerage and drainage system.
2. "On balance", the construction of separate wastewater and storm water systems was preferred over the use of "combined" systems.
3. An inventory of existing systems should be commenced at once.
4. Studies should be initiated of the sanitary quality of the waters in the Chao Phrya River and the tributory Klongs (canals).

Against this background of studies, from the Litchfield plan in August, 1960 to the World Bank findings in February, 1964, the Bangkok Drainage and Sewerage Planning Committee began its work in February, 1965.

INITIAL POLICY

Believing that none of the previous reports were sufficiently adequate or comprehensive to be accepted as a Master Plan for the Metropolitan area, the Committee determined to seek and recommend the employment of the most capable consulting engineers available in whatever nation to : (1) review all previous studies, investigations and reports (2) consider alternative comprehensive solutions and (3) prepare a Master Plan of Sewerage, Drainage and Flood Protection for the entire metropolitan area. The Committee decided at the outset not to seek any "single package plan" for financing, engineering and constructing the needed facilities. The Committee preferred rather to proceed in three phases, as follows:

1. Employ the most capable professional talent available to develop a Master Plan.
2. Based upon the findings and presentation of the Master Plan, to obtain the financial resources necessary to enter into the initial stages of construction.
3. Employ consulting engineers to prepare final construction plans, and award construction contracts on a competitive basis.

The Committee decided to obtain the professional engineering services required for the first and third phases on a non-competitive basis with regard to professional fees—competition between available consulting engineers should be based entirely on their professional skill, as demonstrated by previous accomplishments in the field of engineering, especially in the field of sanitary engineering.

IMPLEMENTATION OF SELECTION OF CONSULTANT

As their first action in implementing the objective of the first phase, the Committee issued Announcement No. 1. This announcement was delivered to the Embassies and/or Consulates of all foreign nations, so represented in Thailand, with a suggestion that each nation may, if they so desired, distribute copies of the announcement to qualified consulting engineers in their respective nations. As stated in Announcement No. 1 (Appendix A) the Committee presented four basic qualifications necessary for consideration by the Committee. The four basic criteria dealt with the following subjects:

1. Reputation and Financial Standing
2. Experience in Drainage and Sewerage Planning
3. Experience in cities similar to Bangkok
4. Experience in River Pollution Surveys

Fifty-seven consulting engineers, as individuals, firms or associations from thirteen nations responded, with presentation of their qualifications. prior to the closing date for receipt of applications on May 20, 1965.

After the closing date for receipt of the presentations, the Committee appointed a subcommittee to study and evaluate the qualifications of the fifty-seven applicants. Four members of the subcommittee, each working alone, evaluated each applicant's presentations against the four basic criteria of Announcement No. 1. After completion of the individual evaluation, the subcommittee tabulated the results. There was remarkably close agreement among the individual evaluations. After some meetings of the Committee, it appeared that eleven of the fifty-seven met the basic requirements. The names of the eleven were then reported to the Main Committee. Further discussions by the Main Committee determined that seven of the eleven appeared best qualified. Five of these seven were American consultants. Two were British.

The Committee then issued Announcement Number 2 dated September 7, 1962 (Appendix B) naming the seven consultants selected for final consideration, and stating that final selection would be made from that list by first selecting the one considered best qualified, and if negotiations with the one selected failed to result in a contract, another would be selected from the same list, etc.

Two letter forms were prepared and sent on September 8, 1965 transmitting Announcement Number 2 to each applicant. One form was sent to the consultants not among the seven selected. Another longer letter was sent to each of the seven selected consultants. In the letter to the short list of seven consultants it was indicated that the Committee did not desire oral interviews for the time being (which might place some in a disadvantageous position with respect to others, due to varying travel distances and availability). The letter also transmitted copies of the following:

1. Greater Bangkok Plan — Litchfield, 1960
2. Report on Sewerage — Husband, 1962
3. Study of Drainage and Sewerage—Tholin, 1962
4. Findings of World Bank, 1963
5. A current statement regarding needed professional services, prepared by the Committee.

REFINED CRITERIA FOR FINAL SELECTION

It was recognized by the Committee that any one of the seven selected consultants could provide adequate services for the proposed project, but the Committee must designate one for first negotiations. The letter to the seven selected consultants, therefore, requested additional presentation of data concerning their experience, in specified types of work, closely related to the type of services needed in Bangkok. The information requested was described in sixteen separate paragraphs or subparagraphs as shown in the copy of that letter in Appendix C. It was requested that the additional data should reach the Committee not later than November 15, 1965.

FINAL SELECTION

The Committee again referred the detailed examination of data submitted to a subcommittee. Again each member of the subcommittee evaluated personally and alone the applicants' responses to the sixteen criteria established by the Committee's letter of September 8. Again, the subcommittee compared results. A grading system was established and after a number of meetings, the subcommittee decided to recommend negotiations with Camp, Dresser & McKee of Boston, Massachusetts, U.S.A. The main Committee, in December 1965, approved the recommendation of the subcommittee, and on January 14, 1966, notified Camp Dresser & McKee.

ASSISTANCE BY WHO

Also, in January, 1966, the World Health Organization, in compliance with a request from the Committee sent two Consultants, Mr. Gunter Bachmann, a consulting Engineer from Dusseldorf, Germany, and Mr. Robert Berry, an Attorney from San Diego, California, U.S.A., to assist the Committee in the drafting of a contract for Engineering Services, and shortly thereafter the Committee initiated negotiations with Camp Dresser & McKee.

NEGOTIATION OF CONTRACT

Negotiations continued until June 1966, when the wording of the contract was approved by the Committee, and translation into the Thai language was begun. After translation was completed the contract was then referred to the Public Prosecution Department for examination and approval as to legality. Final action by the Council of Ministers authorized the Bangkok Municipality to sign the contract. The contract was signed by the Lord Mayor of Bangkok and by Ernest R. Leffel of Camp, Dresser & McKee on 13th of September, 1966.

COMPLETION OF MASTER PLAN

The contract provided for the consultants to proceed with the preparation of a Preliminary Report (termed Phase 1), the completion of a Master Plan (Phase 2) and, upon completion of the first two phases, to enter into negotiations for construction plans, etc. (Phase 3). The Preliminary Report was submitted on 1 July and approved by the Committee on 23 August 1967. The Master Plan was completed and presented to the Committee on 10 April, 1968.

A supplementary contract with Camp, Dresser & McKee is being prepared for work under Phase 3, to provide complete plans, specifications, estimates and other construction documents for the First Stage of a construction program, estimated to cost approximately twenty-two million dollars (US). Sewerage, drainage and flood protection is to be provided in the most heavily built-up area of Bangkok and some adjacent government and temple areas. Another supplementary contract with the same consultant, but of lesser scope, is also ready for approval to cover construction of a main sewer extension, pumping station and a pilot sewage treatment plant.

A CONTINUING COMMITTEE

The Bangkok Drainage and Sewerage Planning Committee, as appointed by and responsible to the Council of Ministers in February, 1965 was composed of persons temporarily assigned from the Bangkok Municipality, Thonburi Municipality and various Government Departments and Ministries, plus some individually appointed members. After the award of the Contract for Engineering Services, the Committee continued as the Representative of the Municipality for the Administration of the Contract. In October, 1967, the Committee was enlarged and reorganized and the present membership was also officially appointed as a Committee, directly responsible to the Council of Ministers. It is now a continuing committee, charged with the implementation of the design, financing and construction of the sewerage, drainage, and flood control project. At present it acts also as the representative of Bangkok Municipality but may also act, if desirable, for Thonburi and other municipalities in the metropolitan area.

Some discussions have begun with regard to formation of a Sewerage Authority or the expansion of the newly formed Metropolitan Water Authority to include sewerage facilities. The latter is recommended in the Master Plan, as now presented to the Committee by Camp, Dresser & McKee. The Committee will continue to keep in touch with the World Bank, the World Health Organization and other selected world agencies or organizations, keeping these agencies informed of all important actions and recommendations of the Committee.

CHRONOLOGY

August, 1960	Greater Bangkok Plan, by Litchfield
September, 1962	Report on Sewerage and Sewage Disposal, by Husband
October, 1962	Study of Drainage & Sewerage, by Tholin
August, 1963	Appointment of Review Committee on Housing, Roads, and Sewerage
October, 1963	Visit of World Bank Representatives
February, 1964	Findings of World Bank Representatives
February 1965	Formation of Bangkok Drainage and Sewerage Planning Committee
March, 1965	Announcement Number 1 Requesting Applications From Consultants
May, 1965	Receipt of Qualifications
September, 1965	Announcement Number 2 Announcing the Selection of a Short List of Seven Consultants & Request For Additional Data
November, 1965	Receipt of Additional Data From Short List
January, 1966	Notice to Camp, Dresser & McKee
January, 1966	WHO Assistance On Contract Preparation
February, 1966	Began Negotiations With CDM
June, 1966	Completion of Draft Contract, Translation Began, Also Examination By Prosecution Dept.
September, 1966	Contract Approved, In Final Form By Council Of Ministries
September, 1966	Contract Signed
August, 1967	CDM Presented Preliminary Report
April, 1968	CDM Presented Master Plan

APPENDIX A.
(COPY)

Bangkok Drainage and
Sewerage Planning Committee

ANNOUNCEMENT NUMBER 1
Selection of Consulting Engineer

The Council of Ministers has appointed a Bangkok Drainage and Sewerage Planning Committee to select a prominent consulting engineer to conduct surveys and to design a drainage and sewerage system for the city of Bangkok.

Because this is a costly project requiring special technical skills, the Committee is very much concerned with the selection of a consulting engineer. Interested parties should submit their qualifications for consideration, bearing in mind the following conditions and requirements.

Conditions and Requirements:

(1) The selected firm will conduct a survey and submit a design for the new Bangkok Stormwater Drainage and Wastewater Sewerage System — including Sewage Treatment.

(2) The design should include a Master Plan for the city of Bangkok, and a detailed engineeing design for the inner districts (about 30 square kilometers).

(3) The selection of the consulting engineering firm will be made on the basis of qaulifications.

(4) It is understood that the receipt of applications in response to this announcement does not in anyway commit the Committee or the Thai Government.

(5) Requests for consideration and presentation of qualifications must be submitted to the Committee before May 20, 1965.

Qualifications:

Criteria for employment of the consulting engineer, as established by the Committee, are as follows:

(1) Excellent reputation and financial standing.

(2) Long experience in the field of drainage, sewerage, and sewage treatment.

(3) Wide experience in large cities similar to Bangkok in topography, climate, and soil condition.

(4) Experience in river pollution surveys.

Interested firms should submit their applications, along with qualification papers before May 20, 1965, to:

The Chairman of the Bangkok Drainage and Sewerage Planning Committee,
Office of the National Economic Development Board,
Krung Kasem Road, Bangkok, Thailand.

Further inquiries may be addressed to:
Dr. Vinyu Vichit-Vadakan
Economic Planning Office,
National Economic Development Board,
Krung Kasem Road, Bangkok, Thailand.

Bangkok Drainage and Sewerage Committee

(Signed) Puey Ungphakorn
(Dr. Puey Ungphakorn)
Chairman

Dated March 22, 1965

Certified true copy
Vinyu
Secretary to the Committee

APPENDIX B.
(COPY)

Bangkok Drainage and
Sewerage Planning Committee

ANNOUNCEMENT NUMBER 2
Selection of Short List of Consulting Engineers

Reference

Reference is made to "Announcement Number 1, Selection of Consulting Engineer", dated March 22 1965.

Action

Pursuant to the publication of "Announcement Number 1" the Committee received presentations from 61 applicants from 13 nations. Four of these arrived subsequent to the official closing date, leaving 57 applications from 12 nations for consideration of the Committee.

The Committee has examined each presentation, and has selected the presentations of the following listed applicants as a "Short List", from which the Committee will make final selection of one applicant for negotiation of a contract for engineering services. The listing herein has no significance with regard to priority.

1. Black & Veatch International
2. Camp, Dresser & McKee
3. Metcalf & Eddy Engineers
   Daniel, Mann, Johnson & Mendenhal
4. Parsons, Brinckerhoff, Quade & Douglas
   Pacific Architects & Engineers
5. Sverdrup & Parcel and Associates Inc.
   Havens & Emerson
   Horner & Shifrin
6. John Taylor & Sons
7. J.D. & D.M. Watson

If negotiations with the one first selected do not result in a contract, the Committee will select other applicants from the above list, for similar negotiations.

Until or unless a contract is signed by the Committee or other properly authorized person of the Government of Thailand, the Committee or the Government of Thailand is not committed, in any manner, to any applicant.

The decision of the Committee in selecting and announcing the above "Short List" is irrevocable. No further presentation or appeal, in any manner, by applicants not listed herein, will be considered.

The Committee will address letters of notification and further inquiry to each applicant on the above "Short List".

The Committee wishes to express appreciation to all applicants for their interest in the proposed work. The high quality of talent and experience presented has made the selection of the "Short List" a time-consuming task.

Bangkok Drainage and Sewerage Planning Committee

(Signed) Puey Ungphakorn
(Dr. Puey Ungphakorn)
Chairman

Dated September 7, 1965

Certified true copy
Sanan
April 18, 1968

APPENDIX C.

Ref. /2508

The National Economic Development Board,
Krung Kasem Road,
Bangkok, Thailand.
September 8, 1965

Dear Sirs,

We trust that you have already received a notification from the Chairman of the Committee with regard to your selection as one of the seven firms on the "Short List".

Enclosed herewith is a copy of "Announcement Number 2, Selection of a Short List of Consulting Engineers".

The Committee is especially grateful for the presentation of those firms now published as a "Short List".

The Committee has considered various procedures for further study of qualifications.

The Committee does not desire, for the time being, any personal appearances by members of your firm or its representatives. Such interviews, at a later date, will be initiated only by the Committee.

The Committee has considered the use of a tabular type questionnaire to obtain further information from those on the "Short List", but has decided that the sole use of such a device would be a sort of clerical straitjacket, unworthy of the problem and persons involved.

In lieu, therefore, of both the oral interview and the questionnaire, we would like to receive a written presentation of the same type of subject matter and arrangement as might be presented in an oral interview. Such a written presentation should afford a clear understanding of your qualifications to all members of the Committee and other government officials.

Since such a written presentation will be studied by some persons who have not read the more voluminous previous presentation, it should present a general perspective of your firm and its capabilities, including its field of activity, number of years of practice, volume of business, etc.

For purpose of reference, the following paragraphs are numbered. Kindly use the paragraph numbers in your reply.

1. Continuity of assignment by individual cities would have meaning in interpreting qualification, so that a simple listing of the length of continuous retainment by specific cities would be helpful.

2. An up-to-date statement of the number of graduate engineers and the number of graduate engineers with principal experience in sanitary engineering should be included.

3. Your presentation should then present some specific illustrations of experience of the types listed below. In each of the three special categories so listed, kindly select and describe in detail one recent assignment performed by you within the last ten to fifteen years which you feel is most similar to the proposed assignment in Bangkok. If other engineering firms or agencies were associated with you in the assignment described, kindly clarify the relationship between your firm and such other firms or agencies. At the conclusion of each specific illustration, add a list of additional assignments of the same type, completed or underway within the last ten to fifteen years.

3.1 A Comprehensive River Pollution Survey.

Most pertinent would be the survey of the tidal reaches of a large river or estuary. Describe the type and purpose of the survey, as well as its extent, date, duration and approximate cost of the survey. Describe pollution conditions and water use, and your recommended means of pollution control.

Follow this illustration with a list of other river pollution surveys supervised by you, giving the places, dates, purposes and costs.

3.2 *The Preparation of a Master Plan of Wastewater Sewerage.*

A "Master Plan" as described for Bangkok, is considered to be a complete sewerage pattern, with locations, sizes, shapes and elevations of all existing, proposed and probable future sewers, and an estimate of constuction cost, by stages. The illustration presented out of your experience should be for an entire city of considerable size or a substantial portion of a large city or metropolitan area. Describe briefly the area, climate, type of land use, population and its living standards, industries, sewage characteristics, etc.

Most pertinent would be a project in a tropical or semi-tropical climate. Indicate whether the project was for a complete new system, or improvement of an existing system, etc. Follow this with a list of several selected projects, in which you supervised the preparation of a Master Plan of Wastewater Sewers, giving dates, locations, population and estimated construction costs.

3.3 *The Preparation of a Master Plan of Stormwater Drainage.*

Most pertinent would be a stormwater or "combined" sewer system for a large urban area on flat terrain, with heavy rainfall and subject to some riverbank overflow, requiring the use of pumping stations, and with wet alluvial soils. Describe briefly the watershed area, rainfall characteristics, land coverage, runoff characteristics, etc. Give number and sizes of pumping stations.

Follow this with a list of several selected projects in which you supervised the preparation of a Master Plan of Stormwater Drainage, giving dates, location, watershed areas, and estimated construction costs.

4. In addition to the three presentations, as requested above, kindly furnish a list of larger sewer projects for which you have furnished detailed contract drawings and specifications, during the past ten to fifteen years, or are now performing such work. Limit the list to projects having individual construction costs in excess of sixty million Baht (three million U.S. Dollars). This list may include projects already described in connection with river pollution surveys and master plans. Tabulate the years, locations, type of sewers (wastewater, stormwater or combined) and construction costs. If other engineering firms were associated, please clarify.

5. Following the list of sewer projects, kindly furnish a similar list of sewage treatment projects, having individual construction costs in excess of forty million baht (two million U.S. Dollars).

6. Further we would like to receive a set of typical contract drawings and specifications for a sewer project and another set for a sewage treatment works or representative portions of each.

7. Besides furnishing information in the form and content suggested, you may, of course, add any other data which you believe desirable. In connection with the three specified items, you may wish to illustrate with small scale maps, charts and photographs. Photographs of the major projects as listed, showing construction methods as well as completed structures, may be helpful.

8. Also, as part of your presentation, the Committee would like a general statement of your approach to the Bangkok assignment, assuming that you are awarded a contract in February 66, or shortly thereafter.

To assist you in this matter, we are enclosing "A Statement, Regarding Professional Engineering Services Needed" which also includes some background data of the proposed sewerage improvement.

We do not, of course expect any statement of detailed technical solution at this time.

You should, however, be able to outline your organizational procedures and identify by name, position, education and experience, the key personnel which you will assign to the project.

8.1 What member, or partner will have prime responsibility as Project Director?

8.2 Who will be assigned to Bangkok as Resident Supervisor or Project Manager?

8.3 What additional personnel with specialized knowledge will be assigned to the project and what will be the approximate duration of their assignment?

8.4 What is your general opinion as to the proportions and types of work that should be assigned to Thai Nationals, either in government bureaus or private engineering offices in Bangkok?

8.5 What has been your experience with regard to training of nationals in the course of a design project such as for Bangkok? Are you willing and able to furnish personnel to conduct such in-service training?

8.6 In what special related fields, if any, would you believe it desirable to employ special consultants, such as transportation, in relation to conversion of canals to vehicular usage, or persons with long experience in the special field of stream pollution investigation, or metropolitan planning as related to future sewerage needs, or hydrologists with wide experience in the field of urban stormwater runoff, etc? If you feel that your present organization can provide some or all of such specialized knowledge, please cite specific personnel.

9. Kindly furnish three professional or business references related to separate major and recent assignment.

The data already at hand will remain a part of your total presentation and will continue as part of the Committee's evaluation of your qualifications. The data now requested will be pointed more directly to the potential assignment in Bangkok. In your new presentation you may wish to cross-reference some specific points to your original presentation.

Please submit the additional data requested herein at your earliest convenience so as to reach the committee not later than November 15, 1965.

Yours sincerely,

(Dr. Vinyu Vichit-Vadakan)
Secretary
Bangkok Drainage and Sewerage Planning Committee

ENGAGING ENGINEERING SERVICES FOR WATER PROJECTS

Dr. VINYU VICHIT-VADAKAN

Director, Social Projects Division, National Economic Development Board,
Secretary, Bangkok Drainage and Sewerage Planning Committee.

Let me, from the beginning, qualify the scope of my contribution. Due to my limited experience, it will be restricted to the works being conducted here in Thailand and will be mainly concerned with the engagement of Engineering Services by the various Thai government agencies.

The previous paper entitled "Evolution of a Master Plan" was prepared by Mr. A.L. Tholin who still remains a member of the Bangkok Drainage and Sewerage Planning Committee. Among other duties and assignments under the National Economic Development Board, the Author is also Secretary of the named Commitee. Mr.Tholin describes in some detail the mechanics involved in the selection of the Consultants for the Bangkok Drainage and Sewerage Project. Almost identical steps were also taken for the selection of the Consultants for our Water Project. The phases of the selection process can be summarized as follows:

1. A selection committee was appointed.
2. The committee set up the scope of work and criteria for the selection of Consultants (Announcement No. 1).
3. A world-wide invitation was sent out to all known Consultants in the field and to all Embassies in Bangkok together with a statement describing the scope of work and the criteria for selection.
4. Proposals from all the Consultants were tabulated and graded by the Committee.
5. A short list was selected and more detailed questionnaires were sent to those in the short list (Announcement No. 2).
6. The Committee again evaluated the information sent in by those in the short list and selected one Consultant.
7. Negotiations were conducted with the one Consultant so selected, details of the Contract document agreed upon, including fees.
8. Contract was executed and the Consultants started work.

During the process of engagement of consulting engineering services the committee also sought assistance from international organizations, mainly the IBRD and WHO. The IBRD has sent several missions to Bangkok on this project. The Committee has tried to keep the IBRD informed about the development of this project. No formal request for a loan has yet been sent to the IBRD, but it is intended that future major construction programs will be done with IBRD financial assistance.

WHO has also sent teams of experts on this project, such as one sent during the period when the Committee prepared contract documents to be negotiated with the Consultants, and another to assist the Committee in the review of the Master Plan Report after its completion and submission to the Committee.

This was the process of selection pursued by the Committee for the Drainage and Sewerage Project and also the Water Supply Project. May I add here that this is not the process of selection of Consultants uniformly and generally used by the various Thai Government agencies. Consulting engineering services are used by quite a number of government agencies here in Thailand, the major ones being the Highways Department, the Royal

Irrigation Department, the Electricity Generating Authority of Thailand, the Telephone Organization of Thailand and the Public and Municipal Works Department. The methods used in the selection of Consultants for all of these agencies are quite varied. Some of them select from a list of Consultants whose capabilities are already on file by the agency involved and start negotiations straight away; some choose from the Consultants that they have previously worked with or known personally; some choose from a short list provided by the Thai Government; and some accept the Consultants suggested by a foreign government which pays the Consultants through an aid program.

Many persons have commented upon the selection process used in our drainage and water projects. These comments can be summarized as follows :

1. Although they all agree that this is probably a very justifiable and fair way of selecting a Consultant, it is at the same time a very lengthy, time consuming and awkward process. It has taken us more than a year of almost full time work of the Committee to go through the 8 steps mentioned above.

2. It is awkward in the sense that much information has to be provided by a very large number of Consultants in vain.

3. It is often argued, and rightly so, that however much effort you put into a particular selection process, there is no *guarantee* that the end product produced by the Consultants so selected will be any better than ones selected otherwise.

4. Suggestions have also been made that one of the criteria for selection should be the fee to be paid to the Consultants themselves. As can be noticed from the steps mentioned above as carried out by the Bangkok Drainage and Sewerage Planning Committee the question of fee was intentionally left out until one Consultant had been selected. Fees were discussed only during the period of Contract negotiation. The Committee thought it appropriate to select the Consultants only on the basis of their qualifications, merits and experience. It was understood that if negotiations with the Consultant first selected failed to result in a contract, a second selection would be made from the short list.

The problem concerning the procurement of Engineering Services here in Thailand is not just the process of selection itself but also the more fundamental problem of the need for Consultants. It is still quite generally believed by many persons that Consultants should not be used for the following reasons:

1. Good consulting services are invariably quite expensive. An agency can spend millions of US dollars on Consultants and get nothing in return but sheets and sheets of paper, portraying projects which are never financed or constructed.

2. A package deal or turn-key job is often preferred because it ensures implementation of construction and more tangible results are obtained. The original decision includes not only plans but financing arrangements and construction.

3. Construction work designed by the contractor as a part of the "package" is often considered to be more economical on the assumption—right or wrong—that large contractors and manufacturers are as reputable and responsible as the consultants.

4. Although it is generally believed by professional societies that high-quality professional planning will produce greater economy and higher quality, it is not always true that a turn-key job is any worse than jobs designed and supervised by Consultants, but constructed or manufactured by someone else.

5. By using the services of the Consultants the client is in no position to know how much the construction work will cost until the engineering plans are completed, after which it is sometimes proven to be too expensive.

6. Consultants from highly developed nations have been known to make proposals and recommendations for underdeveloped countries, which are so advanced in technology and often so expensive that the Consultant's report appears unrealistic and is, therefore, shelved. There have been too many reports shelved because the Consultant's recommendations have not given sufficient consideration to the financial and administrative capabilities of the client.

Obviously, the Bangkok Drainage and Sewerage Planning Committee decided, and we think rightly so in that case, that consultants were needed to prepare a Master Plan of Sewerage and Drainage for the entire metropolitan area, before embarking on a financing and construction program. Having now canvassed the world and acquired extensive data on available consultants in the fields of sewerage and water supply, the future employment of professional services can be simplified. Also, having now achieved a Master Plan of Sewerage and Drainage, their financing and construction can proceed selectively, and a competent staff of Thai engineers and administrators can and must be created to guide the implementation of the work. As the staff develops its capabilities in the field of sewerage, drainage and sewage treatment planning and implementation, the need for foreign consultants will diminish. Also as proper sources of local revenue are derived, the need for foreign financing which is the basic attraction of the "package plan" will diminish. With a staff of growing competence, augmented only as necessary by local or foreign consultants, and local or international financing assured, construction work will be carried on under competitive bidding by construction contractors. The sewerage and drainage problems have not, up to the present, had the public attention that they deserve and therefore the development of a staff, and the provisions for revenue, have lagged behind that of other public functions, such as irrigation, railways and highways. In those agencies, competent staffs have existed for a long time.

In summary, we would state that the need for consultants, either local or foreign, depends upon:

1. The relative strength and competence of Thai staff involved, and
2. The portion of the work load in the particular field which is beyond the capacity of the staff or its reasonable enlargement.

We would also state, in principle, that the staff augmented as necessary by the assistance of consultants should determine the needs and the program of design, financing and construction to meet those needs. Having done this, funds should be sought and obtained from local revenue or, if borrowing is necessary, funds should be obtained at the lowest interest rate and construction carried out by competitive bidding. The package plan need not be completely nor arbitrarily ruled out, as it may, under proper control by an adequate staff, be still desirable in some cases. All packages however should be labelled, as parcel post packages are generally labelled, "may be opened for inspection." The buyer of a package should always know, as far as possible, what is included or not included in the package.

CONTRACTING FOR CONSTRUCTION, MATERIAL AND EQUIPMENT

TASOS VALANOS

Director of Southeast Asia Operations and Construction, Louis Berger, Inc., Bangkok.

The subject of this discussion is how to prepare Contract Plans and Specifications to insure delivery of good quality materials at fair prices and how to avoid costly extras due to errors, omissions or skull-duggery on the part of unethical contractors. The area covered is South East Asia, and the examples as mentioned are drawn from my past experience in Thailand.

If a single solution to this problem exists in the preparation of Contracts and Specifications we have not found it. To be honest I do not believe there is a single specialized step in the design process, but an integrated continuous procedure from the very initial concepts till the last opening day of the project. From a recent article of the *Consulting Engineer* I would like to quote the following:

> "The Consulting Engineer, it seems, may finally have come to the Supermarket..... The Concept of the Supermarket — one-stop shopping — appears to be upon us, and the future of Consulting Engineering would seem to belong to those firms that can assure the client that he need go no further than their own doorsteps to get his work done......"

I believe that the answer here does not only lie in trying to plug the legal loopholes and eliminating errors, but greatly increasing the Consulting scope towards more quality control from the beginning to the end.

In order to understand the reasons for this expansion of responsibilities, maybe we should examine the areas where construction of projects such as waterworks, sewage plants and industrial facilities, differ from similar construction in the United States. These basic areas where differences occur are as follows:

1. In the United States most contractors fall into categories as to the type of work which their organizations can handle efficiently, expeditiously and profitably. A heavy construction contractor specializing in structûres such as airport runways, highways, bridge abutments, etc. usually foregoes bidding on such work as churchs, banks, hospitals or office buildings. A Contractor whose organization and personnel are geared to a particular category of construction finds himself in difficulty if he strays from his specialty. *This is not true here*, there are no specialized contractors as such.

In addition, in the United States and Europe we have the organized and skilled Trade Unions. Here the divisions of trades are not well defined and training is lacking, especially in the mechanical trades.

2. Another area of difference is estimating. In Europe and the United States the specialized contractors develop cost information from their vast pool of experience and they supplement it with a great amount of cost information that is published, so that they can always spot and check deviations from the norm. Here specialized cost information is lacking, and if U.S. catalogs and estimating books are used, they may result in unfair costs to the owner or even sometimes to the contractor. For example, consider the labor differential. A laborer in Thailand gets 15 to 20 cents per hour while a union laborer in the United States gets 4.65 to 4.80 US $ per hour. In addition, materials may have 10 to 15 per cent ocean freight charges as well as 25 to 50% tax, depending on type and use. It thus

becomes very obvious why cost information for other parts of the world may not apply here.

As a result of non-specialization the situation might easily arise when the contractor attempts, for the first time, to construct such a project. The dangers and pitfalls in the course of construction of that project are very obvious. This is why I mentioned that it is often necessary to increase our scope of work. A consulting firm here may have more freedom for imaginative solutions and creativity, the challenge is greater but also, as a result, so are the responsibilities.

As previously mentioned this expanded scope of work starts from the very beginning of the design stages. Not only should we design the structures but also we should visualize the construction methods, which normally is the contractor's job and responsibility. In many instances the contractor, having limited capabilities, may request the aid of the Engineers in construction methods. For example, in the summer of 1966 we constructed a full-scale model bay of a 3-story precast concrete building and thus helped the contractor improve his methods of pouring and handling the system elements. Sometimes, in order to optimize for local construction conditions, it may be possible to change a design or revise portions of the specifications in such a manner that the cost of the project will be reduced without sacrificing its essential value. On a present industrial project we are reviewing and may revise the size of the elements of industrial equipment to be shipped from the factory, so that they can be handled by barges from Bangkok Port to the construction site some 50 km away, thus greatly reducing transportation costs. Of course, this step of visualizing construction is an absolute must in the development of an accurate cost estimate.

The next step, concurrent with design, is the establishment of a fair value of the project. For this, all the relative details must be taken into account. Local labor rates and sometimes even the added differential to the rates due to the additional demand must be considered. Productivity rates have to be adjusted for the amount of skill available, weather, types and condition of available construction equipment. If all details are treated thoroughly and accounted for, the cost will not be far off. Three years ago in one of our projects we investigated the use of a slipforming method. Since there was no past information we designed all the slipforming equipment, assumed the rate of ascent and the required crew based on the design, and estimated the total cost. Six months later an Australian firm did the first slipforming job in Thailand; we were only one cent off per square foot.

The next important item is *Specifications*. Specifications should be such that they clearly define quality and methods in a simple and readable language to enable the contractors to read and understand them. Large verbose volumes as associated with various government agencies and references to non-existing standards should be avoided. As far as possible specifications should be simplified and standardized.

Selection of Contracts — Strictly speaking the selection of the contract form is a function of the owner, but it usually becomes the duty of the Engineer to furnish recommendations on which the owner may base his decision, or even furnish the entire contract format. Independent of the type of contract these essential elements must always be present:

1. There must be a real agreement or "meeting of the minds."
2. The subject matter must be lawful.
3. There must be a valid consideration.
4. The parties must be legally competent.
5. The contract must comply with the provisions of the law with regard to form.

The absence of any of these elements is sufficient to void the contract here, as well as in other parts of the world.

The most typical contracts used are:

Lump-Sum Contracts — The use of the lump-sum contract is indicated where the types of construction are largely standardized and where a variety of operations is required, making it impracticable to break down the work into units. As a prerequisite, the plans and specifications should be comprehensive and should show in complete detail the requirements of the work. Changes and extra work orders after the contract is signed are expensive and lead to controversies and disputes. If the plans are indefinite, the contractor is forced to gamble on the uncertainties or, as usually the case, increase his bid to cover the worst expected conditions. If these hazards are avoided, then of course the owner has the advantage of knowing in advance his total cost.

The second most used contract is the Unit Price Contract. When the work requires large quantities of a relatively few types of construction and the volume of work cannot be exactly determined in advance, the unit-price contract has many advantages. Again the plans and specifications must be complete, in that they must show the nature and details of the work, but its limits may be left more or less indefinite, the magnitude and scope of work being indicated by the engineers estimate. Unit prices may also cover laborers and various trades, to be supplied by the contractor, to work under the supervision of the manufacturers specialists. This is especially true in some equipment installations, where it would be too costly to bring in complete crews of installers.

Combined Contracts — Frequently it may be advisable to combine the significant features of lump-sum and unit-price bidding in one contract. Thus the contractors bid will include lump-sum amounts for some items and estimated quantities with corresponding unit prices for others.

As mentioned above, one of the essential elements in the contract validity is that the contracting parties must be competent. To avoid future costly problems, the contractors requested to bid must be able to show that they have both the knowledge potential and proper organization to successfully complete the project. Ignorance and over-expansion are common reasons for contractor failures. The contractor must show that he has office and supervisory capabilities to adequately handle the job within the required time.

After the bids are in, the Engineer usually will help evaluate the bids and help with the selection of contractors. He may also find certain discrepancies in costs of items that the contractor has figured. At this time all items must be negotiated until all known questions are answered prior to signing of contracts. Then the Engineer's detailed estimate may be found well worth the additional effort.

All the above steps are important but they lead to one thing: starting the job right. Then, of course, the next goal, both of the contractor and the Engineer, is to have the project completed properly and on time. Here comes the role of proper supervision; in this case it is mostly not *inspection* but *full time supervision.* Much too often in between periodic inspections, broken piles remain in the ground, inferior and lesser reinforcement is covered with concrete, bad concrete work can be expertly plastered, insufficient welds and bad joints are painted and covered up. Extras at the same time can become numerous and beyond control and somehow these things do not become obvious until all the Bank Guarantees and Bonds have expired. A good design thus may end being good on paper only. Clients are slowly realizing the value of good design services, but as of now, unfortunately, this does not apply to construction supervision. Much too often this is an area where the owners feel they should save money. This then becomes the area where Engineers have to assert their professionalism and they should try hard to educate the owners and change their attitudes. The ultimate results could be rewarding by having good cost control, meeting schedules and ending in a good overall project.

The Resident Engineer, and his backup organization depending on the project size, must be of the proper caliber, and must retain complete knowledge and control of the progress and quality of the work from start to finish. He must be firm in keeping the standards of quality set by the designers and must be able to resist all kinds of pressure for inferior substitutions. If, however, we want the contractors to be good we must also be fair to them. Thus we may help even in a small way to create a better professional spirit among contractors and Engineers and owners

I hope in my hasty review I have not implied that there are no competent and real professional contractors. On the contrary, the levels of their competence and sophistication are rising fast. Only 3 years ago I watched the pouring of concrete at the President Hotel in Bangkok, with a human chain of 40 to 50 workers, mostly women, handling the concrete bucket. The last used to throw and flip it in the air, and they never missed. Now, several major structures are being slipformed using the latest hydraulic jacking systems and the skyline of this city is being adorned with quite a few climbing crane towers, a true indication of their level of competence, and their genuine response to the added demands.

WATER DATA FOR PROGRESS

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The initial source of water supply is precipitation; thus, we need to know the quantities and spatial and temporal distributions of rain and snow. Eventually in the earth environment, water except as it is evaporated or transpires appears in streams, lakes, and reservoirs; thus, we need to know about evaporation and the quantities and distribution of runoff. Some of the water passes through soils and rocks of the earth; thus, we need to know the quantities and distribution of soil moisture and ground water. Also, because water carries sediments and dissolved chemical constituents, we need to know about its quality.

In short, our interest in water encompasses all phases of the hydrologic cycle, and data concerning it are a foundation for all stages of water development and management. By way of illustration, in the appended Table are listed some typical questions whose answers are determinants in water-resource development and management at different levels of sophistication. A glance at the variety of water data needed to answer these questions is convincing evidence of the essentiality of these data. Two significant characteristics of the data are: first they are multipurpose and each kind contributes to answers for several questions; and second, answers to most questions require analyses involving more than one kind of data.

TECHNOLOGY OF DATA ACQUISITION

Precipitation

Point measurements of precipitation, utilizing standard and recording rainfall gages and the extension of these data by interpolation and extrapolation to provide areal coverage, continues to be the principal means of acquiring precipitation data. The main advances in this field have been in telemetry of information to data centers for real-time processing, and in application of radar and other remote-sensing techniques for detection and measurement of precipitation. The latter technique offers much promise, but much additional research is needed to provide quantitative results.

Streamflow and River Stage

The individual stations in nationwide networks for the collection of data on streamflow and stage represent point samples in space, but unlike point samples of precipitation, they reflect a summation of the runoff of the total drainage area above the measuring station and are an indication of areal precipitation input. Also, they reflect changes in runoff resulting from water and land management practices upstream. Hence, methods of evaluation of the acquired data require a more complex stochastic approach for proper analysis. Great advances have been made in automation of data collection by processing by computer.

Storage in Lakes and Reservoirs

Staff-gage readings of water levels and the related stage-capacity curves for the water-filled depressions in the earth's surface are the principal means of determining storage in lakes and reservoirs. The major recent advances here have been in the area of instrumentation and techniques for telemetering water-level information to control centers for "real time" use in regulation of floods, low flow, and pollution dilution. Considerable work is presently underway on remote-sensing instruments and techniques for estimating and identifying and describing various water-body parameters and the subaqueous features of lakes.

Ground Water

Because of the mode of occurrence of ground water, the variety of basic data essential to describing aquifer systems is imposing and the techniques for acquiring data are complex. The body of data commonly includes geologic information, hydrologic parameters, and measurements of water quality. These data must be subjected to coordinated analyses by various techniques to yield data in the form commonly required by the user—that is, determination of the quantity of water in storage and changes in storage, the rate and direction of ground-water movement, quantity of recharge and discharge, and variations in quality of water from place to place and in time. The principal recent advances in technology have been concentrated largely on application of digital and analog computers to simulation modeling of ground-water systems, and in application of nuclear technology, such as environmental-isotope techniques to define better the ground-water models.

Soil Moisture

As in the case of ground water, information on soil moisture at such scale as to be broadly useful requires data on numerous complexly related factors. These include many different soil types and their physical, hydrologic, and chemical characteristics. They include land cover and land- and water-use practices, seasonal variations in temperature, evaporation and transpiration, and surface and subsurface drainage. The most important recent advance in this field has been the development and effective use of nuclear soil-moisture gages utilizing the gamma-ray absorption principle to obtain density and neutron scattering to obtain water content.

Quality of Water

At the present time the greatest recognized need for work in instrumentation and methodology for data acquisition probably is in the field of water quality. The effects of man's activities and his developments on the quality of the resource are becoming more and more difficult to identify, measure, monitor, and control. The physical, chemical, biological, and microbiological characteristics of water resources are sorely needed to aid in identification of substances once they are released to the water environment, to determine their occurrence and persistence, to appraise the capacity of the environment to assimilate them, and to improve means for evaluating the general quality. Because of the importance of the field there is a major thrust underway; among the more significant recent developments are:

1. Adoption of new and more efficient analytical instrumentation and techniques for analysis of chemical and organic constituents; including specific ion electrodes, automatic analyzers, infra-red spectrophotometry, atomic-absorption spectrophotometry, neutron-activation analysis, electron-capture and gas chromotography techniques, mass spectrometry, and isotope-dilution techniques, to name a few.

2. Development of continuous multichannel monitoring equipment for surveillance of river waters; these can be adapted to real-time operation or to tape output for direct input to computers.

3. Automatic storage, processing, and retrieval of water-quality data employing digital computers.

4. Infra-red remote sensing from aircraft and satellites to detect thermal pollution, especially in open waters of lakes and estuaries.
5. Tracing of organic particulate matter with radiotracers.
6. River quality modeling, stochastic and deterministic.
7. Techniques for determining reaeration and assimilative capacities of stream reaches.

Sediment Transport and Deposition

Sediment movement from the source to the sea or other base level involves physical, chemical, and hydrologic interrelationships which are so complex and variable as to be poorly understood. The standard methods of estimating fluvial sediment transport are based on sampling the stream bed and the water-sediment mixture, determining the particle-size distribution and the concentration of the sediment, and computing the sediment discharge; instruments and techniques presently available are considered to be generally inadequate. Significant developments in this area in recent years lie in the use of sonar, radioactive tracers and neutron-activation analysis of non-radioactive tracers, and fluorescent-labeled particles.

Estuaries

Because of their location, estuaries are mixing grounds for water together with its dissolved substances, entrained materials, and heat from the land, and water from the sea. Also, they are important water resources for navigation, industry, and recreation. However, the highly variable river flows, tidal cycles, sources of dissolved and entrained materials and heat, and the hydrodynamic patterns of water movement present very complex problems in acquiring significant data on characteristics of the water resource. Among the major technological advances in recent years are the development of computer models for calculating tide-affected flows and the application of dye tracers to monitor water movement, infra-red remote sensing to detect thermal anomalies, and the application of radioactive tracing of sediment and organic matter to monitor, respectively, movement of bed material and suspended particles.

Recent Advances

Development of new and improved technology is moving rapidly, and we should like to emphasize some of the new equipment and methodology that offers special promise. In so doing, however, it is not our intention to downgrade standard techniques. There are no easy short cuts to knowledge, and for the foreseeable future the basic foundation for water-resource planning will continue to be such prosaic activities as streamflow gaging, rain gaging, water-level measurements in wells, sampling streams and the like. However, many new techniques now make the overall data-collection task more efficient and permit more effective interpretation of the data.

Among the most significant advances over the past two decades are automation of some elements of data collection and telemetry to operating centers; remote sensing by camera and geophysical sensors from aircraft and satellites; automation of data storage, processing, and retrieval by use of digital computers; the use of electric analogs and digital computers to simulate hydrologic systems and for complex water-resources analysis; and the application of nuclear technology. In the developing nations, remote-sensing techniques deserve particular attention because of their utility for reconnaissance studies in terms of coverage, timeliness, and cost. Hydrologic modeling, though commonly viewed primarily as a predictive aid to management, also has great feedback potential toward improving the data-acquisition program.

PROGRAM PLANNING

Although the foregoing array of tools and techniques for collecting water data of all sorts is impressive, it can be effective only if employed systematically within the framework of an organized program. No ready formula exists for planning all the details of such a program, but an understanding of the relationship between the progressive stages of water-resources development and associated water-data needs serves as a useful conceptual guide.

In the United States, and we suspect in the rest of the world as well, water-resources development and economic development in general pass through three distinct stages. Different parts of a region may be in any of these stages at a given point in time, and changes in technology and economics may cause rapid shifts from one to the other.

The first stage emphasizes exploration. Water resources are essentially undeveloped, and the public interest is in finding water and putting to use the more readily available supplies. Hydrology is in a natural or steady state, unaffected by man. The need to know about water emphasizes the question, "Where is it?" To help answer this question, data at reconnaissance scale ordinarily is sufficient, and the answer accordingly tends to be qualitative.

The second stage emphasizes active development. This proceeds apace, with interest in economic gain dominating. Man and his activities as a hydrologic factor become increasingly significant, and hydrology moves toward an unsteady state. The need to know about water emphasizes the questions, "How much, and how does it behave?" Data collection is increasingly directed toward answering these questions quantitatively and in detail.

The third stage emphasizes conservation. Essentially all resources have been tapped, and the matter of managing them for optimum service to man is paramount. It is in this stage that values other than economic tend to receive their greatest recognition, depending upon the affluence of the society, and problem areas as a consequence of developments in the preceding stage receive much attention. Water-data acquisition trends toward the end point of metering for operational purposes.

Consideration of these three stages suggests that a national water-data program should provide for:

1. Completion of reconnaissance-scale hydrologic studies countrywide as soon as possible. These should classify the country in terms of hydrologic characteristics as an early aid to development and as a foundation for further investigations. They should include the establishment of networks for making measurements of hydrologic elements such as precipitation, streamflow, and ground-water levels, which initially require long-term records. These networks should allow for sampling the principal classes of the environment and the hydrologic variables of each.
2. Such additions to the basic hydrologic network as are appropriate to provide warning of emerging water problems and to monitor changes in problem areas. The "tolerability" of risk is the principal guide to the effort to be expended for this part of the program.
3. Such additions to the foregoing as are needed to portray the changing conditions of water supply from stresses applied by man. In developed areas the additional activities should account for water uses and disposition because they directly affect the available supply.
4. An arrangement as a recognized part of the resources planning process, to schedule quantitative hydrologic studies for areas of impending active development. Studies should include enough detail to identify and evaluate hydrologically the alternatives for water supply and to foresee hydrologic problems that are likely to occur.

The planning process should give attention to the full range of hydrologic variables and their interdependence. For example, the complex of data needed to understand water quality includes not only imformation on the physical, chemical, biological, and microbiological characteristics of the water, but also flow characteristics of the water and the reaction characteristics of the environment through which it passes; chemical analyses of a few samples without knowledge of the related variables would be incomplete and could be misleading. Also, the planning process should give attention to the full range of the communications chain, from sensor to user—and including processing, review, and storage and retrieval or other means of dissemination.

SKILLS AND TRAINING

The staff for planning and implementing water-data programs should be professional and multidisciplinary. It should include people with backgrounds in geology, engineering, and chemistry at least, and they should be involved in the full spectrum of water-data activities, although many of them will specialize in one aspect—such as ground water, streamflow, or water quality. All parts of the program, even those seemingly routine tasks that can be carried out by subprofessionals, should be supervised by the professional staff. It is essential, too, that each new professional initially participate directly in the field work—as a basis for recognizing the kinds of limitations the field realities place upon the data. Also, the professional staff in general should be broadly knowledgeable about the users and uses of water data.

The accelerating rate of technological changes makes a training program imperative for personnel engaged in the water-data program. In particular, attention should be given to retraining for mid-career people. We think it absolutely essential that competent hydrologists be trained in the uses of new sophisticated tools, such as computers, before these tools are put to work. Failure to do so may make the tool the master and destroy its usefulness.

Training Opportunities

While training at the subprofessional level is generally considered the proper responsibility for the home nation, broad opportunities exist for training at the university and post-graduate level in the developed nations. Many programs are offered, generally in the form of fellowships, under both bilateral and multilateral auspices. Among the leading nations offering bilateral training assistance are the United States, Canada, Great Britain, France, and the Federal Republic of Germany. The main avenues of multilateral training assistance are the fellowship programs of the United Nations agencies and through regional treaty arrangements, such as SEATO and the Colombo Pact.

In the United States, fellowships can be had under government sponsorship, coordinated through U.S. AID; under private foundation sponsorship, such as the Ford and Asia Foundations; and directly through universities. Of special interest in the water-resources field are the efforts of the Universities Council on Water Resources, a group in which 62 universities participate. The council coordinates announcements of fellowships available in the field of water resources; the list is advertised under the U.S. program for the International Hydrological Decade. Candidates interested in such training are encouraged to correspond directly with the universities involved.

FOREIGN ASSISTANCE IN SOUTHEAST ASIA

Although water resources have been developed for human use in many parts of the world for centuries—indeed in Southeast Asia for millenia—it has been only with development of modern engineering practice, mainly within the past century, that there has been a growing appreciation of the need for a firm data base for resources management. In part, this was due to the fact that in the past most planning decisions were local in scope and involved little large-scale construction. Now that we are in an era of projects that embrace nations or several nations, and involve tremendous capital investments, we can no longer take the risk of decisions based upon inadequate data.

Much has already been accomplished in the direction of providing adequate water data for future development in Southeast Asia, but much remains to be done. Prior to World War II most water-data activities in Southeast Asia were carried out by European hydrologists. These programs were for the most part interrupted during the war and many were discontinued thereafter. Presently, national and international programs must fill this gap insofar as feasible.

Technical and financial assistance in support of water-resources investigation, including data acquisition, are available from a number of sources. Chief among these are technical advisory services and training fellowships privided by United Nations entities, regional treaty organizations, and under bilateral arrangements. A particularly important assistance is the pre-investment surveys made under the United Nations Development Program. These projects are executed by the UN and UN specialized agencies on behalf of UNDP, on a basis of matching of UNDP funds by recipient nations. The international agencies also perform a most valuable service through publications of handbooks, manuals, and guidebooks.

The United States has supported water-data activities in several nations through the US Agency for International Development (US/AID) program, and through technical and financial support of the Lower Mekong Basin project under the auspices of the United Nations Economic Commission for Asia and the Far East (ECAFE). Much has been accomplished in Thailand. Bilateral cooperative efforts began in 1954 with a reconnaissance of the Khorat Plateau of northeast Thailand by the U.S. Geological Survey, in collaboration with geologists and engineers of the Thai Mineral Resources Department, Irrigation Department, and Public Health Department. These investigators, using data previously acquired by the Thai Public Health Department in drilling 374 exploration wells in 1952-54, recommended an extensive drilling program in northeast Thailand. This ground-water research and development project (1958-61) resulted in an exploration of 60,000 square miles and drilling of some 400 exploration wells. This was followed up with a further program of additional drilling of 600 wells and interpretive studies (1961-65), and resulted in a comprehensive report published in 1966. A similar program in Cambodia (1958-63) resulted in drilling of some 1,100 wells, of which 760 were productive and were completed as small municipal supplies.

Probably the outstanding water-planning effort in the entire region is the Lower Mekong Basin program. Following a recommendation of ECAFE in 1957, a committee was established of the riparian nations of the Lower Basin to look into the possibility of developing and managing the Mekong River for water supply, irrigation, drainage, hydropower, flood control, and navigation. Based on this recommendation, Cambodia, Laos, Thailand, and the Republic of Vietnam established the Committee for the Coordination of Investigations of the Lower Mekong under the aegis of UN/ECAFE with the UN Development Program (Special Fund), the International Bank for Reconstruction and Development, other UN technical agencies, 12 nations, the Ford and Asia Foundations, and 4 major private industries in technical and financial support.

Because of political problems unrelated to water development, the Mekong project has been limited mainly to planning activities and data collection, but much has been achieved in these areas. Examples of U.S. contributions include, for example, a contract under US/AID by a private contractor for construction of 21 stream-gaging stations on the Mekong and its tributaries, and rehabilitation of 8 existing stations. The company also initiated a series of hydrologic yearbooks which were taken over by the Mekong Committee on completion of an industrial contract in July 1962. In all, 21 stream-gaging stations (13 recording on the main-stem Mekong) were established and 2,903 discharge measurements were made during the life of the contract. The contractor also set up 4 sediment laboratories, initiated sediment sampling at 24 stations, and operated 79 precipitation stations and 19 evaporation stations.

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APPENDIX TABLE

TYPICAL QUESTIONS REQUIRING WATER DATA, AND PROCESSING AND SYNTHESIS TECHNIQUES

Economic Interest Category	Typical Questions Requiring Water Data	Types of Information Synthesized to Answer Questions	Principal Parameters
1. Water supply, significant consumptive use	Without surface storage, will low flows be sufficient and of suitable quality (biological, chemical, physical) to meet needs of municipality?	Streamflow generalization. Discharge records supplemented by correlation with longer records of discharge and precipitation. Flow-duration-frequency analysis. Precipitation-discharge analysis. Relations of flow to water quality. Base-flow of streams. Influence of ground-water withdrawals on low flow.	Discharge, drainage-area, slope, precipitation, evapotranspiration, infiltration, base flow, chemical quality, sediment content, temperature, microbiological quality, base-flow analysis.
	With surface storage, will mean flows be sufficient. How much storage is needed for safe margin?	Analysis of discharge as above. Storage-yield analysis. Reservoir capacity. Evaporation from reservoir. Water demand estimates. Sedimentation in reservoir.	Discharge, water needs (draft), drainage area, runoff, reservoir surveys, evaporation, sediment loads in streams, economic studies.
Municipal supply (As asked by city water manager or regional planner)	Is ground water suitable as supplemental supply or as main supply? Is ground water storage feasible? Are stream-bank collectors feasible?	Investigation of occurrence, movement, storage of ground water, including physical and chemical character.	Extent and thickness of aquifers, permeability of confining beds, movement of ground water, storage capacity, recharge and discharge, chemical and physical, character of ground water.

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	Is a lake a suitable alternate source? Would withdrawals affect other uses? Will quality be suitable at all times?	Records of inflow and fluctuations. Analysis of ground-water interchange. Evaporation. Study of chemical and biological regime.	Inflow, outflow, stage, ground-surface water relations, evaporation, mineral inflow and outflow, and change, sediment budget, biochemical relations, temperature variations.
	Is low flow of stream sufficient and of suitable quality for process involved?	Flow-frequency analysis. Discharge records extended by correlations. Relations of flow to water quality (chemical, physical, microbiologic). Prediction of extreme conditions.	Discharge, runoff, precipitation, chemical and physical quality of water, sediment content, microbiological quality.
Industrial supply (as asked by company engineers or planners promoting industrial development)	Would wells be cheaper than stream supply? Is ground water adequate and of suitable quality for process?	Information on availability and quality of ground water, fluctuations in water levels, temperature, or quality costs of ground-water and surface-water supplies.	Well depths and yields, water-level records, chemical quality, temperature, economic data.
	Is a lake a suitable supply?	Fluctuations of lake level, range of quality parameters, shoreline erosion properties.	Stage, chemical, physical, and microbiological quality.
	Can estuary water be used for process in lieu of fresh water? What are quality characteristics of the estuary?	Tidal data. Information on temperature, biological and chemical fluctuations. Special emphasis on movement of sea water.	Tidal stage, movement of fresh and salt water, chemical and microbiological quality, temperature.

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	Is low flow sufficient to meet crop needs?	Discharge records extended by correlation. Crop requirements. Low-flow frequency.	Discharge, precipitation, runoff, water requirements.
	Would high flows damage structures?	Flood-frequency analysis.	Peak stage records, flood frequency, velocities, basin characteristics.
	Can surface water and wells be economically combined as supply?	Analysis of discharge records as above. Investigation of occurrence and movement of ground water. Study of conjunctive operation. Production economics.	Discharge, precipitation, runoff, well depth and yield, water-level records, chemical quality, cost data.
Irrigation supply (As asked by individual farmers, irrigation district management, or regional planners)	Is quality of supply suitable for irrigation, or can water or soil be treated to improve crop yields?	Study of chemical quality of surface and ground water including variability and relation of quality to stream flow.	Chemical quality of water, soil moisture, soils characteristics.
	Will wells be a feasible longterm investment?	Investigation of corrosion characteristics of ground water and functioning and perennial yield of aquifer system.	Chemical quality, well depths and yields, water-level records, aquifer hydraulics.
	Is ground-water recharge economic?	Evaluation of usable ground-water storage of aquifer system.	Extent and storage capacity of aquifers, infiltration thickness and character of unsaturated zone.
	Is mean flow of stream sufficient to justify surface storage. Can surface and ground-water be operated conjunctively?	Cost-benefit analysis of surface-and groundwater-storage operation, developed separately or for conjunctive operation.	Discharge, precipitation, runoff, well depths and yields, water-level records, infiltration pumpage, water use, diversions, chemical quality.

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	What is best method of distributing water?	Economic analysis with special emphasis on canal and ditch losses through seepage and evapotranspiration.	Evapotranspiration, infiltration, drainage characteristics of soil.
	Is nearby stream or spring suitable for development? Will seasonal fluctuations in quantity or quality be troublesome? Would a well be more satisfactory? Is ground water of suitable quality available at reasonable depth?	Flow-frequency analysis. Stream-flow generalization. Analysis of stream discharge extended by correlation. Records of spring discharge and fluctuations. Information on chemical and microbiological character of streams and springs and relation to flow. Information on availability and quality of ground water.	Discharge, precipitation, runoff, spring flow, well depths and yields, water-level records, chemical quality, basin characteristics.
Domestic supply (As asked by individual home owner, builder, local regulating authority, federal or state health authorities)	Should treatment of water be considered?	Information on chemical and biological character of proposed supply.	Chemical and biological quality.
	Where should a well be drilled?	Geologic information.	Depths and yields of wells, rock types.
	Should consideration be given to building a small pond?	Precipitation-runoff relation. Geologic and soils data.	Runoff, infiltration, evaporation.
	Will pollution endanger supply?	Information on geology and hydrology and potential sources of pollution.	Infiltration, rate of ground-water flow, filtration properties of soil and rock, character of pollutants.

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	Are mean and high flows of small streams compatible with stock-pond construction?	Streamflow statistics by generalization. Discharge records extended by correlation. Precipitation - runoff relations. Runoff-sediment relations.	Discharge precipitation, runoff, peak stage, evaporation, basin characteristics, sediment load.
	Is ground water available and suitable for watering points?	Information on availability and quality of ground water.	Well depths and yields, chemical quality.
Stock supply (As asked by rancher or regional planner)	Can springs be improved for stock supply?	Information on discharge and chemical quality of springs.	Discharge, chemical quality.
	Is stream flow sufficient for stock use without storage?	Discharge records or generalization of precipitation-runoff relations, low-flow frequency information.	Discharge, precipitation, runoff, basin characteristics.
	Will stock ponds fill up with sediment?	Sediment content of streams. Runoff-sediment relations.	Sediment loads, discharge, precipitation.
	Will construction of stock ponds adversely affect down-stream water users? Is a pond an efficient use of limited water supply?	Precipitation-runoff relation Evaporation data. Surface - water-ground-water relationship.	Discharge, precipitation, runoff, evaporation.
2. Water supply, consumption negligible but water altered.	Are temperature variations in streams sufficient to affect adversely use for air conditioning, public supply, or industrial processes?	Water temperature discharge relationship.	Discharge, temperature.

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	Is ground water superior to surface water as a coolant or for heating?	Temperature characteristics of streams and ground water.	Ground-water temperature, stream temperature, discharge.
Heat exchange (As asked by industrial and municipal water managers and planners, air conditioning contractors, and home owners)	Are surface and ground waters chemically and biologically suitable for use in heat exchange processes?	Information on chemical and biological character of supply and consideration of effect of temperature changes.	Chemical, biological, and microbiological quality, temperature.
	Will changes in temperature have serious effect on other uses of water in streams, lakes, estuaries?	Thermal characteristics and movement of water in body of water. Information on other uses of water, especially biological.	Temperature, stream flow, storage in lakes and estuaries, biological and microbiological quality.
	Will ground water recharge with warm water affect efficiency of system.	Information on heat-exchange characteristics, permeability of aquifer system.	Temperature, permeability, storage capacity.
	Will disposal of sewage to stream, lake, estuary adversely affect other uses of water?	Biological and microbiological regime of water body and information on present and potential water use, time of travel of water. Extent of natural purification.	Discharge, movement of water in lakes and estuaries, flow velocity and channel parameters, chemical and microbiological quality.
Waste disposal (As asked by sanitary engineers, public health authorities, petroleum and industrial planning personnel, irrigation specialists, conservationists)	Will disposal of waste to ground water be a hazard or endanger the reservoir?	Information on permeability and time of travel of water in subsurface. Study of degradation of waste considered. Data on other uses of water.	Permeability, time of travel, ion exchange capacity, chemical, biological and microbiological quality, ground-water flow pattern.
	Is deep-well injection of wastes economically feasible? Is it safe, now and in future?	Information on hydrology of deep aquifer systems and compatibility of waste fluid with formation water.	Permeability, storage capacity, water-level records, chemical quality, microbiology.

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	Can wastes be altered to make them non-offensive?	Information on waste treatment and degradation in hydrologic system.	Chemical quality, time of travel.
	Is disposal of garbage as landfill a hazard to water supplies?	Studies on chemical and microbiological character of leachates from sanitary fill and degradation of contaminants in transit. Time of travel of contaminants and data on other uses of water.	Permeability, time of travel, chemical and microbiological quality, ground-water flow pattern.
	What are adverse effects of pollution and sedimentation from storm drainage? How can these be alleviated?	Investigation of inorganic, organic, microbiological content and sediment load of storm drain discharge, and effects on other water uses.	Discharge, precipitation, runoff, chemical quality, sediment load.
Storm Drainage (As asked by sanitary engineers, regional planners, conservationists)	Is use of storm water for ground-water recharge desirable or feasible?	Study of wastes as above. Investigation of permeability of aquifers, time of travel of ground water, and degradation of waste in transit.	Permeability, infiltration, time of travel, chemical quality, runoff rates and volumes.
	Will storm drains aggravate flood hazards?	Flood-frequency studies, precipitation-runoff relations, discharge data, effect of artificial drainage on runoff rates.	Discharge, precipitation, runoff, basin characteristics, indices of extent of artificial drainage.
3. Water supply, consumption and alteration negligible	Is low flow adequate for power generation without storage?	Discharge records supplemented by correlation. Low-flow frequency analysis. Sediment load and sizes.	Discharge, precipitation,, runoff sediment loads, and particle-size distribution.

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Hydroelectric power (As asked by private and public power managers and planners)	Are mean flows and reservoir capacity adequate for firm power with storage?	Discharge records extended by correlation or generalization. Precipitation - runoff relations. Flow-frequency analysis.	Discharge, precipitation, runoff, reservoir capacity.
	Will regulation for power generation adversely affect downstream users or damage structures?	Downstream water use, flow-frequency studies, ground - water—surface - water relations downstream Evaluation of effect of rapid changes in stage on levees and other structures, system modeling.	Discharge, base-flow analysis, water-level records, infiltration.
	Forecasting low flow for immediate future?	Precipitation data and evaluation of base-flow relations upstream, routing.	Precipitation, discharge, base-flow analysis.
	Will sedimentation be a problem in reservoir?	Investigation of sediment loads and runoff-sediment relations. Study of sediment yield characteristics of tributary area.	Discharge, runoff, sediment loads and particle-size distribution, channel characteristics.
	How can necessary storage be provided without serious damage to esthetic values?	Studies of reservoir sites, data on stream discharge and frequency, sediment content, and runoff-sediment relations and chemical, biological, and microbiological quality of water.	Discharge, runoff, sediment load and particle - size distribution, chemical quality, reservoir storage.
Recreation (As asked by conservationists and recreation planners)	Will fluctuation in reservoir permit development of water sports?	Discharge and stage.	Discharge, reservoir storage.

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	How can adverse effects of pollution and sediment be alleviated in streams and estuaries?	Investigation of sources of pollution and sediment, data on water quality, and sedimentation. Investigation of relations of discharge.	Discharge, precipitation, runoff, chemical, biological and microbiological quality, and sediment load and particle-size distribution.
	Can wells and springs be relied upon for campground water supplies?	Investigation of occurrence and movement of ground water in area of interest. Information on regional occurrence of ground water. Data on chemical quality.	Extent and thickness of aquifers, precipitation. Water-level records, chemical quality.
Wildlife (As asked by wildlife managers, conservationists, water planners)	How will diversion or storage affect downstream environment of fish and waterfowl? Will existing species adapt to altered regime or will new species have to be stocked?	Analysis of discharge and flow-frequency data. Investigations of relation of flow to biota. Analysis of channel scour below dam.	Discharge, runoff, chemical, biological, and physical quality.
	Are ground water and surface water available for waterfowl ponds?	Analysis of discharge records, flow-frequency data. Information on occurrence and availability of ground water.	Discharge, precipitation, runoff, evaporation, depth and yield of wells.
	How will alteration of water temperature affect fish and shellfish?	Temperature characteristics of streams, temperature-discharge relations before and after, studies of effect on biota.	Discharge ,temperature.
	How can microbiological, chemical, and sediment pollution from urban areas be alleviated in streams and estuaries?	Inventory of pollution sources; information on chemical, microbiologic ,and sediment character of pollutants and water. Discharge-pollution relations.	Chemical and microbiological quality, sediment content, discharge.

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	How will irrigation return waters affect biota?	Investigation of quality of applied waters and drain waters. Drainage-flow relations. Study of effects on biota.	Discharge, chemical and biological quality.
	Will low flows be sufficient to maintain required channel depth without storage?	Channel surveys. Analysis of discharge data, low-flow frequency analysis.	Discharge, channel characteristics.
	Are low flows sufficient to maintain channel with dams and locks or will off-stream storage be required?	Data as above plus studies of reservoir sites including sediment-flow relations.	Discharge ,precipitation, runoff, sediment loads, reservoir storage.
Navigation (As asked by ship operators, planners)	Will maintenance of high stage adversely affect nearby lands?	Investigation of occurrence and movement of ground water. Relations of surface water and ground water in reaches affected.	Stage, water-level records, permeability.
	Will sediment be a problem in reservoirs?	Discharge-sediment relations, channel surveys.	Discharge, sediment loads and particle-size distribution.
4. Water as a hazard.	Do high flows constitute a serious problem? Recurrence intervals of various high stages. Extent of inundation.	Streamflow generalization. Discharge records extended by correlation with longer records and precipitation. Flow-and stage-frequency analysis. Flood-inundation mapping. Land-use studies. Discharge-sediment relations.	Discharge, precipitation, runoff, channel and flood-plain surveys, basin characteristics, sediment loads.

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	Are pollution and sediment a serious problem at high stage in addition to damage from inundation?	Information on microbiological and sediment content. Runoff-sediment relations. Land-use studies.	Discharge, chemical, and microbiological quality, sediment loads.
	How will flood control measures affect other water uses?	Discharge records. Ground-water surface-water relations. Water-use studies. Sediment-discharge relations and channel morphology.	Discharge, channel surveys, stage, infiltration, water-level records, sediment loads.
Flooding (As asked by flood-control planners, multiple purpose project managers, regional land use planners, land developers)	Will sediment transport be significantly affected by flood-control works?	Sediment-discharge relations. Channel surveys. Analysis of discharge records.	Discharge, precipitation, runoff, sediment loads, channel surveys.
	What is proper flood-control reservation for multiple-purpose reservoir?	Flood-frequency analysis. Economic studies of water and land use.	Discharge, precipitation, runoff, channel and flood-plain surveys.
	Flood forecasting on basis of meterological data and upstream flows?	Discharge records correlated with precipitation records on real-time basis. Precipitation-discharge relations. Snow surveys. Flood routing.	Discharge precipitation, runoff, routing coefficients.
	What are maximum stages and frequency of occurrence in lakes?	Lake stage-runoff precipitation relations. Frequency analysis.	Stage, precipitation, storage.
	Prediction of damage from flooding and sea-water intrusion from tidal flooding in estuaries?	Tidal stage records. Wind-runoff-tidal relations. Tidal-runoff-water quality relations.	Tidal stage, wind velocity and direction, chemical quality, topography.

Economic Interest Category	Typical Questions Requiring Water Data	Types of Information Synthesized to Answer Questions	Principal Parameters
	Can land be drained effectively by gravity ditches or will ground-water pumping be required?	Information on occurrence and movement of ground water. Data on permeability of soils and subsurface materials.	Permeability, water-level records, ground-water flow patterns.
Land Drainage (As asked by farmers, regional planners, land developers, water managers)	Will quality of drain water adversely affect other water uses? Is drain water a suitable quality for use for water supply?	Investigation of quality of ground water and drain waters. Inventory of downstream water use. Streamflow-drainage discharge relations.	Discharge, chemical quality.
	Will importation of water to area create drainage problems if water is stored underground?	Information on occurrence, movement, and quality of ground water. Data on permeability, chemical character of soil and subsurface materials.	Permeability water-level records, infiltration, precipitation, chemical quality.
	What proportion of irrigation water must be wasted to provide adequate salt balance?	Information on quality of soil moisture and ground water. Drainage characteristics of sub-surface materials. Analysis of mineral input and outflow.	Chemical quality, water-level permeability, inflow and outflow.

MODERN WELLS PRODUCE QUALITY WATER ECONOMICALLY

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The distinctive advantages of ground water make it an especially valuable resource in any country. Ground water is the favored source of potable water for most communities. Today's techniques in well construction can assure supplies of quality water at low cost per unit of production. Specific characteristics of ground water which make its use advantageous are the following:

- Freedom from turbidity and bacterial contamination.
- Uniformity of temperature and soluble mineral content.
- Availability of constant supply from wells, contrasting with fluctuating stream flow in seasonal wet and dry periods.
- Ground water sources may be drawn upon in areas where surface water is already allocated to users to the limit of its availability.

Local availability of ground water in many places, without the need for transport over long distances, means that community and industrial water needs can be provided at low cost from modern wells. Wells can be located near the point of water use for convenience and economy. Surface water, on the other hand, may have to be carried over stretches of several miles in expensive canals or pipelines. In most situations, ground water can be developed more economically than can surface water sources to supply all but the largest of cities. Surface water may have to be used in places where ground water can be obtained only at excessive depth, where it cannot be obtained in sufficient quantity at any depth, or where its quality is unsuitable because of excessive mineral content. Where surface water can be used to produce hydroelectric power along with its exploitation for community or industrial water supply, it may be more economical than ground water.

One midwestern state in the U.S.A. has 433 public water systems supplied by ground water. Most of the wells supplying this water are constructed in sand aquifers. Two communities in the state draw upon surface-water sources. The 433 water supplies from wells are periodically examined in accordance with requirements by the state health department. Tests of water samples invariably show the well water to be of excellent sanitary quality. Experience with wells in many of the public systems spans a time period of more than 60 years and provides massive evidence of the dependability of ground-water sources.

Ground water is one phase of the hydrologic cycle. As in the other phases of this cycle, ground water is in relentless motion. Its rate of movement through the interstices of an aquifer is slow but measurable. It moves from areas of recharge at higher elevations to areas of natural discharge at lower elevations, or it may be diverted at points of artificial discharge such as by wells constructed by man. Recharge areas are places where water can enter the aquifer from the land surface by percolation through permeable materials. An aquifer serves two functions of which we may take advantage. One of these we call its "pipeline" function, since the aquifer conducts water underground over extensive distances from areas of recharge to areas of discharge without depletion by evaporation. At the same time, an aquifer performs what we call a "storage" function. Because of the slow movement of ground water through it, an aquifer detains enormous quantities of water as stored water. This great storage capacity permits water to be drawn from aquifers through wells at relatively constant rates, even though climatic cycles may operate to vary substantially the rate of recharge to the aquifer.

GROUND WATER AS A NATIONAL RESOURCE

The aquifers that make up the total ground-water reservoir in any country or region contain far more fresh water than the combined storage in all surface reservoirs and natural lakes. The rate of movement of ground water depends a great deal on the permeability of the porous material which makes up the aquifer. The permeability of the aquifer is its capacity for transmitting water under the influence of an hydraulic gradient. In permeable materials, gravity is the force which moves water downward from the land surface to the zone of saturation and thence laterally towards lower elevations. Ultimately, ground water moves to the oceans or to places where water is discharged at the land surface in springs or seeps. Channels and banks of surface streams are usually the most extensive areas of natural discharge of water from the ground-water reservoir. The entire flow of any stream during periods of no precipitation and no surface runoff consists of ground water, except where the stream flow is artificially regulated or is sustained by melting snow. Thus, ground-water discharge makes up the base flow of almost all streams. This interconnection between ground water and surface water suggests the importance of studies of the close relation between precipitation, surface runoff and ground-water occurrence. As a natural resource offering both economic and aesthetic values for community water supplies ground water should be carefully evaluated. Studies undertaken should aim to identify both the possibilities and the difficulties of ground-water development and to indicate what can be done to overcome the difficulties.

MEASURING POTENTIAL YIELD OF AQUIFERS

Quantitative studies are an integral part of the evaluation of aquifers that serve as sources of community water supply. These studies guide the design and proper spacing of wells, and they form the basis for estimating long-term yield of an aquifer. The worth of an aquifer as a fully developed source of water depends on the two hydraulic characteristics already referred to: Its ability to store, and its ability to transmit water. These properties of an aquifer, called the coefficient of storage and the coefficient of transmissibility, generally provide the very foundation on which quantitative evaluations are based. Knowledge of these characteristics, linked with knowledge of the geology of the aquifer, is applied in estimating recharge, leakage and evaporation-transpiration effects. Determinations of the coefficient of storage and the coefficient of transmissibility are commonly made from observations of changes in water levels in one or more observation wells during a period of pumping. In some cases, these coefficients can also be estimated from a flow net analysis.

The selection of the equations or the computing procedures to be used for analysis is governed largely by the physical conditions of the aquifer insofar as they establish the hydraulic boundaries of the flow system. The quantitative values revealed by the analysis permit extension of the observed data to the design of well fields, to the determination of optimum well yields and to the prediction of future water levels—all under stated conditions. The principal method of ground-water hydraulics analysis is the application of equations derived for particular boundary conditions. A steadily growing number of equations available are described in a wide assortment of publications. Variations in values of coefficients of storage and transmissibility from place to place, together with irregularities in the shape of flow systems in aquifers, require that the calculations of the coefficients be based on adequate data. One quantitative test does not satisfactorily provide a quantitative study for an entire aquifer. An individual test is merely a guidepost or segment of knowledge which must be supplemented by additional tests. Often, the initially calculated results may require revision on the basis of discoveries resulting from additional geologic investigation or from additional hydraulic testing as the field investigation proceeds. Calculations from pumping test data provide accurate values of aquifer constants, but each test represents only a small sample of the aquifer. Flow-net analysis may include larger areas and hence may provide integrated and more representative values of aquifer characteristics throughout the area.

WELL FIELD MANAGEMENT

Management of a ground-water development logically begins in the exploratory stage before the water supply facilities are constructed. A thorough geologic and hydrologic study, including test drilling and test pumping, is usually involved in the exploratory work. All records concerning each test well, including construction details, description of materials penetrated and quality of the ground water should be carefully collected. Particular attention should be given to preparing an accurate map of all test wells with a simple identification system that can be maintained over the years. Records of fluctuations of ground-water levels are among the most useful data to be compiled. These constitute a permanent history of ground-water conditions both before and after new water supply facilities are constructed. Such a record aids in analyzing problems that may later develop, and it also serves as basic evidence in applications to public regulatory bodies where withdrawals of ground water may be regulated by law.

After production wells are in operation, a regular program of observation should be carried out. Water levels should be measured periodically in all wells, whether pumping or idle. Water samples should be collected for chemical analysis, detailed records of well performance should be maintained and a running tabulation of pumping should be recorded. The value of these records to the long-term operation of the wells and the effect of the pumping upon the performance of the aquifer cannot be emphasized. Problems arising from excessive pumping, contamination, salt-water intrusion, decline of water levels and unusual changes of temperature can best be solved when adequate data are available concerning the performance history of the well field. Because ground water is an unseen resource, extra effort must be made to keep track of its availability. A sound well management program will not only pay in keeping operating expenses under control but will help to permit action to prevent problems from arising by giving adequate warning of unusual changes in ground-water conditions.

RECOMMENDED PRACTICES FOR WELL CONSTRUCTION

Recommended practices or standards for designing and constructing wells aim to satisfy four objectives:

1. The well should be adequate in diameter and depth to obtain the water available from the water-bearing formation.
2. The well should be hydraulically efficient and should produce sand-free water.
3. The well casing should be sealed in the subsurface formation to a depth that will prevent polluted surface water and undesirable ground water from flowing or seeping vertically into the intake section of the well.
4. Materials used for the permanent well structure should be sufficiently strong and durable to insure long life and be capable of being readily installed by proven methods.

Ground water in its natural state in most places is of good sanitary quality and is safe to drink. This is particularly true where the water is found in saturated strata of sand or mixtures of sand and gravel. The water found in sand aquifers has had the benefit of natural filtration usually afforded by percolation through porous earth materials. Construction of a well with adequate sanitary protection involves drilling deep enough to tap the desired source of ground water, installing the well casing, installing the well screen (when required), and installing pumping equipment so that the water may be brought to the point of use without introducing comtamination into the water being pumped or into the aquifer from which it is taken. A well should be located on the highest ground practicable in order to provide surface drainage away from the well site. The well casing should terminate above ground and the ground surface at the well site should be built up if necessary so that surface water can drain away in all directions. The well should be located so it will be accessible for pump repair, cleaning, treatment, testing and inspection. When adjacent to a building, the well should be at least 2 meters outside any projection such as overhanging eaves.

Distance from any source of pollution is an important consideration in the development of safe ground-water supplies. Minimum distances from a well to possible sources of pollution should be great enough to provide reasonable assurance that subsurface flow of contaminated water will not reach the well. Establishment of an arbitrary minimum distance is not in itself a satisfactory solution of the problem of well sanitation. Although a 15-meter minimum distance from a source of pollution may be an adequate safeguard in unconsolidated formations such as sand, an even greater distance may be inadequate in coarse gravel. Where the earth formations near the ground surface consist of limestone, disintegrated rock, or other subsurface materials that permit rapid percolation of water with little chance for natural purification, distance can be relied upon in only a limited way. Establishment of a minimum depth of casing requires consideration of the filtering ability of the formations above the aquifer.

The design of a well should be based on four factors:

1. Probable yield of the well.
2. Types of formations penetrated by the well.
3. Depths and thicknesses of the available waterbearing strata.
4. Proximity of existing or probable future sources of pollution.

Design and construction of a well must be adapted to the geologic and the ground-water conditions existing at the site so as to utilize fully every natural sanitary protection afforded thereby. The installation should be designed to facilitate any supplementary construction that may be required to provide a sufficient and safe water supply.

DESIGN CRITERIA

It is helpful to consider the well structure as consisting of two main elements. One element is the portion of the well that serves as a housing for the pumping equipment and as a conduit through which water flows upward from the aquifer to the level where the pump is set. This is commonly the cased portion of the well, although part of this portion may be uncased where the well is drilled in consolidated rock formations. The other main element is the intake section of the well. Since this is where water enters the well from the aquifer, design of this element requires careful consideration of the hydraulic factors that influence well performance. A well screen is commonly installed as the intake portion of a well that is completed in a sand aquifer. A properly constructed well screen allows water to enter the well freely at low velocity, it prevents sand from entering with the water, and it serves as the structural retainer to support the loose formation material. In a consolidated rock aquifer, the intake portion of the well is usually an open borehole drilled into the rock to an adequate depth. The yield of such a well varies with the number and size of openings that are encountered in drilling the open borehole in the rock.

One of the first steps in well design is selection of the size of the well casing. Well diameter must be chosen to satisfy two requirements:

1. The well casing must be large enough to accommodate the pump with proper clearance for installation and efficient operation.
2. The diameter of the intake section of the well must be such as will assure good hydraulic efficiency.

Choice of proper well diameter is important because it affects significantly the cost of the structure. A well may or may not be the same diameter from top to bottom. After starting construction with pipe of a given size, drilling conditions sometimes make it necessary to reduce the diameter at some depth and complete the lower portion of the well in a smaller size. In deciding on well diameter, the controlling factor is usually the size of the pump that is expected to be required for the desired or potential yield of the well. Well diameter is not usually a major factor in determining or limiting the yield of the well. The diameter of the intake portion may be less than that of the upper part of the well without seriously affecting the efficiency of well operation. The diameter of pipe to be used for the well casing should be two nominal sizes larger than the nominal size of the well pump. To choose the diameter of the casing, then, it is first necessary to estimate the nominal size of vertical turbine pump with capacity corresponding to the estimated yield of well. The optimum well diameter is then indicated as two nominal pipe sizes larger than the estimated pump size. For example, if an 8-inch (203mm) turbine pump is estimated to be required for a possible yield of 500 gpm, the optimum size of well casing is 12 inches (305mm). Cost factors may make it necessary in some instances to select a well size smaller than the optimum indicated here. In such cases, the casing should be at least one size larger than the nominal size of the pump. For example, 10-inch (254mm) pipe is the smallest diameter that will accommodate an 8-inch (203mm) turbine pump with reasonable clearance. Table 1 gives the details of sizes of turbine pumps of best efficiency for various rates of pumpage and the recommended size of pipe for well casing corresponding to each size of pump. A well large enough to accommodate the pump is usually large enough to be hydraulically efficient. Below the maximum anticipated depth of pump setting, the diameter may be reduced, if desired, for cost reasons. This practice is frequently followed in the construction of wells in deep artesian aquifers where the static water level and pumping level do not require unusually deep pump installation.

The expected depth of a well is usually determined from the log of a test hole or from records of other wells that penetrate similar geologic formations in the vicinity. Generally, a water well is completed to the bottom of the aquifer. This practice usually permits developing highest efficiency in terms of specific capacity, because the well penetrates the entire thickness of the aquifer. In addition to this advantage, available drawdown is greater where the well is carried to maximum depth. (Available drawdown is the difference between the static water level and the lowest permissible pumping level.) Poor quality water occurs in some situations in the lower portion of an aquifer. This may dictate completion of the well at some level above the bottom of the aquifer to avoid pumping undesirable water. This condition is encountered most frequently in a coastal aquifer where salt water encroachment may become a problem if the well is not properly designed. In such a case, highest well efficiency is a less important consideration than is protection against contamination of the fresh water in the aquifer.

Table 1—Recommended Well Diameters

Anticipated Well Yield, in gpm	Nominal Size of Pump Bowls, in inches	Optimum Size of Well Casing, in inches	Smallest Size of Well Casing, in inches
Less than 100	4	6 ID	5 ID
75 to 175	5	8 ID	6 ID
150 to 400	6	10 ID	8 ID
350 to 650	8	12 ID	10 ID
600 to 900	10	14 OD	12 ID
850 to 1,300	12	16 OD	14 OD
1,200 to 1,800	14	20 OD	16 OD
1,600 to 3,000	16	24 OD	20 OD

To secure best well performance, the length of the well screen must be chosen in proper relation to the thickness of the water-bearing formation. The length of the well screen (intake section of the well) largely determines the flow pattern in the aquifer near the well. If converging flow toward the well is appreciably distorted from a strictly radial pattern additional head losses develop within the aquifer and in the area where water enters the well. This increases drawdown and decreases specific capacity. The specific capacity of the well is particularly sensitive to distortion of the flow pattern in the vicinity of the well. Selecting a screen of adequate length and proper design minimizes this distortion. In a homogeneous artesian aquifer, the well screen should be 70% to 80% of the aquifer thickness to achieve the practical maximum specific capacity for the well. Designing for maximum specific capacity may not always be practicable when the aquifer is unusually thick—say 30 meters or more—in which case a screen length on the order of 50% of thickness might be chosen. In a stratified artesian aquifer, the relative difference in the permeability of the various strata must be considered in selecting the screen length. The relative permeability can be estimated from either laboratory permeability tests or from a study of the grain-size curves of samples representing the respective strata. The well screen should be of such a length as will correspond to 80 to 90% of the thickness of the more permeable strata within the aquifer.

Selection of a screen for a water-table aquifer requires the exercise of more judgment on the part of the engineer than in the case of an artesian aquifer. Pumping from a water-table aquifer always produces a distorted flow pattern around the well. This occurs inevitably because the operation of the well necessarily dewaters that part of the aquifer which is within the cone of depression surrounding the well. The saturated thickness of the formation within the radius of influence of the well then becomes less than the normal aquifer thickness. Theoretically, maximum total yield will be obtained from a water-table aquifer when the well screen length is one-third of the aquifer thickness and the well is pumped with the drawdown equal to two-thirds of the thickness. In practice, it may not be desirable to maintain the pumping level as low as this criterion would indicate. A screen length from one-third to one-half of the thickness of the aquifer is a practical choice in most cases. Stratification of a water-table aquifer also influences the selection of screen length because of the difference in permeability of the strata making up the aquifer. In many cases, the lower part of the aquifer is the more permeable. If the more permeable stratum makes up as much as one-third of the total thickness of the aquifer, a screen length about equal to the thickness of the more permeable stratum will produce best and most economical results.

Selection of the size of well screen openings is made from a study of the grain-size analysis curves. Where the well is to be naturally developed, openings of a size that will retain 40 to 50% of the formation material, by weight, is the best choice in most situations. In completing the well, the finer fraction consisting of sand particles smaller than the screen openings are brought into the well by the development operation. This fine material is removed from the well as a part of the work of completing the well. The development is continued until little or no fine sand comes through the screen, and until the formation has become stabilized around the well screen sufficiently to insure sand-free operation. Selection of well screen openings where an artificial gravel envelope is to be used around the screen is made from somewhat different criteria. Situations that favor artificial gravel-pack construction include wells in fine, uniform, sand aquifers, poorly cemented sandstone aquifers, and formations consisting of several differing strata of unconsolidated materials. The artificially graded gravel pack consists of fine gravel or coarse filter sand which is placed in an annular space around the well screen. This construction is used in lieu of a naturally developed gravel envelope. The proper grading of the artificial gravel pack is determined by choosing a size that will control the fine sand of the water-bearing formation and prevent movement of this sand through the gravel envelope. The first step in the design of a gravel packed well is to prepare grain-size analysis curves of samples of the formation material. A gravel that is relatively uniform in grading and of grain size 4 to 6 times larger than the sand of the water-bearing formation will usually assure a sand-free well. The size of screen openings to retain the artificial gravel envelope should be such as will retain 90% or more of the gravel. The criteria for selecting the proper length of well screen for an artificially gravel packed well are the same as those for a naturally developed well.

After the conditions already described for selecting the well screen have been satisfied, the entrance velocity of the water through the well screen openings should be checked. It is calculated by dividing the pumping rate by the aggregate open area provided by the well screen openings. Experience and research have shown that the entrance velocity through the well screen openings should not exceed 0.1 feet per second. At this velocity, laminar flow in the material immediately surrounding the well screen and through the screen openings can be assured. Also, the head loss or additional drawdown attributed to the flow through the well screen openings will be less than 0.1 fps. In addition, the possibility of precipitation of dissolved minerals that may be found naturally in the ground water is minimized. This is because high velocity and concomitant high head loss tend to aggravate the tendency for dissolved minerals to precipitate. These will clog the well screen and the pores of the water-bearing formation immediately adjacent to the screen. If the well screen initially chosen does not provide sufficient open area to keep the entrance velocity to 0.1 feet per second (30 mm per sec), an adjustment in the screen should be made in order to meet this criterion. Usually this means increasing the diameter or the length of the screen since the size of the screen openings is dictated by the grain size of the water-bearing formation. Different types of well screens provide different amounts of intake area per square meter of screen surface for a given size of screen opening. The continuous-slot type of well screen provides the largest amount of open area for a given size of opening. At the same time, the continuous-slot screen has adequate strength to resist the stresses involved during installation of the screen and development and operation of the well.

The last design feature considers the life of the well which is largely influenced by the chemistry of the ground water and the durability of materials used in the well structure and its appurtenances. Usually a well is designed to last a minimum of 25 years. Since many ground waters are somewhat corrosive to ordinary steel, corrosion damage could cause steel components to fail in considerably shorter time. Well components most susceptible to corrosion damage are best made from corrosion-resistant materials, therefore, to insure adequate service life. These are the pump shaft, pump impellers and well screen. The shaft is normally made of stainless steel and the impellers of bronze. Well screens are made of any kind of material, but type 304 and type 316 stainless steel are the preferred materials of fabrication. For less corrosive environments screens fabricated of brass, silicon bronze and iron are often used. Usually, materials for all susceptible components are selected after study of a chemical analysis of the water to be pumped. The pH, alkalinity, calcium hardness, iron, manganese, temperature and total dissolved solids are the principal factors and constituents that are considered. The well casing is almost always mild steel pipe. If the water is exceptionally corrosive, pipe of heavier than normal wall thickness can be used to extend the life of the casing.

LOCALIZED CORROSION-EROSION IN PUMPS

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Appreciable turbulence may be created in water flowing at a sufficiently high velocity. Intense localized corrosion may then occur from the combined action of corrosion and mechanical abrasion. The result is corrosion-erosion which includes both impingement attack and cavitation. At high velocities, suspended solids or gas bubbles can create corrosion-erosion and impingement. Still higher velocities produce cavitation. A small amount of general turbulence only leads to serious attack when the resistance to corrosion is generally low. Impingement attack is produced by the break-up of large entrained gas bubbles in the water. It can be produced without gas bubbles when the water velocity is very high, by suspended particles or by turbulence alone. Cavitation attack occurs under conditions of turbulent flow of the water. Vapor-filled cavities are formed and collapsed by sudden changes in pressure and by vibration.

The main cause of damage is mechanical but the impact of liquid, vapor and solid tends to keep the affected surfaces free from any product or protective film and hence encourages corrosion. Both impingement and cavitation attack can be reduced by keeping the absolute pressure as high as possible to restrict the release of gas bubbles. Pump impeller blades and diffuser vanes and also the inner walls of the column pipe and outer walls of the protective tubing may be subjected to corrosion, erosion, impingement and cavitation attack. These four kinds of damage can easily be distinguished by observation and relative of the affected parts in the flow passages. The places attacked by cavitation are somewhat displaced in direction of flow, in relation to the place where the vapor bubbles burst.

IMPINGEMENT

Impingement occurs when a turbulent aerated water stream impinges against a metal surface. With non-resistant materials it can occur at water velocities as low as 3 ft/sec, although generally it occurs when water velocities are 6-12 ft/sec. Local breakdown of a protective layer on the metal is caused by gas bubbles, or suspended solids or by turbulence alone. The entrance to pipes, sharp bends, abrupt changes in cross-section of the flow stream, deposits, etc. induce impingement attack. The force with which large gas bubbles strike the metal surface and break up into smaller bubbles releases sufficient energy to disrupt any film or corrosion product. With removal of the protective film or product, a small area is rendered anodic to the adjacent areas and suffers rapid corrosion. Oxygen in the air bubbles may also act beneficially in helping to keep any oxide film repaired. Thus the corrosion potential may move in a negative direction indicating mechanical destruction of the film or in a positive direction indicating film repair.

Impingement impacts often keep occurring at the same points on the surface. The attack by air bubbles produces smooth-sided pits with a sharp-edged appearance and usually a freedom from corrosion deposits. The pits are deeper and often undercut on the downstream side, and are either tear-drop in shape, or in the form of horseshoes if the turbulence is produced by particles of matter on the metal surface. These are oriented to give the impression of a horse walking upstream.

CAVITATION

Cavitation is basically a dynamic action within a liquid and begins to occur when the liquid flows through a zone where the absolute pressure is below the vapor pressure of the liquid corresponding to the operating temperature. Small vapor-filled cavities form and grow within the liquid during the movement through the low-pressure zone. The vapor suddenly condenses upon arriving at a higher pressure zone and the cavities collapse with great rapidity. The fluid molecules of the vapor and the boundary layer of the surrounding liquid then rush together at high speed, again forming cohesive continuity of the liquid. The impact of these molecules upon each other, in the case of large cavities, is so great that the molecules rebound and reform usually smaller cavities which again collapse further downstream. Formation and collapse may occur several times before the energy is absorbed.

The destructive power of cavitation comes into play when the cavities form near and collapse against the wall of the material in or around which the water flows. The molecules at the collapsing cavities bombard the wall with such rapidity and intensity of impact that the microscopically fine structure of the surface finally cracks under the strain of local pressure and vibrations. Small particles break out of the wall materials, then larger bits. The surface becomes rough, then honeycombed with holes or pits. The pitting creates more conditions favorable to more cavitation so that the pitting may spread over wider areas while the earlier formed pits grow perhaps to large holes through the wall of the material.

The cavitation cycle repeats many thousands of times. Ductile material by this action may resist erosion for a period of time, but breakdown of large areas that take on the appearance of hard hammered surfaces eventually occurs. If the metal is brittle and of relatively low strength, such as cast iron, the appearance of pitting will be quite pronounced. If the material is dense and with high fiber strength, there will be only a roughening of the surface.

Cavitation may be initiated by:

1. Too low a pressure in relation to the vapor pressure of the pumped liquid at the prevailing temperature which occurs with an excessively large suction head or with too small a submergence head.
2. Increased velocity of flow and the pressure drop connected with it after the normal discharge rate has been exceeded.
3. Incorrect shape of the streamlines and sudden changes in the direction of flow, sudden expansion of passages and bad conditions of approach.
4. Vibration of parts in contact with water without apparent local drop in pressure due to high velocity flow. Water is unable to follow the frequency of a vibrating body and at each reversal of the deflection, vapor-filled cavities are formed between the water and the vibrating body and these collapse upon reversal of the deflection.

Reduction of pressure to the vapor pressure of the liquid does not simultaneously produce a vapor phase in this region. The point of vapor inception lies below the point corresponding to the vapor pressure. Differences in the pressure levels of the vapor pressure and the inception of the vapor phase depend on the stability and nucleation characteristics of the individual liquids. Cavitation symptoms only occur when the static pressure falls below the vapor inception point, since a certain time must elapse before a significant vapor phase develops, that is, the particles of flowing liquid must remain in the low-pressure region for a sufficient length of time.

Cavitation research has shown that the efficiency of the pump increases slightly just before cavitation sets in, owing to the formation of a few small vapor bubbles at the beginning of cavitation, which reduces the friction losses. At the incipient stage of cavitation the collapse of the bubbles terminates within the impeller passages. In the fully developed stage of cavitation the main part of the vapor bubbles collapses in the impeller itself and the rest are carried out of the impeller into the intermediate casing, and even into the next stage in a multistage pump where they collapse and cause cavitation pitting.

Cavitation damage occurs not only on the blades of the impeller but also on the shrouds. The places with the lowest pressure are situated on the back faces of the blades near the inlet edge. In this region there is a sudden increase in velocity, which favors the development of cavitation. When cavitation is intense, the tips of the blades at the outlet and the diffusion vanes may also be damaged. In pumps with open impellers and propeller pumps, cavitation pitting appears near the inlet edges of the impeller blades; on the top of the blades in the vicinity of the casing and on the inner wall of the casing (this is known as marginal cavitation); and on the inlet edges of the diffuser vanes (this phenomenon is usually due to incorrect shape of the patho of the streamlines).

In handling liquids containing dissolved gases, the pressure at or near the suction vanes of the impeller may be reduced sufficiently so that the dissolved gases are liberated and the pump is actually handling a gas-and-liquid mixture. If the amount of gas liberated is not excessive, the only effect may be a reduction in capacity output and efficiency. This separation of gas from liquid is often mistaken for cavitation; it is not. If both cavitation and gas separation occur in a pump, the cushioning effect of the gas often quiets the cavitation noise. The cushioning effect has sometimes been used to quiet noisy cavitating pumps by bleeding air into the suction. Although it serves as a temporary expedient, the most economical solution should be replacement of the impeller by a design suitable for the suction conditions or a redesign of the pumping system so that the pump has sufficient suction head to operate on its normal characteristics. The diagnosis may be checked. Throttling the pump discharge will reduce pump capacity and possibly restore pump operation to a range in which sufficient suction head is available at the pump suction. If this step eliminates the crackling noise, the diagnosis is correct.

Cavitation manifests itself by a sudden reduction in the total head and efficiency, accompanied by noise and vibration. The noise is produced by collapse of the vapor bubbles at the moment when they enter the region of high pressure. The vibrations of the pump are caused by the vibrations of the walls of the metal parts attacked by bursting and rapidly condensing bubbles. The larger the pump, the greater are the noises and vibration. Although these phenomena may occur within the range of normal operating conditions of the pumping installation, cavitation is more likely to develop the more the flow conditions depart from the normal ones, corresponding to the best efficiency point on the complete characteristics. Break-off or cut-off of characteristic curves occurs in various ways, the shape of the break-off depending, above all, on the *specific speed of the pump.*

The resistance of materials to cavitation depends both on the chemical composition and on the method of machining, and in particular, on the smoothness of the surface. The behavior of metals subjected to cavitation is similar to that of metals exposed to corrosion. All sorts of notches, flaws, cracks and scratches facilitate and accelerate the destruction of the material by cavitation. Surface hardening increases cavitation resistance, although the hardness itself is not the deciding factor as far as the resistance to cavitation is concerned. Protective coatings which adhere tightly and are properly applied may improve the resistance of metal surfaces to cavitation.

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PLANNING FOR MUNICIPAL WATER SUPPLY FROM SURFACE WATER RESOURCES

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Surface waters in lakes and rivers have provided water supplies for man's communities since ancient times. Rivers such as the Nile, Tigris, Euphrates, and Tiber provided, in addition to water supply, irrigation and transportation, arteries for the civilizations which grew up on their banks. Highly organized societies with strong central organization were needed to conceive, build, operate, and maintain extensive systems for controlling and collecting water. When civilizations fell or become disorganized, the systems fell into disrepair and communities had again to resort to more primitive means of obtaining water supplies. It was not until a few hundred years ago that the accomplishments of ancient times could be equaled or exceeded.

New materials, new sources of energy, better understanding of hydrologic processes, and new capabilities for purification allow us, as engineers, to provide water supplies adequate for almost any conceivable urban situation. As a result of this relatively new capability, cities need not be located near their source of water supply, nor need their growth and economic activity be limited by the immediate adequacy of their water supply.

Although engineers may have the capability to provide water supplies under the most adverse circumstances, as planners they often have a tendency to ignore concepts of resource utilization and conservation to concentrate on design details. The water-supply engineer, when planning the extension of an existing system or the development of a new system sometimes fails to consider such basic questions as:

Should urban growth in a particular area be encouraged by provision of a bigger water supply?

Have the most economical resource and scheme of development been selected through comparison with alternatives?

Will the proposed scheme of resource development be in conflict with another present or potentially more desirable use?

Can other beneficial uses be made of the water resource in addition to water supply?

Will the proposed water resource be diminished in quantity or degraded in quality by prospective upstream uses?

Does the proposed system provide a cheap short-range solution that forecloses on a solution that would be more economical in the long run?

Most urban water resources uses have been planned in a non-integrated, non-comprehensive, and single-purpose manner. This happened because engineers have considered water supply planning to be comprised of pipe system layout and pump selection.

Rapidly growing, and often competing, demands for water supply, waste disposal, agriculture, navigation, flood control, power and recreation make it necessary that uses, allocations, and development of resources be comprehensively planned. In the field of municipal water supply, quantity demands are increasing at an accelerating rate because of population growth compounded by ever increasing per capita use. The improvement of a piped municipal water supply itself creates an increase in demand as people's water-use habits change. None of our water resources, surface or ground, are so large or unlimited that comprehensive planning for their use is not necessary.

OVERVIEW OF THE PLANNING PROCESS

Planning for sound resource development must be carried out in a systematic manner. A step-by-step procedure is summarized below:

1. Design the planning study program. Although it may appear obvious, it is very important to decide what is to be done before starting. What are the objectives and what are the data, procedures, schedules, and budget? Most importantly, what agencies or people should be involved from the beginning because they will either influence or be influenced by the ultimate development?

2. Establish the need for water at present and the rate of growth of needs in the future.

3. Identify and assess the alternatives of water and related resources, reservoir sites for example, in terms of quantity and quality.

4. Determine the type and size of facilities and the type of treatment required for development of each of the alternative resources.

5. Identify and assess potentials for other uses of the resource and whether such other uses are competing or compatible.

6. Determine the cost of construction, operation, and administration of alternative systems, including the costs and benefits of multiple-purpose uses.

7. Select a course of development through comparison of economic costs and benefits and intangible considerations associated with each of the alternatives.

8. Establish a schedule of development and financing and recommend an administrative structure for management of the system.

ASSESSMENT OF RESOURCES

In most cases, alternative basic water resources are available and should be given consideration. The possibility of use of an alternative ground-water resource must be considered in the process of evaluating potential alternative sources of supply. Several alternatives of surface water development may exist. The planner who feels that the selection of the basic resource is obvious should at least pose to himself the question, "If the obvious resource did not exist, what would be the source of water?" A combination of resources is often used.

In the assessment of the adequacy and quality of basic water resources, it sometimes happens that ground-water potentials are overlooked because data on well yields and aquifer sustained yields may not be as readily available as are comparable data for evaluating the alternative surface water resources. Collection of ground-water data is also generally more expensive than collection of surface water data. The planner or engineer should assure himself that inadequacy of information on ground water is not what leads him to the selection of the surface water alternative. The extra cost of investigating the ground-water resource may be saved many times over if the ground water turns out to be a more economical resource.

River flows vary in quantity and quality from day to day, season to season, and year to year. If the lowest flow of the river exceeds the maximum water supply requirement, development of the river as a water supply source may be merely a matter of withdrawing the water and treating it. However, it is more frequently the case that the water supply requirement, or the combination of uses of the river, exceeds the low flow of the river. In this case, some means must be provided for storage of surplus flood waters for use during the low-flow season.

The potentials for water storage are an integral part of the assessment of a river water resource. Storage reservoirs may be created by damming the river if topographically suitable sites exist. It may also be possible to store water in an off-channel reservoir to which flood waters are directed either by gravity or by pumping. Such reservoirs can be created by construction of ring dikes on flat land or by damming tributary valleys. Off-channel reservoirs often have advantages over conventional on-stream reservoirs in that they often may be filled with water of selected quality, they are less subject to loss of space due to sediment accumulation, and they do not require costly spillway construction.

The amount of storage volume required in order to regulate the supply rate to any desired minimum can be readily determined using observed or hydrologically synthesized streamflow records. Of course, it is not possible to regulate streamflow to a minimum equal to or greater than the long-term average streamflow. Graphical methods based on mass curves were commonly used for determination of required storage for given draft rates until electronic computers came into common use. Graphical methods continue to be used for gaining initial perspectives.

The electronic computer makes it possible to simulate or model the river-reservoir system under a variety of hydrologic and operational conditions. Reservoir site characteristics are represented by volume-elevation and area-elevation relationships. The streamflow variations may be represented by an observed record or by a stochastically extended record derived from the statistical characteristics of the observed record. Operation of the reservoir is represented by a simple bookkeeping program relating inflow, change in storage and outflow with adjustments for evaporation and rain on the reservoir. Additional considerations such as hydroelectric power generation potential can be readily incorporated into the program. The results of computer operations for a variety of conditions can be assembled to provide relationships of draft rate, reservoir volume, and frequency of shortage. The finally selected storage volume must be increased to provide for storage of sediment. General practice in the United States is to provide for 100 years of sediment accumulation before encroaching on active storage.

Assessment of river potentials for water supply, with or without storage regulation, is based primarily on the historical flow and sediment transport record. This record should be reviewed to determine if any changes have been imposed on the river's performance during the period of record, such as diversions for irrigation or major changes in land use in the watershed. Consideration should also be given to prospective future changes in the river's regimen. If changes in regimen have occurred or are expected, the record should be adjusted to represent conditions during the period that the water supply project will be in operation.

Water supplies may often be obtained from fresh water lakes which are, in effect, large reservoirs and should be analyzed as such. As with a reservoir, the withdrawal rate cannot equal or exceed the average rate of inflow to the lake. A particular problem with the use of lakes is that the using community is frequently located in the watershed of the lake which may be used for waste disposal as well as water supply. These two uses are not necessarily incompatible but obviously considerable care is required in management of the lake for both purposes.

QUALITY OF WATER

The major costs in developing a surface water resource are in storage and conveyance facilities and in facilities for water treatment. In comparing alternative water resources, particularly surface and ground water, the variation in costs for required treatment may exert substantial influence.

Ground waters are usually filtered by their environment and, as a result are free of suspended matter and pathogenic organisms. If mineral content and hardness are low, chlorination may be the only treatment needed. Surface waters are ordinarily lower in hardness and other dissolved minerals but are usually higher in suspended minerals and organic materials and pathogenic organisms. Coagulation and filtration are generally needed and special treatment for removal of color and odor may be required. Treatment costs of surface waters may possibly be reduced by selective withdrawal from different elevations in the reservoir and by withdrawal from flowing streams at seasons when dissolved minerals or suspended sediment may be at a minimum.

Two other water quality considerations should be taken into account. One is the possible effects on water quality and costs of treatment which may be caused by additional uses of the storage reservoir, particularly for recreation. Attitudes and practices in the United States range from total exclusion of any other uses of the reservoir to unrestricted use for recreation and fishery. Exclusion of other uses seems to prevail mostly in areas where historically water was used directly after withdrawal from reservoirs without treatment. Even though treatment, at least chlorination, is universally applied, the tradition of reservoir sequestering is still prevalent in some of these areas. Another water quality factor which must be considered, especially in tropical areas, is the possibility of excessive growth of aquatic weeds, particularly the floating varieties such as the water hyacinth. Growth of these weeds can increase explosively to the point of completely covering the reservoir water surface. Not only do the weeds interfere with recreation and fishing on the reservoir and clog intakes and gates, but also greatly increase reservoir evaporation losses and provide a habitat for disease vectors. Since water hyacinth and similar weeds are usually introduced by individuals who do not understand the hazard they present, careful surveillance on transport of plants is important. Colonies of weeds can be economically destroyed by chemical treatment if they can be caught before they grow large. Therefore frequent inspection of reservoirs, particularly along the shoreline, is highly desirable.

COST OF RESOURCE DEVELOPMENT

Determination of the cost of development of a water supply source serves two purposes. The first is to provide a basis for selection between alternatives and the second is to prepare a basis for arranging the financing of the project. Ordinarily several cost estimates of varying levels of detail will be made during the process of selection and planning. Cursory estimates are made in the first reconnaissance to establish rough costs for the first comparison of alternatives. More precise estimates are made as the basis for final selection among alternatives and an estimate aimed at complete reliability is made for financing the finally selected alternatives.

Costs for surface water resource development include acquisition of land for reservoirs and pipelines; relocation of roads, pipe lines, electrical transmission lines and other utilities in the reservoir area; construction of dams, pumping stations, treatment plants and pipelines; operation costs including labor, chemicals, and power; and costs of financing.

Alternative water resources systems may range from those with high construction and low operation cost to others with low construction cost and high operation cost; also development may require initial construction of more capacity than is needed immediately such as reservoirs and pipe lines, while others may be suitable for staged construction where capital investments are made in smaller increments over a long period of time.

Techniques of economic comparison based on the time value of money are used to make comparisons of projects with such varying types of costs and schedules of investment. The basic concept of the time value of money is that receiving an amount of money right now is worth more than receiving that same amount at some time in the future. In the same manner the investment of a given sum of money right now is more costly than that same investment at some time in the future. This variation of value with time is expressed by means of the interest or discount rate.

Use of an interest rate allows the determination of the value today of a cost or benefit which will occur in the future. This "value today" is known as the present worth of a cost or benefit. The present worth becomes smaller with increasing interest rates and with increasing length of time. It is also possible to express annual costs for maintenance and operation as an aggregate present worth. Present worth can be readily converted into an equivalent average annual cost over the project life. In this way a consistent and fair comparison can be made of alternatives which vary in the ratios of capital and operational costs and have dissimilar schedules of costs and benefits.

If all projects for development of water supplies provided exactly the same service, the selection between alternatives could be based on a simple comparison of present worth or average annual costs. However, it frequently happens that one or more alternatives may, by their nature, provide additional services or benefits - for example, hydroelectric power generation at a reservoir site. One way that the value of these associated benefits may be incorporated in the comparison is by reducing the economic cost of that alternative by the economic value of the benefit.

POTENTIAL MULTIPLE-PURPOSE USE

As noted above, projects for development of surface water resources frequently have intrinsic values for other purposes in addition to water supply. These other purposes allow for more economical development of the resource through the sharing of joint costs. One of the ways commonly used for the allocation of the joint costs of a multiple-purpose project—for example, the dam and reservoir — is to share the joint costs in proportion to the benefits remaining for each purpose after subtracting the separable costs for that purpose. Separable costs of water supply might include the cost of treatment facilities and pipe lines which do not contribute to any of the other project purposes.

Unfortunately, it has been the tradition in urban areas of the United States that water supply developments tend to be planned and developed on a single-purpose basis. To some extent this is the case because separate agencies have responsibilities for water supply, waste water management, flood control, recreation, and power. A new trend is developing, however, in which land use and natural resource planning for urban and urbanizing regions is being carried out in a comprehensive, multiple-purpose manner by regional planning agencies.

Rarely can a surface water supply reservoir serve two or more purposes without any conflict or without some extra cost to the dam and reservoir. Hydroelectric power can often be developed at a water supply reservoir. However, lowering of water levels may interfere with the head required for power generation, or the daily fluctuations in power generation may require that re-regulating storage be provided downstream.

Storage reservoirs can often provide flood control. When the major floods are caused by snowmelt, and are, therefore, very predictable, it may be possible to accomplish both flood control and water supply at no extra cost because the reservoir can be drawn down prior to the flood season and then refilled by the flood. In this manner, no extra flood storage volume may be required above the volume provided for water supply storage. If floods are unpredictable, the total storage requirement would be greater than that required for water supply alone but often can be provided in one reservoir at less total cost than for two separate reservoirs.

Recreational needs are assuming greater and greater importance in resource development — both to supply a basic need of the public and as a way of enhancing the economy through the development of a tourist industry. Reservoirs often present substantial opportunities for recreation development. Recreation use, however, desires that fluctuations in reservoir level be small, while water supply use may lead to substantial lowering of water levels at certain times of the year or during extended dry periods. One possibility is to compromise by establishing tolerable limits for reservoir fluctuation. As mentioned earlier, there is sometimes a psychological reluctance to allow recreation on water supply reservoirs.

Irrigation use is generally in direct conflict with water supply use because both uses are of a withdrawal nature. Even though these uses, by their similarity, tend to be in conflict, if the basic resource is large enough and if the reservoir size is adequate, economies may be obtained by using one large reservoir rather than two smaller ones.

PLAN SELECTION

Plan selection should be based on an economic comparison of alternatives tempered by judgments of intangible considerations. The economic comparison will account for the variations in capital and operating costs and for the variations between alternatives in staging or scheduling of construction. Economic values should not, however, be the only basis for selection. Present techniques for economic analysis are not capable of incorporating social preferences, political implications, aesthetic values, and other intangibles. These considerations are outside the competence of the engineer and economist and should be evaluated by the public or their representatives.

Such contribution to the selection process can be meaningful only if the participation by representatives of the public has been included in the planning process. Participation by public representatives gives protection from misunderstanding and tends to coopt or disarm potential disruptive individuals, as well as to assure that planning has been responsive to realities of need and setting. Plans in which the public has had an opportunity to participate have high probability of acceptance — those which have excluded public preferences have a high risk of being judged unacceptable or unsatisfactory.

Alternative opportunities for financing may have significant effect on the selection between development alternatives. This is unfortunate because a poor solution may be selected because it can be more readily financed than the best solution. However, financing agencies are recognizing this problem and in addition, are requiring that planning procedures be made more comprehensive, opportunities for multiple purpose use more fully explored, and economic analyses be more complete.

WATER PROJECTS IN SOUTHEAST ASIA

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THE BUREAU OF RECLAMATION

The Bureau of Reclamation was established in 1902 for the purpose of reclaiming the arid lands of the 17 westernmost States of the United States where the annual precipitation pattern is so uncertain and spotty that man-made facilities are necessary to store and distribute available water supplies for irrigation, domestic and industrial uses. Vast areas of the West were empty and unproductive, even though their soils were among the most fertile in the world. Without water they were worthless. Reclamation's mission was to bring water to those lands, settle them with farmers and make them productive. Today, after nearly 70 years of building Reclamation water resource developments in the West, that huge, once empty land has been converted into a great economic asset to the Nation rather than a relatively worthless dependency.

As the face of the West has changed during the Reclamation years, the Reclamation program itself has changed along with it. We are no longer a single-purpose irrigation agency. As the West has become more populated, other factors in water resource development emerged and became more and more important: flood control, navigation, the enhancement of fish and wildlife resources, recreation, community and industrial water supplies, water quality control, and the protection of the environment.

During the evolution from an agency primarily involved in irrigation to an organization fully committed to the multipurpose concept of water resources utilization for the greatest good to the most people, we have developed a broad spectrum of technical and administrative expertise to accomplish our objectives in planning, design, construction, operation, and management of project facilities. Through the program of the U.S. Agency for International Development (AID), various international organizations, and frequently in response to requests of individual governments, we have made this expertise available to many countries of Southeast Asia. The Bureau of Reclamation currently is involved in planning multi-purpose surface water development projects in Korea, Taiwan, the Philippines, Thailand, and Laos. Additionally, we have assisted Australia, Malaysia, Singapore, Cambodia, and Japan. Some of this work has been devoted to comprehensive master planning for the orderly and economic development of the total water resources potential of entire river basins; some to planning single projects such as the Pa Mong astride the Mekong River between Thailand and Laos; and some to evaluating the magnitude of available water resources and estimating future water needs.

ACTIVITIES IN THAILAND

The first Thailand development for which we undertook advisory services was the Chao Phraya Project, beginning in 1951. The project, which is now one of this country's largest irrigation undertakings, supplies irrigation water and controls floods to increase Thailand's rice production by a million tons a year. Chao Phraya Dam, the project's principal structure, was completed and dedicated by the King of Thailand in early 1956.

A second major Thailand project for which the Bureau provided technical assistance was the Yanhee Project. In 1953, a seven-man Reclamation team came to Thailand to make a reconnaisance appraisal of its engineering and economic feasibility. The Royal Irrigation Department had proposed this multipurpose scheme and applied for a construction loan from the International Bank for Reconstruction and Development. Before granting the loan, the Bank required that the project be reviewed by an outside experienced engineering organization. By special request of the Thai Government and with the approval of the Bank, the Bureau of Reclamation served as the reviewing agency. After the loan was approved, private engineering firms were selected to prepare detailed designs, construction drawings, and supervise construction of the project's main structures Bhumiphol Dam and Powerplant. The 154-meter-high concrete arch dam, Southeast Asia's highest, was topped out in 1963 and dedicated by the King of Thailand in May 1964. The dam and its large hydropowerplant have had a profoundly beneficial influence on the economy of Thailand.

ACTIVITIES IN TAIWAN

The Bureau of Reclamation has also assisted with water resource development projects in Taiwan. In 1953, a team of Reclamation engineers visited this island country and inspected the Wu-Sheh damsite as part of a preliminary evaluation of the feasibility of proceeding with construction of the dam. Subsequently, the Bureau assigned experts to assist with investigations, perform laboratory tests on construction materials, and advise on construction of the dam.

In response to a request from AID, in January 1964, a five-man Reclamation team made an on-site review of the Tsengwen Reservoir Project investigations being conducted by the planning staff of the Taiwan Provincial Water Conservancy Bureau. The following year the Conservancy Bureau, with assistance from our review team, prepared a project feasibility report. The Taiwan Provincial Government accepted the report and designated the Tsengwen Reservoir Development Commission to administer construction of the island's largest rockfill dam, with the actual construction being done by the Retired Servicemen's Engineering Agency of Taiwan. Detailed design work is being done by Nippon Koei of Japan, and a second five-man Reclamation team remains in Taiwan in an advisory capacity. Tsengwen Reservoir will supply irrigation water to 85,000 hectares of land and domestic, municipal, and industrial water to more than a half million people. An adequate supply of good water for domestic use will be a great asset to the villages, towns and the city of Tainan. It will contribute substantially to improving health conditions.

ACTIVITIES IN THE PHILIPPINES

At the request of the Philippine Government and the Agency for International Development, a Reclamation team of engineering planners was assigned to the Philippines in April 1963 to study possible multiple-purpose development of seven major river basins on the islands. Four of these river basins are on the Island of Luzon, two on Mindanao, and one on Negros. As part of the work, a contract was awarded to a private firm for aerial photography and mapping of the reservoir sites and watersheds. The investigations were concluded in November 1966 and disclosed that the substantial need for irrigation, domestic, municipal, and industrial water supplies could be met from reservoir storage.

There were sufficient data available in one of the potential areas of development, the Upper Pampanga River Project in Central Luzon, to justify the preparation of a feasibility report. The Bureau completed and published the report in September 1966. The National Irrigation Administration of the Philippines is now proceeding with detailed design and construction of this project with a loan from the World Bank. A consulting engineering firm is designing the Pantabangan dam for the project. Included in the plans is an allocation of 10,000,000 cubic meters of storage capacity in Pantabangan Reservoir to serve the estimated municipal and industrial water requirements of the area through the year 2010.

ACTIVITIES IN KOREA

A Reclamation team has been in Korea for about four years, under AID sponsorship, assisting the Korean Government in planning for multiple-purpose development of the Han River Basin. The basin, Korea's most important watershed, covers a quarter of the country and has a quarter of its population. About 50 percent of the Korean industrial production comes from the Han River Valley. Seoul, the capital and largest city of Korea, lies along its banks. Of the nearly 8 million people in the basin, about 6.5 million reside in and near the capital city. Although several single-purpose power dams have already been built and others are planned, the Korean Government realizes the necessity for re-evaluating the overall potential of the basin and developing future projects to serve all aspects of water needs.

The average flow of the Han River at Seoul is 18 billion cubic meters annually, or about 50 million per day. The minimum recorded flow is 95,000 cubic meters per day, which is grossly insufficient to meet present requirements. The area's 1965 estimated daily need for domestic, municipal, and industrial water supplies was 510,000 cubic meters. Five times that requirement have been forecast for 1990. Regulation of the river's flow is essential if these needs are to be met. The completed studies will outline a plan for obtaining the necessary, constant, dependable supply of water.

MEKONG RIVER STUDIES

Additionally, the Bureau has for some time been engaged in cooperative studies in the Mekong River Basin under the auspices of AID. Earlier studies included reconnaisance investigations of projects on the Mun, Chi and Yang Rivers which are tributary to the Mekong. Capacity allocations are needed in the potential storage reservoirs to help supply dry-season irrigation requirements as well as domestic, municipal, and industrial water needs. Return flows from the irrigated land would increase flows in the river channels during the dry season to add to supplies for such needs in downstream areas. Reconnaissance investigations revealed the advisability of proceeding with further studies of a number of projects in the three basins.

Since the area involved is contiguous to the Pa Mong service area and it appeared that, if needed, future supplemental water could be supplied from the Pa Mong reservoir, the Bureau was requested by AID to coordinate continuing studies for the projects until the planning work is completed. The Bureau prepared the specifications for the feasibility investigations, negotiated the contract with a consulting engineering firm, and is now administering the contract. The engineering firm is preparing feasibility grade designs and cost estimates for five storage dams, two diversion dams, and one powerplant that have been proposed. The firm is also performing special studies in the fields of hydrology, sedimentation, economics, crop water requirements, land use, power generation and cooperative plans for multipurpose use of project facilities. Using results of these studies, the Bureau will refine its plan formulation which will identify the facilities to be included in the final, recommended project plans.

Reclamation's largest activity in Southeast Asia is investigation of the proposed Pa Mong Project, a key mainstream development on the Mekong River. Our first involvement in the project was 15 years ago when a reconnaissance survey of the river by a Reclamation team disclosed that the site had development possibilities warranting investigation. Responsive to a 1961 request of the Lower Mekong Coordinating Committee, the United States agreed to perform a comprehensive feasibility study of the Pa Mong Project. An 8-year, 3-phase program was outlined with the understanding that Phases II and III would be undertaken only if the preceding phase showed favorable findings. On behalf of AID, the Bureau of Reclamation launched Stage I in the summer of 1963. These studies indicated sufficient likelihood of a feasible project to warrant further and more detailed investigations. On the basis of the Bureau's recommendations, Phase II studies were then undertaken. Its objectives were to bring the studies to reconnaissance standards, defined as generalized estimates of costs and benefits including irrigation, power, flood control, navigation, municipal and industrial water, and reduction of salt water intrusion in the Mekong delta.

It was obvious from the outset that a complete Phase II investigation would be a very time-consuming process, particularly in view of the vast area to be explored to delineate the irrigable lands which could be served from Pa Mong reservoir. Therefore, part way through the Phase II program, AID/Washington submitted to the Bureau a set of ground rules to further refine, and focus into a more logical time frame, the objectives of the study. We, in turn, agreed to prepare a feasibility report on Stage I of the project.

Stage I is described as follows: "The first stage is expected to be the smallest viable component that constitutes a financeable construction start. It ought to be a package that can stand on its own financially, yet be capable of later expansion — in stages — to ultimate project size.... Basic requirements are that Stage I be economically feasible, capable of sustained operation and maintenance, and that there be reasonable prospects that it is financeable." It is our view that staged construction of a dam across the huge Mekong River, although not impossible, would be impracticable. On the other hand, power installations and irrigation facilities are readily adaptable to staged construction. Thus, Stage I facilities would include Pa Mong Dam, located 20 kilometers upstream from Vientiane, Laos, and the Nam Lik and Nam Mong Dams on tributaries of the same names at distances of 69 kilometers north and 48 kilometers south of Pa Mong Dam, respectively. These three dams, together with associated dikes, would form a single reservoir with a storage capacity of about 107 billion cubic meters at the top of normal active water surface elevation of 250 meters.

Preliminary designs of Pa Mong Dam call for a concrete gravity structure with a height above streambed of 115 meters and a crest length of 1360 meters. The spillway would be a gated overflow section over the center of the dam. An outlet works with a capacity of 700 cubic meters per second would allow minimum river releases. Nam Lik (in Laos) would be a concrete arch dam with a height of 93 meters above streambed. It would be about 435 meters long at the crest. A river outlet works with a capacity of 35 cubic meters per second would be included but no spillway or power plant is contemplated. Nam Mong Dam in Thailand would be earthfill, about 70 meters above streambed, with a length of 2,000 meters at the crest. Irrigation diversion would be through a combination outlet works and river diversion tunnel.

The Pa Mong Stage I project is feasible from the standpoints of engineering and economics. This conclusion is reached on an isolated-project basis instead of visualizing Pa Mong operating in concert with other developments on the river. The downstream benefits that will accrue from Pa Mong will make the project even more attractive than on an isolated project basis. However, data were not now available to establish quantification of these downstream benefits. The Amplified Basin Plan now being prepared by the Economic Commission for Asia and the Far East will provide more specific data on how the Pa Mong Project would fit into a basin-wide operation.

CONCLUSION

The foregoing comments exemplify the Bureau of Reclamation's participation in water resources development in Southeast Asia. We are proud to have had a hand in providing solutions to this area's increasing requirement for water at the time and locations it can beneficially serve the people. This has been a gratifying experience. We are glad that we have been able to assist with these important and necessary development projects and look forward to continued cooperative efforts assisting with the development of the water resources of Southeast Asia and elsewhere.

WATER QUALITY MANAGEMENT

NEW IDEAS FOR EVALUATING PUBLIC WATER SUPPLIES

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A public water supply can be either a natural resource of great benefit to the consumer, or a vehicle by which disease organisms or toxic chemicals can be widely distributed. The public has no way of directly protecting its own water supply. Public health and waterworks officials must exert constant vigilance to insure continued safe water production and distribution by completing regular evaluations of existing public water supplies and thorough study of proposed installations.

The evaluation of a public drinking water supply appraises the origin, treatment, distribution, and storage of water, and the bacteriological, physical, chemical, and radiochemical qualities of the water as it flows from the tap. The "Manual for Evaluating Public Drinking Water Supplies," the basis of this discussion, recommends procedures for surveying and evaluating a water supply and describes the elements of water treatment generally necessary to ensure the production of water that continuously meets the requirements of accepted drinking water standards, such as the U.S. PUBLIC HEALTH SERVICE (1962) drinking water standards.

GENERAL EVALUATION

A water supply system is defined to include "the works, auxiliaries for collection, treatment, storage and distribution of water from the source of supply to the free-flowing outlet of the consumer." Proper evaluation of a supply requires a careful study of the source and of the practices and protection applied to the supply. Such studies should include a compilation and evaluation of the following:

1. A field and office sanitary survey of the water and its environment from source to consumer's tap.
2. A description of the system's physical features, including adequacy of supply, treatment processes and equipment, storage facilities, and delivery capabilities.
3. An analysis of 12-months' bacterial and chemical content on water from source, treatment plant, and distribution system.
4. Analyses of operating records.
5. A review of management and operation methods, and of training, experience, and capabilities of personnel.
6. A review of treatment plant and supporting laboratory equipment, including qualifications of personnel.
7. An examination of state and local regulations.
8. A summary and analysis of all pertinent facts.

Health hazards are defined as "any conditions, devices, or practices in the water supply system and its operation which create, or may create, a danger to the health and well-being of the water consumer." Detection of such health hazards requires a careful survey as herein described. The survey should be carried out by, and the report written by, a qualified person (Survey Engineer) who has a technical education in basic sanitary science and engineering and who has a broad knowledge and understanding of the essential features of water purification plants and systems, including their operation and methods of laboratory control.

WATER TREATMENT REQUIREMENTS

Adequate protection by treatment means any one or any combination of the controlled processes of coagulation, sedimentation, absorption, filtration, disinfection, or other processes which produce a water consistently meeting the standards. This protection also includes processes which are appropriate to the source of supply; works which are of adequate capacity to meet maximum demands without creating health hazards, and which are located, designed, and constructed to eliminate or prevent pollution; and conscientious operation by well-trained and competent personnel. The type of treatment required depends on the characteristics of the watershed, the raw water quality, and the desired finished water quality. The production of water that is free from pathogenic organisms, aesthetically satisfactory to the senses, and reasonably acceptable chemically, becomes increasingly difficult when the raw water has a high and varying chlorine demand, contains large numbers of coliform bacteria, or contains high concentrations of dissolved solids, toxic substances, or taste and odor producing substances. When evaluating the ability of a water supply system to constantly produce a safe and satisfactory product, the following factors should be considered.

1. The quality of water produced at times of unusual stress, such as during heavy run-offs, periods of drought, or periods of excessive demand.
2. The quality of raw and finished waters, as determined by laboratory data and sanitary surveys.
3. The purification processes, including the facilities used to apply disinfectants at various locations in the treatment process, and their capacities compared with the capacities considered necessary to meet maximum needs.
4. The minimum residual chlorine concentration in the plant effluent water, when chlorine is used, together with the time that this or greater chlorine levels are maintained.
5. The qualifications of the operators and laboratory personnel, i.e. appropriate training or certification.
6. The laboratory facilities and analytical procedures, frequency and extent of use, and application of data to operational control.

EXTENT OF TREATMENT

It is recommended that all municipal water supplies, whether they be ground or surface water, receive treatment by disinfection regardless of the quality of the water. This procedure provides added protection, in cases of unanticipated contamination of the supply during processing and distribution. When coliform density is used as a criterion for judging treatment requirements, raw waters can be divided into clear and polluted water groups. The coliform densities of raw waters can be expressed in terms of the most probable number (MPN) from the multi-tube fermentation technique, or actual coliform counts determined by the membrane filter (MF) technique.

Requirements for raw water needing disinfection only are:

1. Physical, chemical, and radioactive characteristics should meet the recommended standards. If the water does not consistently meet all these requirements, consideration should be given to providing additional treatment during periodic decrease in quality.
2. Bacteriological Quality.

   Total coliform density should be less than 100 per 100 milliliters as measured by a monthly arithmetic mean.

   When fecal coliform density is used, the above total coliform density may be exceeded, but fecal coloform density should not, in any case, exceed 20 per 100 milliliters as measured by a monthly arithmetic mean.

Requirements for raw water needing treatment by complete conventional means, including coagulation, sedimentation, rapid granular filtration and disinfection are:

1. Bacteriological Quality.

   Total coliform density less than 20,000 per 100 milliliters as measured by a monthly geometric mean or, if fecal coliform density is measured, the above coliform density may be exceeded, but fecal coliform should not exceed 4,000 per 100 milliliters as measured by monthly geometric mean.

   Bacteriological examination of water estimates the hazard due to fecal pollution, and therefore the probability of disease-producing organisms being present. Because tests for the presence of pathogens are time-consuming and expensive, normally occurring bacteria in the intestines of warm-blooded animals have been used as indicators of fecal pollution and, indirectly, as indicators of disease producing potential. The coliforms and fecal coliforms are usually used in making these estimations. Coliforms, as described in Drinking Water Standards, differ in biochemical and serologic characteristics, and in their natural sources and habitat. Some are characteristic of human and animal feces, others subgroups from vegetation, in joint and valve-packing materials, in soils, plant pathogens. All may be found in sewage, run-off and surface waters. The coliform group includes all of the aerobic and facultative anaerobic, Gram-negative, non-spore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35° C.

   All fecal coliforms must be considered indicative of dangerous pollution. The fecal coliform content of a water source more nearly reflects its disease-producing potential than does the total coliform content, determined simultaneously. Nearly all coliforms in fresh feces are fecal coliforms. In sewage, 30 to 40% are fecal coliforms. In aged sewage and polluted water, the fecal coliform fraction decreases with time. In heavily polluted surface water, fecal coliforms are usually 10-35% of total coliforms. Non-fecal coliforms survive longer in water and are somewhat more resistant to chlorine than fecal coliforms or pathogens. Under some conditions, enteric virus survive longer and are more resistant to chlorine than either fecal or non-fecal coliforms

   Under unusual conditions, where the raw water supply contains large amounts of sewage or where there have been mechanical or human failures in water treatment plant operation, waterborne disease may result. Under normal conditions of raw-water supply and of adequate treatment plant operation, however, the pathogenic bacterial and virus content in drinking water is below the infectious level when the Standard Methods coliform test shows no gas in any tube. The paucity of waterborne disease outbreaks supports this view.

2. Physical Quality.

   Color of water should not exceed 5 units.

   Odor: a limit of 5 threshold numbers should not be exceeded.
   Turbidity should remain within a range that is readily treatable by complete conventional means.

3. Chemical Quality.

   Since there is little reduction in chemical constituents with complete conventional treatment, raw water should meet the limits set for potable water.

4. Radioactivity should comply with Drinking Water Standards.

Infectious material, the increasing diversity of chemical pollutants in raw waters, and the many diverse situations encountered in regional and local problems, make it impracticable to prescribe a limited selection of facilities and processes that can effectively handle all problems presented by raw water and its sources. Types of disinfection other than chlorination must be demonstrated to function effectively in all compositions of water likely to be encountered from the source used. If a distribution system is of any considerable length, the disinfection method should provide a residual protection that can be easily measured. Where water sources show continuing quality deterioration or the quantity of water available is not adequate for future demand, the water purveyor should examine alternative or auxiliary sources of supply and should have positive plans to produce adequate facilities and sources.

RECOMMENDED SANITARY REQUIREMENTS FOR WATER SOURCE PROTECTION AND TREATMENT

Ground Water Supplies

Ground water, when available in sufficient quantity, is often a preferred source of water supply. Such water can be expected to be clear, cool, colorless, and quite uniform in character. Underground supplies are generally of better bacterial quality and contain much less organic material than surface water but may be more highly mineralized.

The ground water source should be located a "safe" distance from sources of contamination such as septic tanks, industrial discharges, feedlots, fertilizers, or pesticides. The facilities should be sealed against surface contamination and should be constructed according to accepted specifications and from acceptable materials.

Surface Waters Used with Chemical Treatment, Filtration and Disinfection

Most surface waters require chemical treatment, coagulation, sedimentation, filtration, and disinfection to make them suitable for use as public water supplies. A combination of treatment methods will, if properly carried out, convert a moderately polluted water into a safe drinking water. The limitations of each treatment process must not be exceeded.

The treatment plant site should be well drained and not subject to flood damage or other contamination. The sanitary survey should re-evaluate location, construction, material, processes, chemicals, laboratory controls, and training and experience of personnel.

Efficient disinfection of a water supply with chlorine depends on the type of chlorine residual and the interrelation of such factors as contact time, dosage, temperature, pH, and the presence of suspended material. Free chlorine is a more effective disinfectant than combined chlorine, and kills bacteria and viruses in less time, or in the same time, at lower concentrations than combined chlorine. Both free chlorine and combined chlorine are more effective at low pH values and high temperatures.

Practical plant operation requires higher chlorine residual or longer contact times than those usually indicated by laboratory test because of "demand" material present. The demand can be determined by breakpoint tests which determine the amount of chlorine that will react with ammonia, organic nitrogen compounds, and/or other substances to form combined chlorine before free chlorine will be present. Treatment to obtain a free chlorine residual means the addition of chlorine beyond the breakpoint. A minimum of at least 0.4 milligrams of free chlorine per liter should be maintained in the treated water for an actual contact period of at least 30 minutes before delivery to the first consumer. If combined chlorine (chloramine) is used, the residual concentration should be at least 2.0 milligrams per liter after at least 3 hours of contact before delivery to the first consumer. The chlorine application apparatus, including the chlorine supplying material and equipment, as well as the sampling frequency, quantitative testing procedure, and results should be frequently reviewed.

OPERATION CONTROL

Every water treatment plant producing water for public, domestic use should be under the full-time control of a technically trained and certified supervisor. For certain types of small plants, part-time, trained supervision may be permissible. In such cases, the supervisor should be on call for any emergency and should inspect the plant at least twice each week.

All water quality tests should be made in accordance with currently accepted standard methods. The schedule of laboratory tests followed in controlling the operation of a water treatment plant will vary with the volume and character of the water being treated. For the conventional plant treating lightly polluted water, the scheduled laboratory tests should be sufficient to assure conformance with the bacteriological, physical, and chemical requirements of the Drinking Water Standards. Such tests should include turbidity, color, alkalinity, temperature, pH, hardness, residual chlorine, and examinations for coliform bacteria.

For an evaluation of a plant's operating effectiveness, information must be available on the raw water characteristics named above, and average and range variations in quality, especially after heavy rainfall or at times of high run-off, as well as the finished water's characteristics. Complete records should be maintained and should include equipment, maintenance, and operating data. Data such as the rated capacity of raw and finished water pumps; character, types, number, and reliability of pumps, and other equipment including standby units; average and maximum daily delivery; and maintenance records are important to an evaluation of plant adequacy.

REFERENCE

U.S. PUBLIC HEALTH SERVICE (1962) *Drinking Water Standards*.

THAILAND'S RURAL COMMUNITY WATER SUPPLY PROGRAM

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BACKGROUND INFORMATION

Thailand is located in the heart of Southeast Asia. It's 33,000,000 plus population is predominantly rural, with an average annual increase of 3 per cent. The economy is primarily agricultural, supplemented by fishing, forestry and mining. About 80% of the population is engaged in agriculture, fishing and forestry. Rice is the main crop. Rice and rubber exports alone account for over half of Thailand's exports. Tin is also an important export. Industrial development has been rather modest. Among the factors responsible have been natural limitations of fuel and materials, power and transportation shortages and limited technical knowhow. Although the Government is full or part owner of much of the country's industries today, there is a pronounced shift in emphasis toward encouragement of the private industrial sector.

Health conditions in Thailand have improved markedly in recent years. This is due mostly to the improved control of Malaria and other tropical diseases, better sanitation, and more competent and extensive medical care. Unfortunately infant mortality is still disturbingly high. The other major health problem is water-borne diseases, which have always been one of the major public health problems in Thailand. These diseases reduce the vigor and productiveness of the people and indirectly inhibit rural development.

Traditionally, the people in rural areas have obtained water from unprotected ponds, wells, cisterns and sometimes streams and rivers. Most of these water sources are heavily polluted by human excreta and debris. In many villages, people have to walk considerable distances during the dry season to fetch their water. Since this nonpotable water is difficult to obtain, it is often transported by vendors and sold at a high price. Water, then, a basic necessity for life, costs more in time and money to maintain a minimum basic hygiene than most of the people can afford.

Development programs have played an important part in the recent development of Thailand. In 1961, Thailand formulated a six-year plan as the first coordinated program for economic development of the country. By the end of the plan period (September 30, 1966) almost all sector targets had been achieved. The country is now nearing the final stages of a second plan (1967-1971). This plan was prepared by the National Economic Development Board (NEDB). The goals of the second plan are higher, including an average annual growth in GNP of at least 8.5% in real terms. This second plan specifically recognizes the need for increased spending on potable water supplies. One of the major emphases of the Second Plan is a concentrated attack on current severe regional inequities, particularly the hardships, isolation and lack of opportunity characterizing the Northeast Region. This region and several border provinces in the North are the focus of both a growing agitation and insurgency problem. It is the concern of the Royal Thai Government to bring into these areas a reasonable level of amenities and opportunities (i.e. potable water, roads, schools, health clinics).

A NATIONAL RURAL WATER SUPPLY PROGRAM

Participants

For many years the Royal Thai Government (RTG) has been concerned about the general health of the country's inhabitants, especially in rural areas. Many health projects have been completed and many more are in the implementation or planning stages. Several Thai Government agencies are interested in the proper development and utilization of water resources. The following is a list of these other government agencies and their responsibility within the period of the second development program:

1. *The Department of Mineral Resources*—Responsible for the drilling and developing of an expected 2,850 deep wells in the Northeast areas,

2. *The Department of Local Administration*—Provision of 3000 ponds as water sources, 1000 cisterns, and 15,000 sanitary dug wells for small communities,

3. *The Department of Public and Municipal Works*—In addition to providing and maintaining water supplies to urban areas (pop. of 10,000 people or more) this department has the responsibility for drilling and developing an expected 700 deep wells outside the north-east area, and

4. *The Department of Health*—Responsible for the design and construction of potable water supply systems in rural areas.

These four departments have been allocated funds to carry out their particular programs as shown in Table 1.

Ground water resource development programs have been carried out by several government agencies. In 1955 a *Ground Water Exploration Project* was begun, aided by an American drilling contractor between 1958 and 1961. Recent statistics have been hard to come by, but past statistics show that the total number of wells drilled in Northeast Thailand from June 1958 through September 1968 were 2424, of which 2051 (approx. 85%) were useable. Most of these were provided with hand pumps, and only the larger yield wells were provided with powered pumps. Presently there are approximately 13,000 community dug wells provided with hand pumps throughout Thailand.

Potable water supplies are the concern of only the last two Departments listed above. Modern potable water supplies have been constructed in larger municipalities in Thailand for about sixty years. There are 166 municipalities, excluding

Table 1 — Planned Budget of the National Rural Water Supply Program

(In Million Baht)

Agency	FY 1967	FY 1968	FY 1969	FY 1970	FY 1971	FY 1972	FY Tot.
Department of Mineral Resources	45.0	49.68	54.37	46.87	46.87	46.87	289.66
Department of Local Administration	25.5	25.5	25.5	25.5	25.5	25.5	153.0
Department of Public and Municipal Works	15.43	18.43	19.68	12.18	12.18	12.18	90.08
Department of Health	13.0 (+12.20)	12.0 (+20.43)	12.0 (+12.83)	12.0 (+23.00)	12.0 (+23.00)	12.0 (+23.00)	73.0 (116.46)*
Total	98.93 (111.13)	105.61 (126.04)	111.55 (126.38)	96.55 (119.55)	96.55 (119.55)	96.55 (119.55)	605.74 (722.20)

* Additional budget for Potable Water Project in sensitive area.

Bangkok, and 14 sanitary districts that have potable water systems already. Under the present plan, the Department of Public and Municipal Works is responsible for continuing the program. On the other hand, rural potable water systems are a more recent activity of the Royal Thai Government. According to the existing five-year-plan, the Health Department takes the responsibility for providing this service.

Before an overall national rural water supply program was established, the various Thai Government agencies engaged in developing water resources often found that their interests overlapped and in some instances conflicted. Therefore, one of the primary objectives of the water supply program was to establish a coordinating committee. At first, this responsibility was handled by the National Economic Development Board itself. In 1966 an Executive Committee on "The National Rural Community Water Supply Program" was formed to carry on these duties.

Executive Committee

The eleven member Executive Committee was appointed by the Central Government Cabinet to take over the duties of coordinating the national rural water supply program. The members of this committee are as follows:

Director General, Department of Local Administration,

Representative of the Royal Irrigation Department,

Representative of the Community Development Department,

Director, Sanitary Engineering Division (SED), Department of Health,

Director General, Department of Mineral Resource,

Director, Provincial Water Works Division (PWWD), Department of Public and Municipal Works,

Chief, Local Administration Division, Department of Local Administration,

Chief, Ground Water Division, Department of Mineral Resources (MRD),

Representative of the Budget Bureau,

Representative of the National Economic Development Board (NEDB), and

Under-Secretary of State for Interior (Chairman of the Executive Committee).

The full committee above meets irregularly, but its work is carried on through meetings of the first seven members listed, constituted as a "Survey Subcommittee". The chief of the Local Administration Division, Department of the Local Administration, serves as Secretary of both the subcommittee and the full committee.

The Health Department Role

As stated above, the Health Department is concentrating on rural water supplies. During the second development program period, it has divided the responsibility between the Village Health and Sanitation Project and the Sanitary Engineering Division. The Village Health and Sanitation Project (VHS) is developing shallow wells as well as school and temple water systems. The Sanitary Engineering Division (SED) is responsible for design and construction supervision of potable water systems in communities of 500 to 10,000 people where a non-potable water source already exists.

The Sanitary Engineering Division Role

The Health Department had the responsibility for assisting local authorities to construct rural potable water systems. It was also obvious that some provinces were in more urgent need of potable water than others. The responsibility for planning, and implementing a comprehensive 'self help' program for the design and construction of potable water supply systems initially in provinces of greatest need, and later on in the other provinces, fell into the hands of the Sanitary

Engineering Division of the Department of Health. In order to accomplish this task, the SED established what is now called the Potable Water Project (PWP).

POTABLE WATER PROJECT (PWP)

Accelerated Rural Development (ARD)

The Royal Thai Government, realizing the necessity for accelerated development, has organized and implemented an Accelerated Rural Development Project (ARD) in many provinces of the Northeast and Northern Regions of Thailand as shown in Figure 1. The specific aim of the project is to develop provincial administration with the trained personnel and necessary equipment to carry out public works activities, such as building roads, bridges and other public works construction, and to develop operational plans for rural development in fields such as agriculture, water resources, and irrigation. It is expected that this program will affect approximately three million of the eleven million inhabitants of the regions. The provinces are, for the most part, located along the frontier between Thailand, Laos and Cambodia. Agriculture is the main occupation, although the soil is generally poor. The climate is extreme in that there is no rainfall for approximately three-fourths of the year. The people are poor and have the lowest income per capita of anywhere in the country. The incidence of sickness is higher in these provinces than in the rest of Thailand. In order to eliminate these severe inequalities the Government must take great strides in developing the economy of the region. Economic improvement will also help the social and political conditions in this area. Because the ARD area is more in need of development than any other area of Thailand, it is logical that the provision of potable water supplies start in this area as an added boost to health and development.

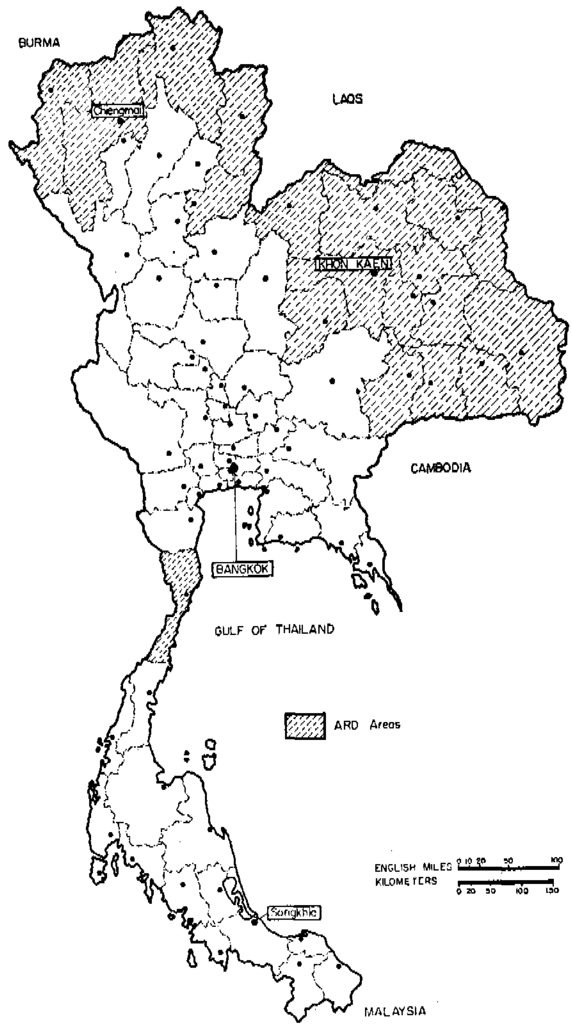

Fig. 1—Accelerated Rural Development Areas in Thailand.

Scope

The first Potable Water Project Agreement between the Royal Thai Government and the United States Operations Mission (USOM) was signed in April 1966. The project is intended to provide piped potable (safe for drinking) water to approximately 600 communities with populations ranging from 500 to 10,000 people in the security sensitive (ARD) areas in the north-east, and north. The project is providing piped potable water to selected villages that:

1. Have an existing but not potable source of water,

2. Are readily accessible by road,

3. Have a high interest in obtaining potable water as indicated by a willingness to assist in construction, and

4. Are willing to develop a rate structure which will cover operation and maintenance costs, as well as provide for future expansion of the system.

The training objectives of the project include an exhaustive formal and informal training program for SED staff intended to develop a higher capability in design and construction of sanitary engineering works. Therefore, in addition to informal on-the-job advice that advisors could give, SED staff personnel are provided with opportunities to continue academic study abroad and receive advanced degrees in diciplines related to project needs. In order to ensure that a large portion of the staff could gain some form of additional experience, observation and study tours lasting up to six weeks were included in the project scope. The objective of these observation tours is not the same as overseas academic study which is quite expensive and keeps people away from the project as long as two years. The observation tours allow staff to see how other Asian countries are carrying out water programs and talk with other Asians involved in water programs. This exchange of ideas and exposure to other programs at first hand will hopefully increase general staff awareness of water projects, goals and methods.

Another training program included in the project scope is the training of village personnel to operate and maintain the plants following completion of construction. A two week water treatment plant operators training course is conducted at regional offices as frequently as necessary, following which the new operators return to their villages to take charge of their treatment plants and distribution system. Although not formally written into the project scope, another objective has evolved during the life of the project. Because of the lack of public understanding of the need for pure water, SED field personnel aided by other personnel of the Department of Health are spending some of their time instructing the people of the villages in the value of pure water and the benefits that come with the use of pure water.

Implementation

At the time the project agreement between the RTG and USOM was signed, the SED was only a small engineering organization already fully occupied with the normal Health Department's sanitary problems. Staffing of the project organization, according to the chart in Figure 2, became the first priority. It was immediately realized that a large increase in the number of engineering and support personnel and the possible provision of outside engineering support would be necessary to meet the project schedule. The Director of the SED was given the responsibility of directing the Potable Water Project. Two experienced SED sanitary engineers were assigned to the project as Deputy Directors. One of these Deputy Directors was sent to Khon Kaen, a central province of the north-east region, to set up a field office there. The other remained in Bangkok. In addition, twelve young graduate engineers were recruited for the initial field operations in the north-east region. The original organization in each field unit consisted of a field engineer, an assistant engineer, three or four construction technicians and a driver. As the program expanded and the assistant field engineers gained experience, they were assigned duties as field engineers and new graduate engineers became assistant engineers as vacancies appeared.

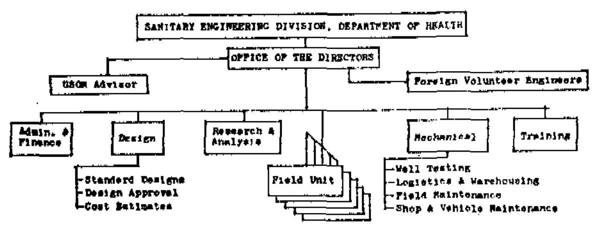

Fig. 2—Potable water project present organization chart.

The field office at Khon Kaen has the responsibility for investigating proposed sites, making recommendations on their suitability, preparing specific system designs and estimates and submitting proposed programs to SED Bangkok for final approval and budgetary processing. After allocation of funds to the various provinces, SED Khon Kaen, through the various field engineers, is responsible for providing assistance and advice to the Province on letting of contracts, technical supervision and inspection during the construction phase and placing plants into initial service. A design staff of three engineers and supporting draftsmen was set up at Khon Kaen to develop standard designs, using criteria given in Table 2, prepare specialized designs beyond the capability of the field engineer, and review field designs. A mechanical staff of two mechanical engineers, skilled mechanics and artisans was set up to make well test, install pumps, maintain and repair automotive and other equipment, provide maintenance and repair support for operating plants and handle various types of research and minor construction projects. A small laboratory to handle water analysis was also included in the organization.

USOM Participation

The Potable Water Project was initially implemented with the joint cooperation of the SED and USOM. From the very beginning, the SED Director and the USOM advisor worker together to develop the plans for implementing the Project. The formal agreement between the Royal Thai Government and USOM provides that USOM will assist the Project by providing certain commodities (i.e. pumps, drives, generators, spare parts, vehicles, and maintenance equipment) as well as technical and other financial assistance.

TAMS Participation

At the beginning of the Project, the SED staff was very small and for the most part inexperienced. USOM, in an effort to provide technical assistance and at the same time relieve some of the immediate demand for technically capable field engineers, assisted the RTG to retain a consulting engineering firm. In August 1966, the Royal Thai Government signed a contract engaging the New York firm of Tippetts-Abbott-McCarthy-Stratton (TAMS), Consulting Engineers. The agreement called for TAMS to provide 252 man-months of engineering advisory service over a period of three years, and to *assist* SED in :

1. Conducting preliminary site surveys and inspections,

Table 2 — Treatment Plant Design Criteria

Potable Water Project	National Community Water Project
Plant life	10 years
Maximum day demand	1.5 × Average day demand
Peak hour demand	$4.0 \times \frac{\text{Average day demand}}{24\text{ hrs}}$
Maximum pumping day	15 hours
Average pumping day	10 hours
Population growth	3%
Total storage	Approximately 70% of average day supply
Elevated storage	Approximately 20% of average day supply
Fire protection	none
Per Capita consumption[1]	
Type 'A' Village	80 lpcd
Type 'B' Village	50 lpcd
Pipe material	Asbestos Cement, PVC, Galvanized Steel
Distribution system life	15 years
Minimum pressure	10 psi at the curb

[1] Villages are classified into one of two categories depending upon geographic location, economic situation, sociological conditions and growth potential. Initially both *Class 'A'* and *Class 'B'* Villages will be served with 100% public fountains. At the end of the design period, Class 'A' villages are planned to have 80% private house connections and 20% public fountains with a weighted average consumption figure of 80 lpcd; and Class 'B' villages 40% private house connections and 60% public fountains with a weighted average consumption figure of 50 lpcd.

2. Review of commodity requirements,
3. Development of design criteria and standard designs,
4. Preparation of final engineering designs, contract drawings, specifications, cost estimates, equipment and material specifications, and development of water rates,
5. All phases of construction supervision,
6. All phases of preventive maintenance, and
7. Management and operation training for SED staff and village water treatment plant operators.

However, it is felt that the objectives of this agreement were not completely fulfilled for three primary reasons. First, there was a difference of interpretation of the terminology, primarily the word "assist", used in the contract scope of work. Second, background experience of the consulting engineers that came to work with the project was not similar to the situation in rural Thailand and therefore the engineers were not as effective as had been expected. Third, the young Thai engineers had never before had experience working with consulting engineers, and could not fully absorb the benefit of the contract services.

NATIONAL COMMUNITY WATER PROJECT

Scope

The Potable Water Project was initiated as a project to set in motion the construction of rural water systems in the ARD provinces of the Northeast and North. Assistance for the project came from USOM and TAMS. However, this project is a short term project with a specific goal of serving only 600 communities. Throughout Thailand there are approximately 12,000 rural communities with populations between 500 and 10,000. The time is fast approaching when USOM may no longer be assisting the Potable Water Project. TAMS has already completed its work. The Potable Water Project, then, can only be considered a pilot project for an overall national project. To prepare itself for the time when the Potable Water Project is completed and not to be caught undermanned as the Potable Water Project initially was, SED set up the nucleus of the overall national community water project in 1967. Presently, this second project, called the National Community Water Project, covers all the provinces not previously covered by the PWP with the exception of the municipal areas. Just as in the Potable Water Project, the Director of SED has the responsibility for implementing the National Project. The Central Office of the National Project is in Bangkok. The day to day operation of the Project is administered by the Deputy Director stationed in Bangkok.

Implementation

This second project has been implemented in much the same manner as the Potable Water Project in the ARD areas, with the organization shown in Figure 3. Field units consisting of an engineer, assistant engineer and several construction technicians divide up the responsibility for supervising and consulting the provincial authorities, conducting feasibility and construction surveys, and supervising construction. If time is available, the units try to assist or at least advise communities that have already had systems built. Outside of administrative work and limited warehousing in the central office at Bangkok, the National Project must rely on the support of the Potable Water Project facilities and staff for such things as development of standard drawings and specifications. The National Project is quite dependent on the Potable Water Project for the development of operational and administrative procedures. This makes sense since the Potable Water Project has

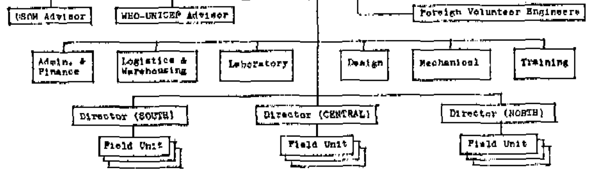

Fig. 3—National water project present organization chart.

been going for a longer period of time, the Project's personnel have had more time to gain field experience and the Potable Water Project has received more outside technical advice. Sometimes the National Project takes advantage of the vast warehouse in Khon Kaen. If procurement of commodities is slow, the National Project sometimes borrows, on a replacement basis, the needed commodities. The National Project is assisted by the World Health Organization (WHO) and the United Nations International Children's Emergency Fund (UNICEF).

WHO Participation

In 1967, at the request of the Royal Thai Government, WHO sent a consultant to evaluate the Project and the feasibility of WHO assistance. After the evaluation was completed, WHO assigned a sanitary engineer to the Project in March 1968. The principal objectives of WHO assistance are to assist the SED personnel in the National Project to:

1. Collect and evaluate basic information on the community water supply situation throughout Thailand,
2. Advise SED personnel on matters related to environmental health,
3. Advise in matters of engineering and administrative organization necessary for the successful implementation of the National Rural Water Supply Program,
4. Promote the training of professional and auxiliary personnel needed for design, construction, operation and maintenance of the Program —this also includes providing funds for studying abroad by a limited number of qualified staff, and
5. Cooperate with and to train Thai staff personnel to administer and manage the project on their own once WHO assistance is no longer available.

UNICEF Participation

UNICEF has responded to the Royal Thai Government's request for assistance to the National Water Project by agreeing to make US$ 250,000 (Baht 5,000,000) available over a three year period (1969-1971). This assistance provides for equipment and commodities needed to implement the Project. Among the major items provided so far are: surveying equipment, vehicles, pumping units, maintenance tools, and fittings. UNICEF also provides an allowance for villagers selected for operator training during their operator's training course. UNICEF material assistance has strengthened the development of the National Project which aims to cover the areas outside the ARD provinces in the north and northeast.

In order to qualify for UNICEF assistance, a community proposing the construction of a potable water system must meet certain requirements:

1. A population of between 1,000 and 2,000 people,
2. There must be at least one or two schools in the community, as well as a health or midwifery center,
3. The existing water facilities must be inadequate or non-existant,
4. The attitude of the community is very important —the community must be conscious of a need for potable water, responsive to the project proposal and willing to help to the limit of its available resources,
5. It is preferable that other development programs are also underway in the community, such as privy projects, etc.,
6. The proposed source of water should not be too difficult or too expensive to develop,
7. Proposed treatment should be simple, typical and adequate, and
8. The village should be accessible and near some training center for health workers.

In general, UNICEF is trying to promote "self help" and to use each system as an example and demonstration to all nearby communities and authorities of the feasibility and desirability of having a proper piped potable water system.

HOW A VILLAGE WATER SYSTEM COMES ABOUT

Since both the Potable Water Project and the National Community Water Project follow basically the same procedure, it seems best to describe how a system is conceived and indicate any differences as they appear. The actual provision for a water system to a village proceeds as follows:

1. The initiative for obtaining a potable water system must come from the villagers themselves, often stimulated by a local Public Health Sanitarian, or the Community Development Officer. Specific requests for water systems generated in any of the above ways are submitted to the Governor's Office through the District Officer or Provincial Health Officer. Sometimes, in the case of ARD provinces in the Potable Water Project, the Governor will generate the request. The Governor's Office makes the final selection of villages and establishes priorities. One significant factor taken into account in the selection of a village is the amount of local contribution, the key to "self help", the village can provide toward construction costs. This, in turn, provides an indication of the villagers' capability for "self support".
2. The SED field unit which covers the area where the village is located makes an initial engineering feasibility study of the source of water available, and gathers other pertinent information.
3. The selections are reviewed by SED and USOM in the case of the Potable Water Project, and WHO and UNICEF in the case of the National Project, for engineering practicability.
4. The field unit returns to the village and conducts a site survey.
5. Standard designs based on the needs and size of the village are assembled and sent to the governor's office for approval. These standard designs and specifications were developed early in the implementation of the Potable Water Project and are continually being updated and revised at the Khon Kaen office. From time to time, new standards are developed to better meet the requirements of rural Thailand. Since the National Project does not have the staff or facilities to develop standards itself, it too uses the Khon Kaen designs.
6. Following the receipt of bids and the awarding of a construction contract to the lowest responsible bidder, the plant is constructed under supervision of the SED construction technicians assigned to the field unit in that area. If part of the system, usually the laying of the distribution mains, is installed by the villagers, the SED construction technician also supervises this work.
7. When construction of a water treatment plant is completed, the plant and water system is turned over to the Local Government of the province for operation and maintenance. The Local Government, in turn, can and usually does delegate authority to the District Officer or village headman or, where applicable, to the Sanitary District to operate and maintain the system.
8. Meanwhile, training is provided for the water treatment plant operator who will be responsible for the proper operation of the system. One villager, selected from the village, is given a two week training course at regional offices by SED staff personnel. Later he is given on-site training of sufficient duration to provide reasonable assurance of his competence to operate the plant properly.
9. Following completion and formal transfer of the system to the Local Government Authorities, SED field engineers, at present only in the Potable Water Project in the ARD areas, or sanitarians visit the plant to give the operator follow-up instruction in plant operation and maintenance.

FOREIGN VOLUNTEERS

From the beginning of the Potable Water Project, SED realized that something beyond the formal training and on the job advisor training was going to be required to build up capability of the young staff. It was hoped that foreign volunteers with their language skills and sensitivity of Thai culture would be able to work side by side with individual SED staff who were their own age and had had roughly the same formal educational background. The major difference between the volunteers and the SED staff with whom they were to work was that the volunteers had been brought up in societies that were well accustomed to the demands and nature of a developed and scientific society. If the volunteers could work out a close relationship with their co-workers, perhaps they could help co-workers adjust to the demands of such a project as the SED was conducting.

Presently there are eight American Peace Corps and three German Volunteer Service volunteers working with the SED in both water supply projects. Initially, two Peace Corps Volunteers were assigned to the Potable Water Project and were stationed in the Project's main office in Khon Kaen. They were instrumental in setting up the water analysis laboraory at Khon Kaen and also assisted in general field and office work. One of the volunteers instituted a water use study which is now being carried on by the Asian Institute of Technology (AIT) and other volunteers. In February 1969, fourteen additional Peace Corps Volunteers arrived. Since one of the original two volunteers had already returned home, there were fifteen volunteers involved in both projects. These newer volunteers were mostly assigned to field units throughout the country. Unfortunately, a few of the volunteers had difficulty in adequately fulfilling their expected roles and have already returned home. Most of those who remain are finding ways to carry out their objectives and a few have fostered quite intimate relationships with their co-workers and are accomplishing a great deal.

The three German Volunteers arrived in August 1969. On the whole, these volunteers have had more practical engineering experience than the American volunteers, but they have not been with the SED long enough to determine if this is a necessarily important factor. Originally, all three volunteers were stationed in Khon Kean. Recently one of them was transferred to a field unit in the National Project. The SED has shown its confidence in the ability of the volunteers by asking them to temporarily take over various field units while their co-workers were away on training trips and during other absences.

FINANCING

Financing in both projects is similar. Therefore there is no need to discuss financing separately. Under the present method of project implementation, villages having 5,000 to 10,000 people are dependent upon budgeted subsidies from the central government, through SED, for the provision of a potable water system. At the time the governor reviews requests and selects villages to receive potable water systems, he has an estimate of the amount of local contribution the villages can provide towards the construction cost of the system. Following the design of the particular system and estimates of the construction cost, the amount of the village contribution is reaffirmed and the SED commits funds from its annual budget to make up the difference between the village contribution and the estimated cost of the system. SED presently subsidizes every village construction project to some extent. Subsidies may run as high as 96% of the total construction cost to as low as 1%. Many of these communities have the ability to pay back a capital development loan if such a loan were possible or available. Some areas applying for and receiving the designation of Sanitary Districts do have a limited lending authority, but even funds provided in this manner need to be augmented by central government subsidy in the case of capital development work such as potable water systems.

System Costs

The costs involved in supplying potable water vary greatly, depending on source of water, degree of treatment required, size of village, etc. Table 3 shows a breakdown of costs, including foreign exchange (US dollar) inputs, for four representative systems—two small systems with

Table 3 — Cost of Potable Water Systems—Sample Villages

Sample Village		Ban Nong San, Changwad Sakhon Nakhon	Ban Khok Si, Changwad Sakhon Nakhon	Amphoe Selaphum, Changwad Roi-Et	Ban Tha Bo I-VI, Changwad Nong Khai
Source		Deep Well	Surface Water	Surface Water	Mekong River
Treatment		Pumping	Complete	Complete	Complete
Storage		Overhead Tank	Overhead	Overhead	Standpipe
Distribution System		Yes	Yes	Yes	Yes
Population Served		1,000	1,100	5,000	15,300
Total Cost of System	- Baht - $ Eq.	215,300 10,760	361,750 15,330	850,000 42,500	970,030 48,501
SED Contribution	- Baht	144,600	291,000	397,000	59,100
Village Contribution	- Baht	15,700	15,750	400,000	847,130
$ Material Contribution	- Baht - $ Eq.	55,000 2,700	55,000 2,700	53,000 2,650	63,800 3,190
Per Capita Cost of System	- Baht - $ Eq.	215 10.75	329 16.45	170 8.5	63.5 3.18
Village Contribution	- %	7.5	4.4	47	87.5
$ Input	- %	25	18	6.23	6.45

different source and treatment, one medium size system, and one of the largest systems. As can be seen from a comparison of the costs, economy of scale is an important factor in the size of plants being constructed in Northeast Thailand, as is the percentage of local contribution.

The average overall cost of supplying potable water to villagers in rural Thailand to date is $6.80 per capita served. Local contributions have averaged $1.70 per capita, and SED subsidies have averaged $5.10 per capita. If foreign technical advisory and SED administrative costs were to be added, the overall cost would probably rise to about $ 8.50 per capita. As a comparison, capital improvement costs for water works extensions in the United States and other more highly developed countries range as high as $ 30.00 to $ 40.00 per capita.

ACCOMPLISHMENTS TO DATE

Potable Water Project

As of September 30, 1969, the physical accomplishments of the project were as follows:

1. Construction in Khon Kaen of a regional field headquarters consisting of engineering design and drafting facilities, offices, water laboratory and warehousing facilities. Although the principal SED engineers are officed in Khon Kaen, it is planned that there be at least one field engineer and several construction technicians stationed in each province. However, because of the number of engineers presently abroad for participant training, the remaining engineers are now responsible for more than one province.
2. Development of standard designs for elevated tanks, clear wells, pump houses and treatment plants. Treatment plants of 10, 20, 30 and 50 cubic meters per hour capacity were designed. The drawings are numbered in such a manner that they can be interchanged and incorporated into designs for communities of different size.
3. Completion of a system for warehousing storage and distribution of commodities at the regional center at Khon Kaen. More than 2 million dollars worth of commodities have been ordered for the project, and approximately 56% of those commodities have arrived in country.
4. A regional office at Lampang was just completed. This office will serve the northern provinces as the Khon Kaen office now serves the northeastern provinces.
5. Twelve SED engineers have been sent abroad for academic training, and four for specialist training. Two engineers have returned to work with the project. Of those remaining abroad, six are in the United States, two are in the United Kingdom and two are in the Netherlands. In addition, eight engineers have attended a two-month course in water supply at the SEATO Graduate School of Engineering (now the Asian Institute of Technology), and twenty nine engineers and technicians have received observational and study training in Taiwan and Korea.
6. Development of a curriculum for water works operator training. Six water treatment plant operators' training courses have been given with an average attendance of 30 per course.
7. Completion of 117 potable water systems for 297 communities having a total population of 318,800. Construction is underway on 19 other systems that will serve 49 communities, and designs are completed on an additional 85 systems.
8. One interesting by-product accomplishment has been the involvement of the village community development committee in the process of soliciting villager support in the initial phases of a potable water system, and their involvement in the management of the system following construction. The direct involvement of these committees is apparent in all too few villages, but where the committees are involved the systems are generally better managed than where they are inactive. It is quite common for the entire village committee to turn up to greet visitors and officials, and explain their role in the management of the system, including collection of water charges and payment of operational costs. In a few instances these committees have later initiated other development projects such as village electrification.

National Community Water Project

The achievements of the National Community Water Project as of September 30, 1969, are as follows:

1. Thirty Four water systems having treatment plants ranging from 10 m^3 to 50 m^3 capacity

have been completed and serve 70 communities with a total population of 72,450.

2. Three of these completed systems have had UNICEF funding.
3. Starting from a small nucleus of experienced engineers in SED in 1966, the project organization has grown to approximately 240 people, including 40 engineers. This number includes personnel working in both water projects.
4. Staff members presently studying abroad are included under the Potable Water Project.

It should be noted that much of the initial ground work for this project has been done by people in the Potable Water Project. This project's main emphasis has been to prepare the SED for the long-range program of the future, and therefore it is difficult to define precisely the true accomplishments of this project in physical terms.

Principal Problems Facing Both Projects and Proposed Solutions

The following are some of the major problems facing the SED as it carries out the two projects. Also included are some of the proposed solutions to these problems.

1. Lack of professional personnel. There is an acute shortage of graduate engineers and the civil service salary scale does not permit the Royal Thai Government (RTG) to compete with private engineering firms for hiring those available. Inexperienced engineers may be hired, but it is necessary to give them considerable additional training. When opportunities for overseas study become available they must be taken advantage of. Unfortunately, this puts an additional strain on the already limited and inexperienced staff left behind to carry on the project. There is always a delicate balance that must be kept between sending personnel overseas to study and maintaining a necessary staff level for the project.
2. Because of the remoteness of the sites and the small scope of individual projects, there is a lack of enthusiasm on the part of the local contractors to bid for the work and also a tendency to increase the price on construction. Recently, both projects have tried to design systems that serve several communities at the same time. This will reduce the total number of treatment units needed to serve the same amount of people. Hopefully, the increased size of individual plants will attract the local contractors. Another problem, however, is to get several communities to cooperate fully in the construction and operation of the plants.
3. Governmental procedures and restrictions make obligation and disbursement of funds difficult. For example, villages must get money to build the systems from the RTG through the SED. The SED, in turn, is allocated a budget that is rarely approved by February and has to have this money allocated before September 30 of the same year. In the future, perhaps more villages will be able to take advantage of low interest, long term development loans instead of direct government subsidy.
4. Lag time in obtaining imported items. It takes a year, or even more in some cases, from the time a commodity is ordered until it arrives on the construction site. This applies to both USOM and UNICEF funded commodities. As the staff become better at forecasting the needs of the sections and units, advanced ordering with reasonable accuracy will help ensure that there is enough time allotted between ordering time and construction time so that construction will not be held up.
5. Transportation over great distances from provincial offices to construction sites and poor conditions of the roads, especially in the rainy season, hamper supervision and impede progress of construction. Not much can be done about this problem, except to make an effort to keep vehicles in top running order and wait for government agencies involved in highway development to increase the availability of allweather roads.

6. Interest on the part of local authorities and villagers, making them willing to pay for the construction and operation costs instead of expecting the government to give them the system and then maintain it as a government entity. In some respects, results to date are somewhat disappointing. Local authorities and villagers do not immediately see the importance of operating, maintaining and managing the systems properly. It is encouraging, however, to note that villages which have had systems for a few years show an increase in interest in maintaining the systems. SED is trying its best to provide monitoring and preventive maintenance whenever possible. Unfortunately, field units are quite busy with the task of preparing and supervizing construction of new plants and, according to the overall water resource development plan, SED is instructed to only advise and assist but not run completed plants. If SED were to run the plants then the idea of "self help" would be lost. SED has recently received several maintenance trucks and has sent units into the field, again first in the Potable Water Project and then in the National Project, to perform routine maintenance on a pre-arranged schedule. Promotion of preventative maintenance will lower the long range cost of operating the systems and increase the reliability of the systems in the eyes of the villagers. However, it is the villages themselves that ultimately must take over the operation of the plants. Also, to make it easier to start up a plant and to compensate for the villagers' unwillingness to pay for water until it is delivered, SED holds about Baht 5,000 of the village construction contribution for covering the expenses of initial start-up and running of the new plants.

RESEARCH

Limited experienced staff and resources and the necessity to concentrate efforts on design and construction in the early years of the water supply projects required the use of assumed criteria and standard construction methods. The work that has gone ahead to date has indicated a need for research to define more accurately the technology of water supply as applied to rural Thailand and to determine the best utilization of these water supplies for the greatest benefit to the people. The Asian Institute of Technology (AIT) has recently undertaken two research projects that are directly connected with the SED and its two water supply programs. The first of these studies is looking into the "*Demand for Potable Water in Small Communities in Thailand*". The aim of this study is to provide more accurate design information about how villagers actually use water. The study will determine how villagers use potable water depending on the availability of water, the type of distribution system, amount of education, employment, and income. The other study, equally as important, will try to determine the "*Benefits and Costs of Providing Potable Water to Small Villages in Thailand.*" The big question this second study is trying to answer is whether or not the high costs of constructing and operating the SED's systems are reasonable in view of Thailand's development priorities.

THE FUTURE

When it is realized that to date the yearly rate of population served through provision of new rural water supply systems is much less than the national annual growth rate, it becomes evident that a much greater effort must be made in the future. Also, to compound the problem, once the rural population becomes used to piped pure water, their demands are sure to increase. USOM, UNICEF and other outside financial assistance to the National Rural Water Supply Program cannot go on indefinitely, and soon the RTG must carry the entire burden. Subsidies possible now under a limited program would be too large for the RTG under the greatly expanded program needed in the future.

Therefore, for the future, certain changes in approach and financing are needed. Principal among these changes are:

1. Subsidies or grants now given by the central government for initial construction costs must

change to investment and long term, low interest loans administered by a development authority or a central revolving loan fund and with repayment terms that make it possible for the community to repay the loan from water revenues,

2. The Sanitary Engineering Division (SED) of the Department of Health must be decentralized, with more autonomy given to the regional offices. Regional autonomy will be possible because of the increased field experience of the project staff and the return of staff personnel from overseas study. The headquarters of the present Potable Water Project (at Khon Kaen) will become the regional office for the Northeast. A second regional office for the North (at Lampang) is just completed. A regional office for the South (at Songkhla) is planned for 1970, and a regional office for the Central region (location not yet determined) is in the planning stage. The Bangkok office will be strengthened and will assume overall control and coordination.

3. Local government at the province and district level will be required to assume more and more responsibility in monitoring operation and maintenance of completed works. This will allow the SED to assume the role more nearly consistent with the duties of other public health agencies, that of quality control.

4. Acceptance by the villagers of the value of potable water supplies must be encouraged through education in public health and hygiene. Water supplies should be part of the overall rural health program, and utilization of local health workers, at present some 10,000 strong, then could be used to educate the people. It is hoped that other personnel such as Community Development workers, teachers, agriculture extension workers, etc., may be interested to the point where they will be useful in assisting in the education of the rural people.

ACKNOWLEDGEMENTS

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SOME PRACTICAL PROBLEMS WITH WATER TREATMENT IN A TECHNICAL AGE

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The technology of water treatment can appear deceptively simple. This paper presents some practical matters which complicate the process and which should be considered in both the design and operation of water treatment plants.

PROCESS

Figure 1 is a diagram of a treatment plant for the removal of turbidity. However, color removal, hardness reduction and manganese removal are also very similar processes using similar equipment and similar comments can be applied to those processes also. The process consists of conditioning the water with chemicals so that the unwanted material is precipitated and forms floc particles which can be separated from the water as a sludge. The equipment and structures used are clarifiers or settling tanks, filters, chemical feeders and mixing basins.

Aluminum sulfate or ferric sulfate are generally added to the raw water as coagulants which, when mixed with the water, precipitate and coagulate with the turbidity particles and are then flocculated, or gently stirred, to promote the formation of particles which will readily separate from the water. The coarse, heavy or larger particles are removed in clarifiers. Subsequent passage through a filter removes the remaining fine particles. Disinfection is provided to ensure a safe water. The pH is adjusted to stabilize the water so that it will not be degraded in its passage through the distribution system.

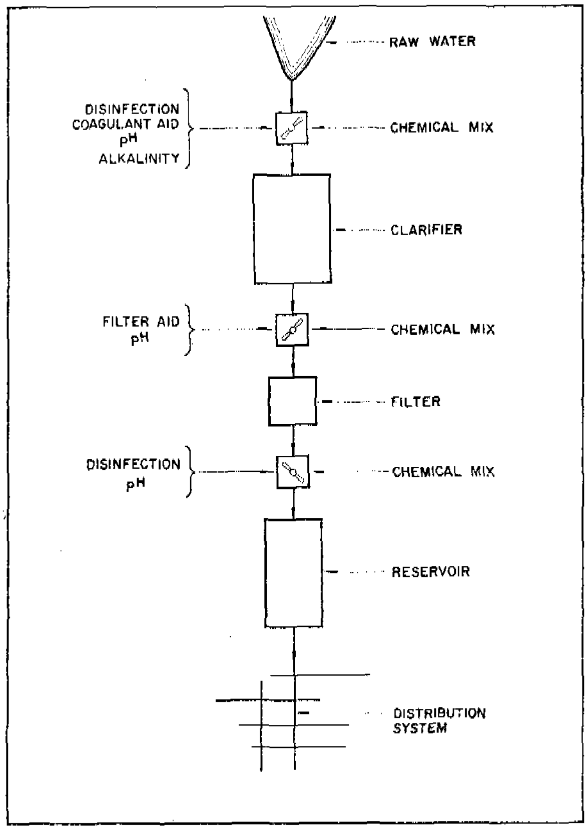

Fig. 1—Typical Flow Diagram.

IMPORTANCE OF pH

Precipitation of the aluminum or ferric salt is quite pH dependent. This means that if the pH is not at the optimum value, excess amounts of the coagulant will remain in solution rather than being precipitated. Figure 2 is the aluminum solubility curve of the water in Bangkok (Sam Sen treatment plant) in March 1969. The left hand vertical scale of this figure is graduated in mg/l of Aluminum, while the right hand vertical scale is in terms of equivalent alum ($Al_2(SO_4)_3 \cdot 18H_2O$). A typical alum dose for this water is 25 mg/l of alum. Only the precipitated aluminum is available

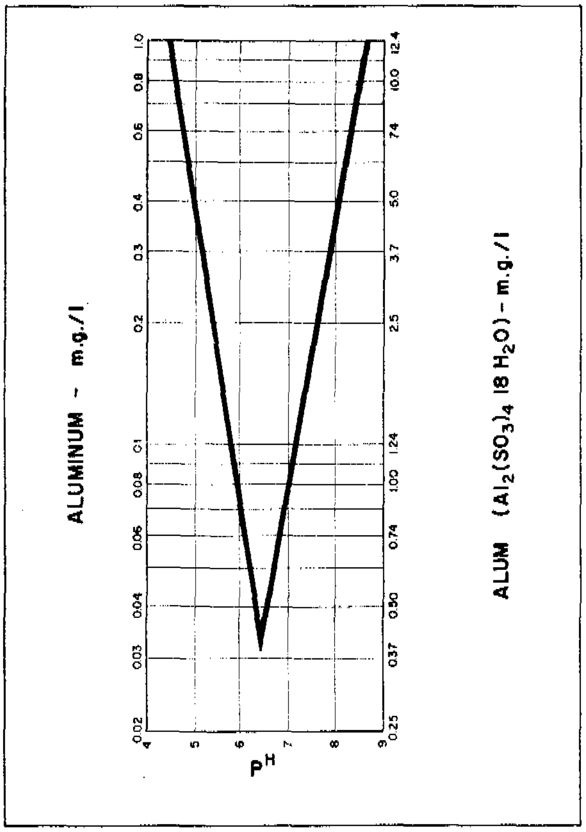

Fig. 2—Aluminum Solubility.

to the coagulation process. It can be seen from this figure that for 95% utilization and removal of this alum dose, the pH range must be between 5.8 and 7.2. The optimum pH where most aluminum is removed from water is 6.5. At many plants where the raw water has a high pH, an excess of alum is added to the water. This excess alum achieves the purpose of reducing the pH, and thus precipitating the alum and promoting flocculation, but a better way would have been to add an acid to adjust pH. This would not only require less alum but another benefit would be the reduced production of sludge.

Adequate flocculation can occur at a pH value other than that at which minimum aluminum solubility occurs. However, it is most desirable that the entire clarification and filtration processes occur at a pH value at which minimum aluminum solubility occurs. The reason for this is that the pH of the water can change during its passage through the distribution system. It frequently occurs that the pH value changes so that less aluminum can be maintained in solution in the water in the distribution system than was possible during the passage of the water through the treatment plant. If this occurs, aluminum will be precipitated in the distribution pipes. Such a precipitate can take either of two forms. In the first form, the aluminum is a light flocculant sludge which hangs in loose suspension in mains where the flow rate is quite low. Then, during periods of high water demand, the water in this main is stirred up and the sludge is discharged in clouds of dirty water to rather irate customers. The second form of this precipitate can be as a coating on the walls of the pipes. Such a coating can be very thin and ridged in texture. This coating can very quickly and substantially reduce the carrying capacity of the main. A notable case of this type was originally reported when the South District treatment plant in Chicago was placed in service. This plant commenced operation with "clarification only" for the first few months. The filters were commissioned later, but by then it was noted that some of the tunnels leading from the plant had a very high loss coefficient. The trouble was located as a thin coating of aluminum and silicate deposited upon the walls of the tunnels. When, the Central District plant in Chicago was placed in service, "clarification only" was not permitted and the plant started in operation complete with filters. However, again at this plant and at other plants too, it has been found that even with filters, if the pH is not properly adjusted, after-precipitation of aluminum can occur.

ALKALINITY

Some surface water sources at certain times of the year consist mostly of rain water. This is quite a common occurrence in tropical countries that have a wet season and a dry season. At those times when the water contains relatively small amounts of dissolved salts, there may be insufficient alkali for the aluminum to precipitate. This will require the addition of an alkali such as lime or caustic soda which unfortunately will raise the pH and require the addition of an acidifying agent to reduce pH again to a proper level for flocculation.

TRUE SOLUTION OF CHEMICALS

When considering the subject of water technology it is frequently observed that the amount of chemicals required for laboratory tests can be quite different from the amounts actually required in plant operation. Further, it can often be observed that two plants treating substantially the same water will apparently require different amounts of chemicals for proper water conditioning. One explanation for this, which is mostly applicable to plant operation, is the degree of the solution obtained with the chemicals involved. This is a matter of particular importance where dry chemicals are used. The process of dissolving a dry chemical is affected by: the type and quality of chemical, the grain size of the particles, the water temperature, the concentration of the solution, and the amount of mixing energy provided, which is a combination of the intensity and time of mixing.

If chemicals are not in proper and complete solution, then that part of them not in solution is not available to the chemical reaction which is to take place. That is, if poor solution or dissolving facilities are provided, an excess of chemical must be added because it will not all be in solution. This is quite a common occurrence and at times it is noticed by the operator that some chemical remains undissolved on the bottom of the mixing tank. The common answer to this is to increase the flow of water to the dissolving tank and this certainly flushes the undissolved material out of the dissolving tank. Unfortunately, it is about the worst thing that can be done because the increased flow of water means a reduction of detention time in the dissolving tank and consequently a decreased amount of chemical is actually dissolved. However, out-of-sight is out-of-mind and just increasing the chemical dose a little appears to make everything all right.

COAGULANT AIDS

Most waters at some season of the year have a tendency to be more difficult to treat than at other times. Coagulant aids are chemicals which have been developed to assist the primary coagulant during these difficult times. For some waters it is economical to use them all the time. These aids can take the form of activated silica, natural polyelectrolytes, synthetic polyelectrolytes or a weighting agent such as bentonite clay. Their action is to weight the floc so that it will separate more readily from the water or to toughen the floc so that it will not break easily in either the clarifiers or the filters. The equipment required to feed a coagulant aid is very simple, and most modern plants are equipped with such equipment for intermittent or continuous use. The aids are sometime referred to as coagulant aids or filter aids. However, the same aid can be used in either location for either purpose.

Although coagulant aids have been a great boon to many plants, too often a simpler and more economical solution has not been properly sought. In many instances proper adjustment of the alum dose or the pH would have sufficed, rather than the addition of a further expensive chemical.

CLARIFIERS

The coagulation and clarifying process can be carried out in a variety of physical environments. Four basic configurations are shown in Figure 3. They are, respectively:

Separate flocculation and horizontal settling tank — In this the coagulant is mixed with the water and an initial rapid mix is followed by gentle agitation in a flocculation tank, after which the water enters a settling tank. The flow pattern through the settling tank is horizontal and the sludge settles to the bottom for subsequent removal. The clarified water is removed at the far end of the tank.

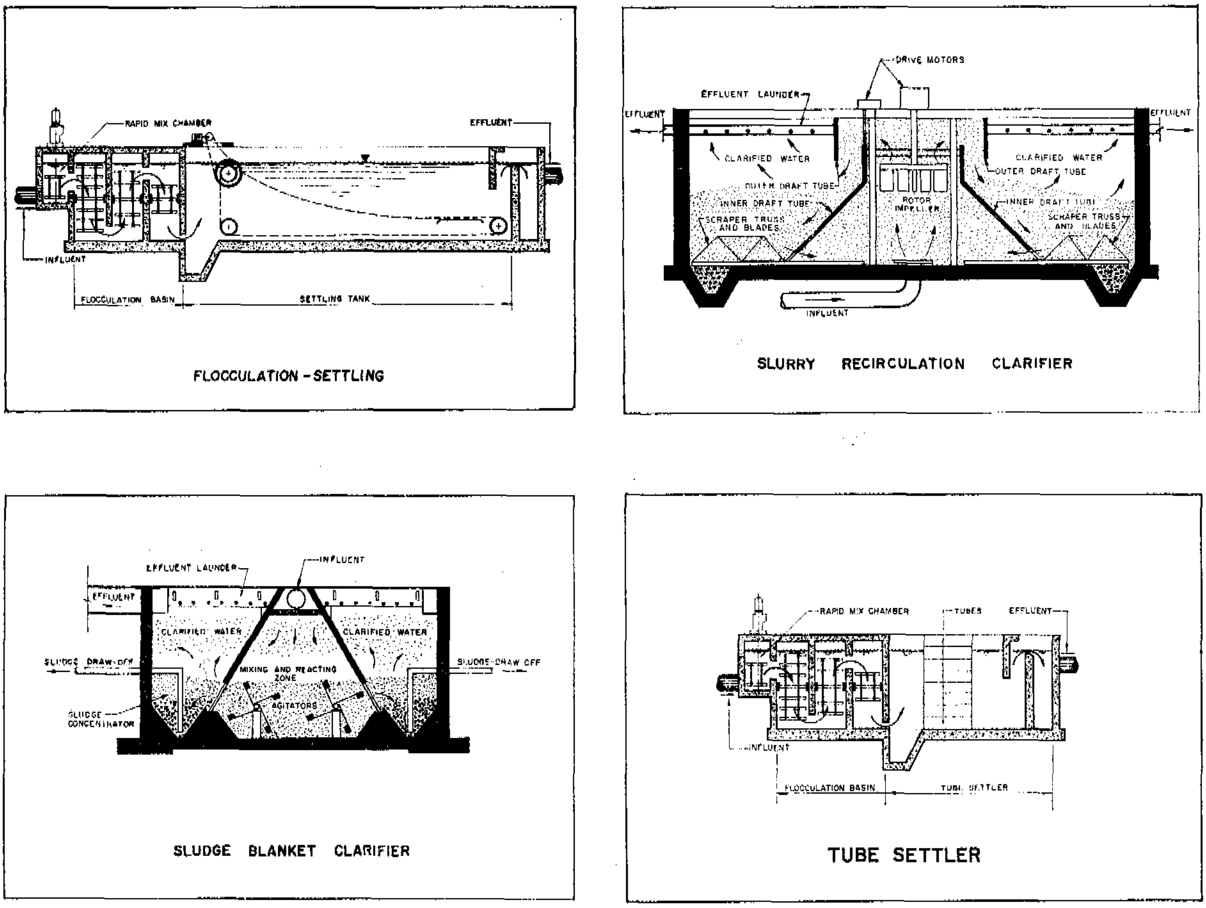

Fig. 3—Types of Flocculation-Sedimentation Tanks.

Sludge Blanket Clarifier — In this unit the chemicals are dispersed through the raw water in a rapid mix and the mixture then flows to the bottom of a clarifier. The flow pattern of the water is to rise to effluent launders at the surface. Sludge particles tend to rise more slowly or not at all and form a layer in the bottom portion of the tank. When this has accumulated into a 'blanket' the raw water is forced to filter through this blanket, achieving additional coagulation and increasing the removal efficiency of the tank.

Slurry Recirculation Clarifier — In this clarifier, chemicals are mixed with the raw water and this mixture is in turn brought into contact with a previously formed slurry of solids of about 5 times the volume of the incoming raw water. This mixture is then pumped in a recirculating pattern within a centrally located chamber. From the bottom of this chamber the mixture is discharged to a surrounding separation zone. In this separation zone the clarified water rises to the surface for removal while the sludge remains at or near the bottom and is subsequently swept back into the central zone for further remixing with new raw water.

The Tube Settler — This replaces the horizontal settling tank described in the first process. These tube settlers function in the manner proposed many years ago by Mr. T.R. Camp. That is, the efficiency of removal of a settler is a function of the depth of the settler rather than the detention time therein. These tube settlers are in essence a multitude of very shallow settling units.

Now, one of the problems with all of these tanks is that the design criteria normally state the size as a function of the surface loading rate, that is the unit rate of flow of clarified water, but the sludge removal rate is generally completely ignored. In waters which have relatively little turbidity or color or which require small amounts of chemicals, the sludge production rate may be fairly small and the sludge removal facilities will be of minor consequence. However, where consistently heavy turbidity or chemical use occur, the sludge facilities must be adequate to prevent the tank from being limited in its operation by choking due to the amount of sludge produced but not removed.

A further problem with sludge is that some tanks provide for sludge hoppers in which the sludge is purported to concentrate so that it can be removed with a minimum volume of water. However, most sludges will thicken to a jel which requires a considerable amount of energy to break up so that it will again flow. If sludge hoppers are to be provided they must be equipped with some device for breaking up a jel when it does occur.

SLUDGE VOLUME

Because of the increasing problem of sludge disposal, it is becoming very desirable and economical to use chemicals which produce small amounts of sludge. Thus, when assessing the value of coagulants or coagulant aids the total cost should include not only the cost of the chemicals themselves but also the cost of sludge removal and disposal.

The volume of sludge is also affected by the conditions under which the sludge is formed. After a few days of settling to concentrate it, a sludge can contain from 90% to 99% of water bound into the sludge particle. A sludge containing 99% water occupies ten times the volume of a sludge having only 90% water. Thus the floc volume concentration can be of major importance in considerations of the amount of sludge to be handled and disposed of.

If the initial chemical precipitation and reaction with raw water occurs under optimum conditions, the water volume of the sludge will be at a minimum. Further, once the sludge has been precipitated or formed it is very difficult to change its character or percentage volume of water.

Mr. T.R. Camp has been a leader in studying ways and means of reducing the volume of sludge. Indications are that the first few seconds of contact between the chemical and the raw water decide the amount of bound water which will be contained by the sludge particle. The rate of intensity of flocculation during mixing and dispersion should be quite high, while the subsequent flocculation may be carried out at quite low intensities.

If, after formation, the flocculant suspension is subjected to intense agitation, then the floc or sludge may be sheared or torn apart and will not be readily reformed into sludge. This danger occurs mostly in the solids recirculation type of clarifier and the area of danger is at the tip of the recirculation turbine. This phenomenon also explains the failure of some early attempts at solids recirculation using an external pump in conjunction with a conventional flocculation and settling basin. The intensity of agitation within the pump was too much for the sludge and it was returned to something akin to its original state of being turbidity particles.

FILTERS

Present day rapid sand filters may use a single medium, two distinct layers of media often referred to as "dual" media, or more than two layers of media generally referred to as a "multi-media" filter. A typical filter of each of these types is shown in Figure 4. There are other filter configurations but they are sub-categories of these three main types. The advantages claimed by the designers

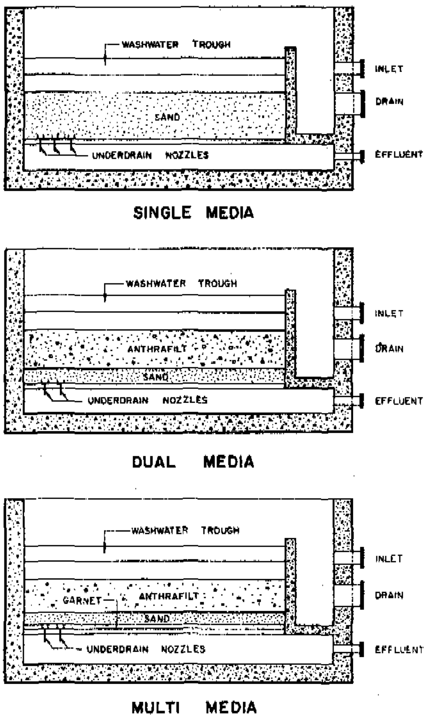

Fig. 4—Typical Filters.

of each type of filter is extended length of filter run and improved effluent quality.

The dual media consists of a layer of lighter material forming a roughing filter on top of the finer regular type medium which forms the bottom layer. This appears to have considerable value over the single layer. The multi-layers are an extension of this, offered on the basis that what two will do better than one, three will do better than two. It is very much open to question as to whether any additional benefit provided by the multi-layer is of any significant value.

In all the types used there has been a tendency in recent years to use ever increasing loading rates. This presumes not only improved chemical control but also proper and adequate control over the size and selection of the media. When a filter is backwashed a regrading of the filter media occurs. This results in the finer fraction of each layer being located at the top of the layer. Thus, the incoming raw water is faced first with media of the finest gradation which is most easily plugged and can result in quite poor operation of the filter. The solution is quite simple and consists of exercising very strict control over the media when installed to ensure that a very narrow size range is specified and that the material actually installed conforms to the specifications. Subsequently, in service it is advisable to check the filter on an annual basis, because the media are subjected to some wear and breakage.

There are many and varied filter control systems, all of which offer to confer great benefit upon the user thereof. However, it would appear that some systems confer benefit mostly upon the salesman and manufacturer of that particular system. "Slow start", "declining rate", "constant rate" and other similar names applied to filters can be proven theoretically to be of some benefit. However, in practice they are very difficult to adhere to and the technology of them is open to question. The owner will generally benefit most from a simple and rugged system which can be competitively bid by a number of suppliers.

ALGAE

A lot of chemical problems associated with clarifiers are repeated again in connection with filters. One additional problem occurs because of the location of the filters in relationship to the clarifiers. Except for some units in very cold climates, most clarifiers are uncovered and exposed to the elements and sun. They have a tendency to grow algae along the walls and, in particular, in the effluent troughs. Algae can cause two distinct problems. First, they can add dissolved oxygen to the water in sufficient quantity so that if the filter has an insufficient head of water on top of the media some of the oxygen will come out of solution within the media and will cause short filter runs by clogging or blinding the media with bubbles of oxygen. A very simple answer to this is to maintain an adequate depth of water on top of the media. Second, the algae by their use of carbon dioxide can increase the pH of clarified water. This may cause aluminum in the form of light particles in the clarifier effluent to be redissolved in the water before its passage to the filter. Of course, after-precipitation in the distribution mains is then possible. This can be prevented by prechlorinating the raw water, which will inhibit the growth of algae in the clarifier. A second alternative is to add acid at the entrance to the filter to depress the pH value.

CONCLUSION

The complications of water treatment technology are shared equally by designers, manufacturers, salesmen and operators. It has not been the intention to remonstrate against any particular group. Although the treatment of water is theoretically quite simple, the foregoing examples illustrate the complications that can arise. Most of our problems have plagued others before us, and solutions have been found, but it is better to avoid these complications where possible.

PACKAGED WATER TREATMENT PLANTS FOR SMALL COMMUNITIES, INDUSTRIES, INSTITUTIONS AND CAMPS

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Water and sewage treatment, distribution and collection systems on the municipal scale must necessarily be custom designed to meet the specific requirements of a given municipality or community in order to cope with such variables as the source and quality of the water supply, the geology and topography of the community, the population and its concentration within the community, the federal, state and local ordinances pertaining to water and waste treatment and other similar variables too numerous to specifically mention. Such projects call upon the valuable services of consultants, hydrologists, engineers, specialists of many types, contractors and eventually skilled technicians to operate the finished plant. Projects of this type involve months and even years of study, design, negotiations, and construction before being placed on stream. In contrast, *Packaged Water Treatment Plants* are water treatment systems prefabricated on a mass-production basis in a factory specializing in the manufacture of such equipment on an efficient and economical basis. The design, engineering and tooling costs for such systems can be amortized over hundreds or thousands of identical systems with resulting economies. These "Packaged Systems" may be completely assembled, tested and inspected at the factory prior to shipment. Many packaged systems can be shipped in their fully assembled and ready to operate condition. Others may be partially disassembled for ease of shipment but may be quickly and easily reassembled on the job site with simple hand tools.

Packaged Water Treatment Plants may be divided into broad categories: for surface water supplies; and ground water supplies.

SURFACE WATER

Water treatment problems associated with surface water supplies generally fall into the categories of turbidity, taste, color, odor and disease-bearing micro-organisms. Water use and reuse contributes to the pollution problem regardless of whether we are in highly industrialized Chicago or in remote jungle areas. Water-borne disease knows no boundaries.

Experience

Hundreds of millions of people living in the tropics drink water taken directly from the nearest stream or other source of surface water without treatment of any kind. For the most part, where water has been treated in remote areas, the conventional approach has been to custom design equipment for the particular needs of a specific installation. This approach involves excessive time, cost, civil construction and, many times, a plant requiring skilled supervision, oftentimes unavailable, for successful results. This experience has emphasized the need for a more economical and less complicated answer to the problem.

The Objective

In evaluating the problem and the experience, logical thinking evolves the need for a relatively *simple* combination of *proven components* combined in a standard *packaged* configuration for ease of installation, operation and maintenance by *unskilled personnel,* to provide potable water from diverse surface water sources.

The Solution

A system to meet this objective has been developed. This system meets the challenge of the objective by combining proven processes and components in a "packaged system" described as follows:

1. The equipment should be completely preassembled at the factory and hydraulically tested prior to shipment to make sure all components are included and in completely satisfactory operating condition. An adequate supply of spare parts and maintenance materials must be a part of the package to avoid shut-downs and long delays in obtaining minor parts at remote installation locations. In our experience, this practice has proved invaluable where installations may be located 300 miles from a major city and accessible only by light aircraft.

   After testing and checkout at the factory, the system is then disassembled into a minimum number of sub-assemblies convenient for packaging and conservation of cubage for economical shipment. Export rating or export boxing may be specified depending upon shipping conditions.

2. Upon arrival at destination, the system should be located as close as practicable to the source of water supply with care being exercised to avoid danger of flooding during the rainy season. Specific limitations with regard to pump suction lift must be provided in the detailed instructions which are an important part of each "package". A suitable load-bearing base to support the system in a firm and plumb manner is the major requirement of on-site preparation.

3. The necessary components of such a system should consist of the following.

   a. A prefilter to be located in the water source should be provided to strain foreign matter such as leaves, twigs, reeds, sizable aquatic life and water-borne debris from the suction line thereby protecting the pump from such foreign matter.

   b. An electrically powered centrifugal pump with a capacity slightly exceeding the design output of the system is required to draw water from the source and deliver it to the initial stages of treatment.

   c. A simple system of aeration consisting of an eductor operating on the Venturi principle is necessary to aerate the incoming water as an aid to the elimination of objectionable tastes and odors which might be present in the raw water supply. This aeration also assists in oxidizing dissolved minerals such as iron or manganese which may be present. The aeration step is also an advantage when the source of water is a slow flowing stream or swampy area not subject to natural aeration through waterfalls or cataracts.

   d. Provision for pre-chlorination should be employed through a positive displacement chemical feed pump adjustable over a wide range, to chlorinate at a sufficient level to oxidize organic matter and destroy bacterial contamination which may be present in the raw water supply. Ample retention time is provided in the system for disinfection by chlorine. Break-point chlorination is recommended in many cases due to highly variable and unknown degrees of contamination in the source. Adequate provisions are included in the system for removal of excess chlorine from the effluent of the system. Gas chlorination is not considered because of the unavailability of this form of chlorine in many remote areas and the dangers associated with its handling.

   e. Coagulant solutions such as aluminum sulfate, ferric chloride, etc., are introduced through positive displacement chemical feed pumps. Thorough mixing of coagulants and adequate retention time for chlorination, flocculation and sedimentation should be provided during countercurrent flow through a vertical clarifier.

   f. A minimum of one hour of contact time must be provided for water passing through the clarifier to allow coagulated turbidity and other suspended matter to settle in the form of sludge in the conical base of the clarifier. This contact time also allows interaction between chlorine, organic material and bacteria.

g. Provision for transfer of clarified water to a suitably sized storage reservoir, preferably by gravity, should be provided.

h. Water from the storage reservoir must be repressurized by a centrifugal electric pump with a capacity in excess of the output of the system. The excess capacity is necessary to provide an adequate volume of water for backwashing the primary filter in addition to the normal capacity of the system. Backwash requirements of the post-filters employed will dictate the additional pump capacity required.

i. Primary filtration of the clarified water should be accomplished through a suitable layered bed type filter. A filter containing anthracite and filter sand is recommended to provide primary filtration and yet require a minimum of backwash water for conservation of clarified water.

j. Secondary filtration for "fine polishing" and excess chlorine removal should be provided. A combination filter using a mixture of diatomaceous earth, for turbidity removal, and powdered activated carbon, for residual chlorine and organic removal is recommended. The use of this type of filter is practical because the bulk of the turbidity and other foreign matter has been removed either during the clarification or primary filtration steps resulting in lengthy cycles for the secondary filter.

k. Post-chlorination of the effluent by a third positive displacement chemical feed pump is required for purposes of sanitation beyond the system itself. The chlorine residual maintained may be accurately controlled to desired levels depending upon the type and method of water distribution beyond the system.

l. A minimum of three chemical solution containers must be furnished as a part of the system for hypochlorite and coagulant solution mixtures.

4. Our experience with systems of this type has indicated that remote communities depending upon surface water supplies are efficiently served with three standard "packaged" models as follows:

   a. 50 cubic meters per day to serve from 300 to 600 persons,

   b. 100 cubic meters per day to serve from 600 to 1,200 persons,

   c. 250 cubic meters per day to serve 1,500 to 3,000 persons.

   The above capacities are based on daily water consumption of from 75 to 150 liters per person per day. For larger requirements, multiple installations of standard "packaged" systems are recommended, possibly at different locations along the source, thus reducing the distance involved in the distribution of treated water.

5. For areas where electrical power is not available, a suitable diesel-electric generator should be provided as a source of power.

Optional Details

A treated water reservoir is not furnished as part of the system since individual requirements for each installation will vary with respect to size and type. Reservoirs may be elevated to provide pressure for distribution where water mains are used or located at any convenient level suitable for less sophisticated distribution methods.

Enclosures may or may not be necessary depending upon climatic conditions. In most cases a protective roof can be used to advantage to protect chemical supplies and the operator from the elements. Local conditions will dictate the type and degree of enclosure necessary to protect the equipment from wild life, vandalism, pilferage or other conditions.

GROUND WATER

Thus far our discussion has been limited to forms of impurities which are suspended in water. Generally speaking, water supplies taken from the ground through wells are usually relatively clear, or free from suspended matter as a result of percolation through the earth which actually constitutes a form of filtration.

Although the earth does perform a filtration function as water seeps through it, we usually find that this process tends to increase the *dissolved* solids, or impurities, in the water pumped from a well as compared to the same water before filtration through the earth strata. The degree of increase in dissolved impurities in ground water will depend greatly upon the geology as well as the distance of the earth through which the water passes.

In areas of the world where relatively insoluble rock, such as granite, is predominant, we usually find ground water relatively low in solids with a tendency to be acid rather than alkaline. This is because the hardness of the granite resists the dissolving action of water, which falls as rain, and does not have a neutralizing effect on the carbon dioxide imparted by the atmosphere through which the rain falls.

In other areas where limestone constitutes the prevalent geology, we find higher concentrations of dissolved solids such as calcium in ground water. This water will usually be neutral or alkaline due to the alkalinity imparted by the dissolving limestone. This is what we commonly refer to as hardness in water which is quite prevalent throughout the North American and European Continents.

In the more arid regions of the world it is quite common to find deposits of sulfate, chloride and carbonate compounds which are quite soluble in water with the result that ground water supplies in such places as west Texas, Nevada, the African deserts, Saudi Arabia and the outback area of Australia may be highly mineralized and often termed as "brackish water supplies".

Another source of dissolved solids in water is the salt water oceans and seas of the world. Many times ground water wells on islands or in coastal areas near the sea will suffer from salt water intrusion thereby increasing the salinity or dissolved solids content of the ground water far beyond acceptable levels for human or animal consumption.

Experience

Distillation, evaporation, freezing and electrodialysis are among the techniques used to treat large volumes of water for the removal of excessive dissolved impurities. Within certain limits of dissolved solids concentrations, the ion exchange process of deionization has also been used to remove dissolved impurities from water.

Each of these methods of water treatment involve substantial capital investments, rather sophisticated technology, technically trained personnel for operation and maintenance and rather sizable installations where economic operation is a factor.

The Solution

Whereas other methods of solids reduction from water involve huge investments for economic feasibility, trained technicians for operation and maintenance, or the handling of dangerous acids and alkalis for regeneration, the reverse osmosis process lends itself to small, simple, easy to operate systems falling within our definition of "Packaged Water Treatment Plants". Simply described, a Packaged Reverse Osmosis System basically consists of a prefilter, to protect the pump from suspended matter, a pump with electrical motor and a membrane module. Such systems are suitable for continuous or intermittent duty, require no regeneration and a minimum of maintenance. Experience with membranes on thousands of different water supplies has proven that, when operated within specification limits, membrane life of one year can be guaranteed. Membranes in service for as long as two, two and a half and three years are not uncommon.

Small household reverse osmosis membrane units with capacities of three gallons per 24 hours of operation on ordinary line pressure of 50 pounds per square inch have been on the market for over three years. Small packaged reverse osmosis systems ranging in size from 500 gallons to 50,000 gallons per day are on the market. Small packaged systems, in the range of 500 gallons to 5,000 gallons per day, can satisfy a tremendous need for the treatment of moderately brackish waters (up to 6,000 ppm TDS) and have tremendous application in many parts of the world including Southeast Asia. If restricted to drinking purposes only, a 500 gallon per day system could provide drinking water for from 1,500 to 2,000 inhabitants of a village with a brackish raw water supply. The economics of treating water by reverse osmosis favor the use of multiple units mass-produced in a specialized factory and installed in a modular fashion to satisfy requirements of 1,000, 2,000, 3,000, 4,000, or 5,000 gallons per day.

Case History

It is often possible for ground water supplies to be so highly mineralized that they are unsuitable for human or animal consumption. Oftentimes when such results are determined in the analytical laboratory, recommendations will be for the owner of the water supply to seek another source such as drilling a new well, hauling water from a distant source or even extending municipal water mains to provide an acceptable supply. A perfect example of such a situation is the rest stop on Federal Highway 1-80 at Adair, Iowa, where the raw water has a total dissolved solids content of 2,090 ppm. United States Public Health Service standards for drinking water specify a maximum TDS of 500 ppm. The effluent from a reverse osmosis system produced water having a TDS content of 180 ppm. Over 80% of the solids in this water supply were sulfates. Reverse osmosis membrane treatment reduced the sulfates to 57 ppm. One of the alternatives to reverse osmosis treatment for this water supply was to bring a municipal water line from a small town a short distance from the highway. However, the town was located on the opposite side of the highway from the rest stop. This is a four lane divided highway and the cost of bringing the water under the highway itself was estimated at approximately $50,000. The completely installed cost of the reverse osmosis system was under $2,000.

Side Benefits

Reverse osmosis membranes are semipermeable and although there is not complete agreement on the theory of how water passes through the membrane, we do know that no pores can be detected, even by an electron microscope, and as a result, the smallest of particles, even colloidal suspensions, are effectively removed from the water as it passes through the membrane. With *ultrafiltration* there is the possibility that reverse osmosis membranes will filter bacteria from water. There is good evidence that this is true but membrane suppliers and equipment manufacturers are carefully avoiding such claims at the present time. The slightest manufacturing defect in the membrane or membrane deterioration after prolonged use could allow bacteria to pass. Therefore, until there has been considerably more experience both in the manufacture and use of membranes, specific claims with regard to bacteria removal are unwarranted. Certain countries in the Far East are noted for their production of micro-electronic circuits. Although deionization is the accepted method of producing solids-free water for rinsing critical electronic circuits, the presence of the slightest amount of organic matter in the deionized water can cause failure of these micro circuits. The *ultrafiltration* capability of reverse osmosis in conjunction with deionization by ion exchange holds great promise for the electronics industry.

OTHER PACKAGED WATER TREATMENT PLANTS

The water conditioning industry offers many other small packaged systems suitable in size for needs from the small home to the small community, industry, institutions, camps, resorts and hotels.

Packaged Filter Systems

Small point-of-use filters suitable in size for treating a single outlet in a home, hotel, factory or laboratory are mass-produced by many manufacturers. Many of these filters may be fitted with interchangeable cartridges specifically designed for removal of turbidity, taste, odor or color from water. Others are also available with cartridges or refills designed to feed chemical additives to water for purposes of purification, corrosion control, neutralization and other similar applications. Larger filters in sizes ranging from that required for a household to a large factory, institution or hotel are manufactured in standard packaged sizes by many water conditioning manufacturers.

Swimming pool water filtration is another category of water treatment best served by packaged filtration systems. Again, a system consisting of a recirculating pump and filter, usually of the diatomaceous earth type, is manufactured by many suppliers and offered in standard sizes to fit the requirements of pools from the smallest private pool to the largest Olympic competitive pool.

Packaged Purification Systems

Positive displacement chemical solution feed pumps and chemical solution containers in a range of sizes are offered as packaged systems for water purification of small water systems and swimming pools. Relatively recent developments in cylinder mounted gas chlorination devices have done much to eliminate the hazards usually associated with handling chlorine gas much to the advantage of the larger industrial and swimming pool water purification requirements.

Packaged Deionizer Systems

Both manually operated and automatic deionizer systems are offered in a wide range of sizes and types. Multiple bed units with cation and anion exchangers in separate columns, unibed units with cation and anion exchangers intimately mixed, or layered bed systems using ion exchangers of different densities, in a single tank, depending upon specific application are all available as packaged systems.

Packaged Water Softener Systems

Wherever anything is washed, whether it be people, clothing, dishes, automobiles or airplanes, an ion exchange water softener has become an economic necessity. A recent two-year study completed by the Water Conditioning Research Council compared the costs of hard water for one year and softened water for another year in motels of various sizes supplied by water varying in hardness from 137 to 360 ppm. Six motels were included in this study. The savings, in one year, resulting from the use of softened water for the entire water supply to these motels did, on the average, amortize 82.2% of the cost of the packaged water softening systems installed.

CONCLUSION

The immediate water treatment needs of small communities, industries, institutions, resorts and camps can, in most cases, be served quickly and economically through the use of packaged water treatment plants as compared to a custom engineered plant. By "quickly served" we mean a system that can be installed and operating within from one day to one week after its arrival on the job site. The equipment may range in cost from less than $1,000 to a maximum of $50,000. The value and the need for small Packaged Water Treatment Plants in all areas of the world where sophisticated municipally treated water supplies are unavailable are clear.

NUCLEAR ENERGY'S ROLE IN WATER RESOURCES DEVELOPMENT

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INTRODUCTION

The United States Atomic Energy Commission believes strongly that by combining the atom with desalting it can make dramatic and beneficial contributions to water resource development, not only in the United States but throughout the world. Nuclear desalting is large-scale desalting and it can help solve large-scale water supply problems. For example, in the United States the "breakeven point" for costs of nuclear power and fossil fueled plants occurs at capacities of about 500,000 electrical kilowatts or greater. This translated into a power-desalting case would be a plant which could produce about 300,000 kilowatts of electricity and over 100 million gallons of fresh water a day. Accordingly, nuclear desalting will not be the panacea for all water problems, but it can become an important tool for many regions in their planning for future water resource development.

DESALTING

Desalting, unlike nuclear energy, is not a product of the 20th Century. In fact, references to desalting can be traced back to the early days of Rome and Greece, and there are Biblical notations about bitter waters being turned sweet. Nevertheless, the development of desalting for other than specialized roles had not been actively advocated or pursued until about 1955 when it was recognized that the application of nuclear power to desalting offered a potential solution to our growing water and power problems. At that time, however, nuclear power had not yet been scaled up in size or achieved commercial acceptance, and desalting was limited principally to very small fossil-fired units for shipboard application and for isolated land-based needs. Neither "conventional" desalting nor nuclear energy had then reaped the benefit of the world's technological capability.

During the past decade, significant progress has been made in the field of desalting and this is being reflected in its increased use. For example, in 1964 the world's total installed desalting capacity was only 107 million gallons per day. In 1967, only three years later, more than 220 million gallons per day capacity was installed or under construction. The Office of Saline Water estimates that at the close of 1969 there were approximately 700 land-based desalting plants with unit capacities of 25,000 gallons per day or larger and that the world's total installed capacity was nearly 300 million gallons per day.

By combining two new technologies–nuclear power and desalting–we can add a vast new dimension to man's continuing search for water and energy. Large nuclear desalting plants can enable us to take advantage of the vast energy resources available from the atom, and the vast raw material for fresh water that the oceans of the world hold in store.

POTENTIAL NEED FOR DESALTING

The potential need of desalting to the southwest United States and to many areas of the world is becoming readily apparent. The need for fresh water already is a fundamental problem facing many communities, regions, and nations. In some areas the shortage of water is a major and perhaps the single most important limitation on increasing the production of food to alleviate hunger–one of mankind's most challenging tasks.

While desalting will be of profound importance to the United States, its role may be even more critical in other countries whose water problems are more urgent and acute than our own. Accordingly, the United States' program has been oriented toward developing technology that will be useful to — and available to — water short nations throughout the world. We have studied the potential application of large-scale nuclear desalting technology to a number of areas of the United States, the Near East, and the rim of the Mediterranean, including Greece, Israel, and the United Arab Republic. Nuclear desalting has also been considered for Italy, Spain, Tunisia, Chile, and Peru and is being considered in such areas as India, Pakistan, and Australia.

CURRENT STATUS OF AEC STUDIES

Dual-Purpose Plants

Several studies have been undertaken on the potential application of large-scale dual-purpose desalting plants. Dual-purpose plants, whether nuclear or fossil-fired, are those that produce fresh water as well as electricity. This type of operation offers economic benefits over separate "power-only" and "water-only" plants since the power can best utilize the high availability energy as it is produced while the desalting plant needs only low pressure-low temperature energy for its operation. Also, the use of a large single heat source offers scaling economies over separate smaller heat sources.

Florida Keys Study

One of the earliest dual-purpose nuclear desalting studies undertaken was that for the Florida Keys. This study, completed in 1964, investigated various methods of supplying Key West and the Florida Keys with fresh water and power. This study indicated that a 220 MWt reactor at 7.3% fixed charge rate could barely compete with a comparable fossil plant using 42 cents per million BTU fuel. Even though this study did not result in a nuclear desalting plant, we believe that our efforts were instrumental in desalting being selected to augment their water resources. For several years now, a 2.6 MGD fossil-fired desalting plant has been serving as a reliable and economic source of fresh water for the City of Key West and the lower Florida Keys.

U.S.-Mexico Study

A more recent study of special interest to the United States and Mexico was completed in 1968 and a report (U.S.-MEXICO IAEA STUDY TEAM, 1968) issued early last year. This study indicated that nuclear plants producing 2,000 megawatts of electricity and 1 billion gallons per day of fresh water were technically feasible approaches to providing additional fresh water and power to the arid southwest region under study, and that favorable economics could be expected from these large plants following the construction and operation of appropriate prototype and demonstration projects. The joint U.S.-Mexico study team recommended, as the next step, a number of technical and economic studies that should be investigated further and we are in the process of assessing the means for carrying out these recommendations. We expect to discuss these recommendations with Mexican representatives in the near future.

U.S.-Israel Study

A cooperative study was also carried out by the United States and Israel on the engineering feasibility of a large-scale dual-purpose project for Israel (U.S.-ISRAEL JOINT BOARD, 1966). The initial study in 1965 was for a plant of 200 MWt-100 MGD*. This study concluded, among other things, that it would be desirable at this time to continue engineering development work on the desalting features, including test modules, which would combine an advanced "evaporator" process with the proven "multi-stage flash" distillation process. It is expected that this work will be carried forward in the United States and that close cooperation will be maintained with Israeli technicians.

Energy Center Studies

As a logical extension to our original desalting program activities, we have initiated investigation into the role that nuclear energy might play in other industrial applications which are large energy consumers as well as the managed use of desalted water in intensive agriculture. The most compre-

* This was subsequently increased to 300 MWt-100 MGD.

hensive of such studies published to date has been the energy center study completed at our Oak Ridge National Laboratory in 1968 (OAK RIDGE NATIONAL LABORATORY, 1968). This was a study initiated in 1967 to assess the technical and economic potential of combining several energy intensive industries and desalting plants in a complex grouped around a large low cost energy installation. While industrial complexes have evolved naturally around low cost fuel sources such as the coal fields in South Africa and the oil and gas fields of the U.S. Southwest, the Oak Ridge National Laboratory study represents one of the first systematic analyses of the energy center concept based on nuclear power. The results of the Oak Ridge National Laboratory energy center study were sufficiently promising that several follow-on studies are being planned. One follow-on study was initiated last summer to specifically explore this concept as it might apply to the Middle East.

Puerto Rico Study

We are also cooperating with the Department of the Interior and agencies of the Commonwealth of Puerto Rico in a study of an energy center for the southern coastal regions of Puerto Rico. I have often referred to this as a "partial energy center" since various factors in Puerto Rico may tend to limit the size of the energy source and favor industrial development over that of agriculture. It may be that other early energy center projects will also have to start as "partial" centers and build up to the large sizes postulated by the Oak Ridge National Laboratory. While the total economic benefits from scale might not be possible in such "partial" projects, reduced investments, reduced risk, early demonstration benefits and other features may make them more acceptable initially.

Indian Studies

The Indian Atomic Energy Commission, in cooperation with other Indian agencies and the Oak Ridge National Laboratory, is studying the energy center idea for two areas in India. One of the projects, which has been proposed for the Gangetic Plain, would supply power for an industrial complex and for pumping groundwater for agricultural uses. The location proposed for the other energy center is on the Gujarat Penninsula. In this project a dual-purpose reactor would supply power for industry and desalt sea water for agricultural uses. Preliminary assessments with favorable results were completed early last year and the Indians are proceeding with more detailed studies of both projects related to their implementation (BHABHA ATOMIC RESEARCH CENTRE, GOVERNMENT OF INDIA, 1968).

INTERNATIONAL COOPERATION

From the outset of the United States' program on large-scale nuclear desalting, a major objective has been cooperation with other nations directed toward widespread application of the benefits of this new technology in the water-short areas of the world. We have shared and will continue to share our knowledge and experience with others. We have gone beyond this by cooperating directly with a number of nations in surveys and studies of the applicability of nuclear desalting to specific needs or regions. In carrying out these activities, we have worked closely with the International Atomic Energy Agency, whose participation has been invaluable both to insure the widest possible exchange of information in the field as well as to bring to bear the special knowledge and judgment of an international organization.

CONCLUSION

In conclusion, I would like to reiterate our optimism for the future of nuclear desalting and the role it can play in future water resource development. Drawing on the technology and experience already available, there is little doubt in my mind that the "success story" of nuclear power can be repeated with large-scale desalting. The world's increasing population and demands for water and energy present a challenge to all of us. We will need in the years ahead energy and fresh water from all sources. The successful development of nuclear desalting will help satisfy these demands. We are looking forward to initiating one or more large demonstration nuclear desalting projects in the not too distant future. The technology from such projects and the results of our cooperative studies and technical programs should provide valuable input to the successful application of nuclear desalting. And, as the President of the United States has previously stated, what we learn from our endeavors we would expect to share with our friends abroad.

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BANGKOK'S WATER PROBLEMS AND SOLUTIONS

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INTRODUCTION

Bangkok has served as the capital of Thailand for 187 years. From its pre-capital days as a quiet fishing village, it has grown to be one of the world's major metropolitan areas. Like most such areas the construction of adequate water supply facilities has not kept pace with the demands made by the rapidly increasing population.

Metropolitan Bangkok

The four municipalities of Bangkok, Thonburi, Nonthaburi and Samut Prakan form the core of the Bangkok metropolitan area. The present (1970) population of all four municipalities is slightly less than 3,000,000. Of this total, about 2,200,000 live in Bangkok, 700,000 in Thonburi, and Nonthaburi and Samut Prakan have less than 50,000 people each.

Bangkok's importance in Thailand results from its position as the capital and as the major financial and industrial center in Thailand. A measure of its importance is gained through the realization that, in a country of 35,000,000 people, the largest city outside of metropolitan Bangkok is Chiengmai, with a population of less than 100,000. In addition, Bangkok is serving increasingly as one of the major cultural and regional centers of South East Asia. Examples of this include the Asian Institute of Technology, the regional offices of several United Nations agencies and the principal office of many commercial organizations doing business in this part of the world. Bangkok's location and history makes it a major air travel center and popular tourist stop. As Thailand's capital, Bangkok houses many foreign embassies and their missions.

Metropolitan Water Works Authority

The Metropolitan Water Works Authority (MWWA) assumed responsibility for supplying water to customers in metropolitan Bangkok in 1967. Before that, each of the four municipalities in the Bangkok metropolitan area served water to their people through a municipal water department.

Bangkok's first piped water supply system went into operation in 1914. Thonburi has had a marginal water system since 1917 but not until 1955 did Thonburi start to serve a significant number of its people. The Samut Prakan system started in 1958 and the Nonthaburi system in 1960. The water systems in these four municipalities are still operated as separate entities, but all are now under the jurisdiction of the Metropolitan Water Works Authority.

Description of Present Problems

Water problems have been experienced in the Bangkok area more or less continuously for many years. The degree of such problems varies from year to year, depending upon the rainfall, the amount of additional water supply facilities provided, and the size of the new demands made upon the system. Low pressures are general throughout the system. In addition, complete lack of water for hours or even days is experienced in some portions of the system which are remote from the treatment plants or the many wells which provide about one third of the total water supply. The primary method used over the past five years to combat the water shortage has been to drill a well in the general vicinity of those areas with the greatest need. While this procedure has been reasonably successful in the past, decreasing ground water levels and increasing salinity indicate that relatively little additional supply can be provided in this manner.

For fiscal year 1969, the total non-capital cost of the metropolitan water system amounted to 5.3 million dollars (US) and the total revenue from all sources was 3.5 million dollars. The Government of Thailand subsidized the water system by the amount of this deficit and by granting an additional 6.8 million dollars for capital expenditures.

One reason for the large deficiency in revenue is the ineffective metering situation. While the system is nominally 100 percent metered, approximately 60 percent of the meters do not function at all and many of the remainder do not function properly. Investigations show that meter readers consistently make low estimates of water use for customers with broken meters. Some magnitude of the problem is gained from the data which indicated that only 35 percent of the total water produced is billed, and that leakage studies show that less than 10 percent of produced water is lost through leakage. The clear inference is that the average customer is billed for less than half of the water used.

These technical and financial problems are at least partly attributable to weaknesses in the field of administration and management. These weaknesses, in turn, are part of the growing process of any new government agency, coupled with the usual problems of lack of trained manpower and budgetary limitations. Nevertheless, these must be overcome if the MWWA is to carry out its functions efficiently and economically.

Purpose of the Master Plan

In 1966 as a result of the deficiencies in water supply, the Government appointed a committee to study the problem. The committee selected a consultant and prepared a scope of work for the Master Plan.

The purpose of the Master Plan is to present estimates of population and water use in metropolitan Bangkok up to the design year 2000, to recommend water supply, treatment and distribution facilities necessary to satisfy the expected water requirements, and to prepare an estimate of the cost of these facilities. The area of study includes the 3,130 square kilometers which constitute the region to be served by the MWWA. This area is shown in Figure 1.

The Master Plan also will present recommendations for the proper operation, maintenance and administration of the proposed facilities and suggest methods for financing their costs. The Master Plan was to be completed in February 1970.

POPULATION AND WATER USE

Total Population

The four municipalities of Bangkok, Thonburi, Nonthaburi and Samut Prakan have a present, estimated population of 2,900,000 people. Over the past nine years, these four municipalities have been growing at an average rate of 5.7 percent per year. The estimated probable future population for Bangkok and Thonburi municipalities is assumed to follow a pattern of generally declining growth rates. Nonthaburi and Samut Prakan, however, are expected to grow at a much more rapid rate than they have for the past nine years. These two municipalities are expected to grow tremendously by the design year. This growth will be the result of the "spill" of Bangkok beyond its borders to the north and south. These four municipalities have a present, total municipal area of 300 square kilometers. To accommodate the

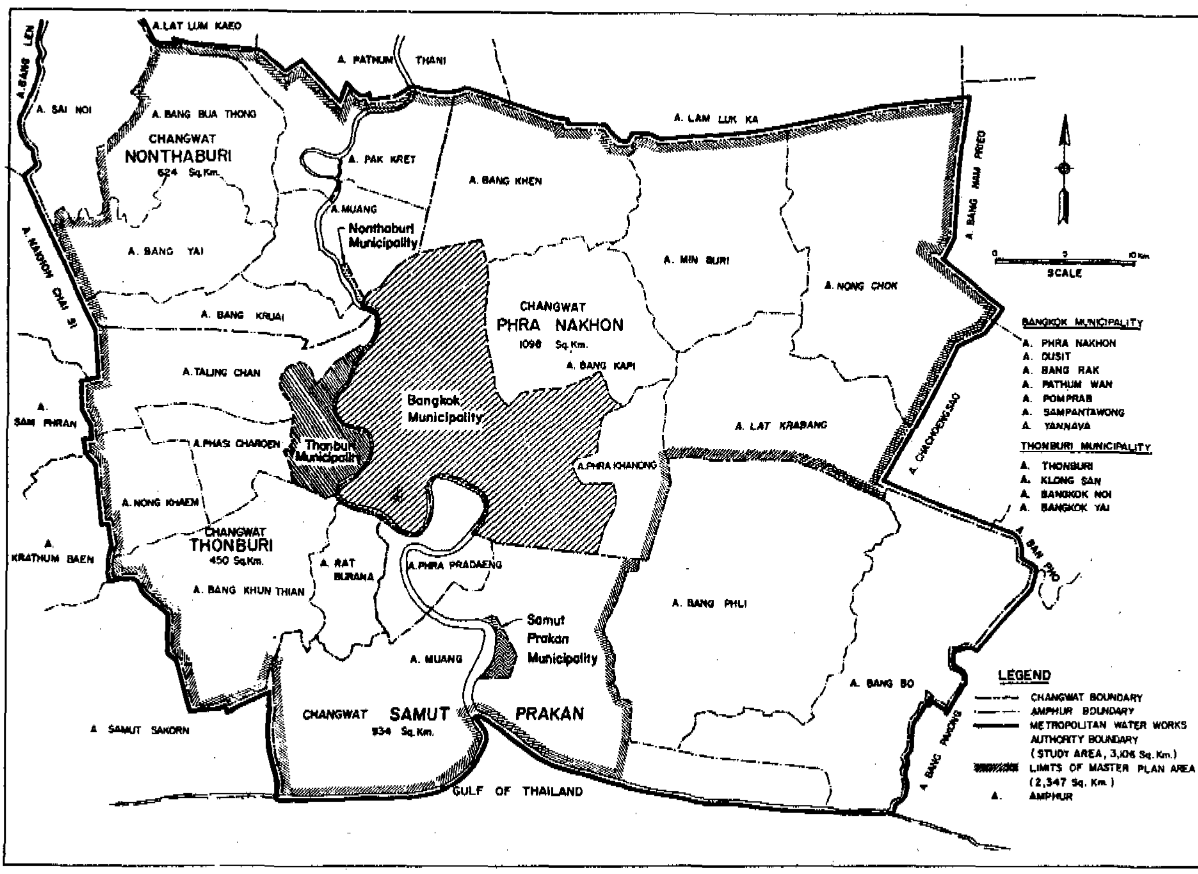

Fig. 1—Plan of Metropolitan Water Works Authority Area.

expected future population, this total area is expected to approximately double by the design year and about 10,000,000 people are expected to be living in the metropolitan area at that time.

Population Served

Not every one living inside of the MWWA area will receive water from a public piped water supply system by the design year. Many persons will still live in populated areas which cannot be served economically. Even in the central areas, some will not be served.

Portions of the present municipal water system extend beyond the municipal boundaries. A total of 3,000,000 people now live in the four municipalities and the other areas into which the water system extend. The present number of persons served by all four water systems is 1,850,000 or 62 percent of the total population.

After about five years, these four municipal systems and several smaller systems outside these municipalities are expected to be merged into a single, central water system. By the design year, an estimated 85 percent of the total number of people living inside the expanded municipal areas are expected to be served by the central system. This represents a served population of 8,500,000 people by the year 2000 A.D.

Present Water Use

For a variety of reasons, limited data are available on present water use in the Bangkok metropolitan area. To overcome this problem, the Consultants conducted numerous field investigations and collected and analyzed information from a wide variety of sources. The present total public water supply in metropolitan Bangkok is approximately 950,000 cubic meters per day (CMD), of which about 35 percent comes from groundwater sources. In addition to this public water supply, 200,000 CMD is utilized from private wells. The total amount of water use in the metropolitan central system, therefore, is approximately 1,150,000 CMD.

Based on the number of persons served and total production of each of the four municipalities, the present per capita water production is as follows, not including private water supply :

Bangkok	580 lpcd
Thonburi	350 lpcd
Nonthaburi	460 lpcd
Samut Prakan	450 lpcd
Average	515 lpcd

These per capita rates are quite high, particularly for Bangkok. Field studies over the past 18 months indicate that not more than 10 percent of this amount is lost because of leakage and that most of this water is either used or wasted by the customers.

Water use in Bangkok has increased at an extremely rapid rate in the past 15 years. One of the reasons for this rapid increase is the large proportion of non-functioning meters and the corresponding low water use charges. In Bangkok, 60 percent of the meters do not function at all and many of the remaining meters do not function properly. In addition, water use charges in Bangkok are approximately one fourth of those in many other communities in Thailand. Conditions such as this encourage the waste of water and do not permit the Authority to collect the revenue due for the amount of water delivered.

Expected Future Water Use

In estimating the future amount of water expected to be required in metropolitan Bangkok it was assumed that the present situation and past trends in water use will be corrected. The Master Plan will present recommendations on how the present trends are to be changed, but it will take several years to do so. By the year 1975, the average water use in the metropolitan area is expected to be about 440 liters per capita per day (lpcd). Following that, water use is expected to increase gradually until it reaches about 509 lpcd by the design year 2000. At that time the total public water use in the central system is expected to be 4,300,000 CMD, on the average day.

For the Bangkok metropolitan area, there are no historical records available to determine the relationship between maximum daily demands and average daily demands. The present facilities operate at full capacity 24 hours per day so that, in a sense, every day is a maximum day and every hour is a peak hour. On the basis of an evaluation of factors affecting variation in water use in communities similar to Bangkok, however, the following rates were adopted for design:

Relationship of Flow	*Ratio*
Maximum Daily Flow to Average Daily Flow	1.25
Peak Hourly Flow to Average Daily Flow	1.70

Knowledge of average daily flow requirements is necessary for determining the cost of power and chemicals and for determining the amount of the expected revenue in the future. Maximum daily flow demands are necessary to determine the capacity of facilities such as water supply and treatment units. Peak hourly flows are used to design the distribution facilities in the water system. Figure 2 summarizes present and expected future population and water use in the Bangkok metropolitan area.

ALTERNATIVES CONSIDERED

Sources of Supply

About two thirds of the present supply is obtained by treating water from the Chao Phrya River. The remainder comes from groundwater.

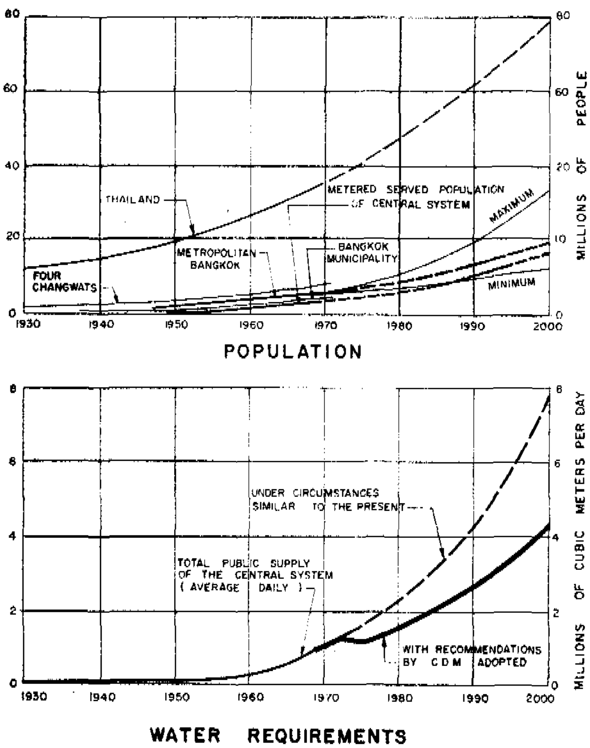

Fig. 2—Population and Water Demand in Bangkok Metropolitan Area.

Present large scale withdrawal of groundwater by public and private wells appears to be exceeding recharge capability. Attendant problems of rapidly falling water levels and rising chlorides, together with excessive iron in many areas, have led to the abandonment of about one third of all the public wells installed in the past 15 years. For these reasons it is proposed to gradually discontinue the use of groundwater as a source of public supply in metropolitan Bangkok.

Reservoirs on other rivers were investigated as alternate sources but such schemes are very expensive because of the long distance. Irrigation canals are not feasible as a source of supply because of strict regulation by the Royal Irrigation Department, and present and potential water quality problems.

The clear decision is that the Chao Phrya River should continue to be used as the principal source of water supply for metropolitan Bangkok. Flow in the river must be regulated to insure an adequate amount at all times for water supply. The intake is proposed to be maintained at Sam Lae, the site of the existing intake, 35 kilometers north of Bangkok. This location will ensure that the water is free from saline intrusion under all conditions.

Treatment

A single new treatment plant will be more economical than several smaller ones. The plant should be located as close as possible to the center of demand in order to minimize the cost of transmission conduits. A site in the Bang Khen area is proposed, approximately 12 kilometers north of the center of Bangkok.

Sedimentation and rapid sand filtration were considered the only feasible method of treatment but several alternatives were evaluated for each. For sedimentation, slurry type, solids contact clarifiers were selected because the high loadings possible result in considerable savings in land and because past experience with this type of clarifier in Bangkok has been satisfactory. Dual media (sand-anthracite coal) filters with an air-wates backwash were chosen because of the high loadingr and excellent results which are possible with this type of filter.

Storage

The principal alternatives in distribution storage lie between elevated and ground storage. The operational advantages of elevated storage are counterbalanced by the practical and economic difficulties which arise from trying to provide the required amount. The use of ground storage reservoirs and pump stations is proposed rather than elevated tanks.

Reliability

The reliability of a water system is dependent upon the power source used to do work throughout the system and the number of the duplicate facilities available when some units are out of service for routine maintenance or emergency repair.

Electric power in the Bangkok area is reasonably reliable with an average of no more than two power outages per year of one to two hours duration. Stand-by power is not recommended for the raw water pump stations or treatment plants. One engine-driven pump is proposed at each distribution pump station, however, to provide somewhat less than half of the average water demand. For cases where the pump station reservoir is only half full at the time a power outage occurs, the engine-driven pump will be able to provide water for up to four hours.

Proposed System

A single, central water supply system is proposed to satisfy the needs of metropolitan Bangkok. Separate systems are proposed for people in populated areas distant from the central system. The central system will consist of an intake pump station on the Chao Phrya River at Sam Lae, widening of 21 kilometers of Klong Prapa, the existing raw water canal, and a major new treatment plant at Bang Khen. The treated water will be pumped into a transmission conduit system to a series of ground level reservoir-pump station units located throughout the metropolitan area. The water will then be pumped into the distribution system for use by customers of the Authority.

SURFACE WATER

Chao Phrya River

The Chao Phrya has a drainage area of 177,000 square kilometers. It is used heavily for irrigation, power and navigation, in addition to serving as Bangkok's water supply. During the drought of the past two years, flows as low as 30 CMS were experienced. In one three-month period, flows past Bangkok did not exceed 60 CMS.

The expected requirements are for 70 CMS (6,000,000 CMD) by the design year, so it is obvious that regulation of flow will be necessary. The Royal Irrigation Department indicates that after the Sirikit Dam is completed it will be possible to maintain a minimum flow of 120 CMS in the Chao Phrya River at all times. The Sirikit Dam is on the Nan River, a major tributary of the Chao Phrya, and it is expected to be completed within two years.

Proposed Surface Water Facilities

The proposed surface water facilities include a new intake pump station on the Chao Phrya River at Sam Lae, improvements to 21 kilometers of the existing raw water canal to conduct the river water to the treatment plant site, and a new siphon structure to allow the flow in the raw water canal to pass under Klong Rangsit, a major irrigation drainage canal.

TREATMENT

Site

The optimum location for the new treatment plant is one which puts it near Klong Prapa, the raw water canal, but as close to Bangkok as possible without encroaching on developed land. Approximately 640,000 square meters will be required. The following facilities will be located at the site:

Treatment Units	Administrative Offices
Pump Stations	Laboratory
Chemical Storage	Maintenance Shops
Sludge Lagoons	Employee Housing

Proposed Treatment Facilities

A plan of the proposed Bang Khen water treatment plant site is shown in Figure 3. The proposed treatment process consists of screening, clarification, filtration and disinfection, and disposal of clarifier sludge and filter washwater. In addition, the raw water is pumped to the clarifiers after screening, and the filtered, disinfected water is discharged into a filtered water reservoir and then pumped to the transmission and distribution system. These facilities are described briefly as follows:

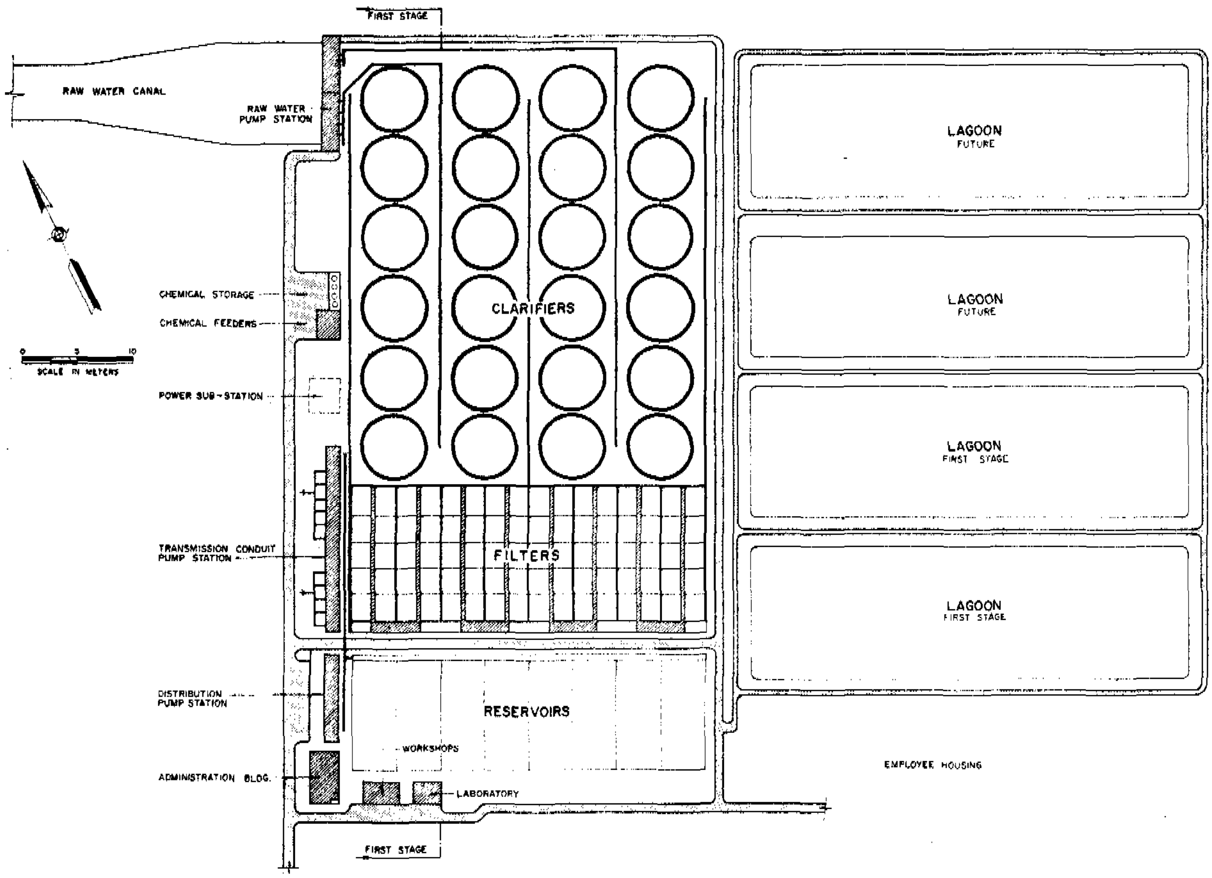

Fig. 3—Bang Khen Water Treatment Plant.

Screening — Mechanically cleaned vertical bar screens are proposed.

Raw Water Pump Station — A total of 12 electric motor driven pumps of 500,000 CMD capacity each will be required by the design year.

Clarifiers — A total of 24 solids contact clarifiers with a capacity of 200,000 CMD each will be required by the design year. The 60 meter diameter clarifiers will be of the slurry recirculation type, similar to those at Sam Sen Plant 10 with a loading rate of 70 millimeters per minute (2,400 gpd/sq ft).

Filters — A total of 80 double filters with a capacity of 60,000 CMD each will be required by the design year. The filters will have media of sand and anthracite coal and will be backwashed by a combination of air and water. The filter loading rate will be 200 millimeters per minute (5 gpm/sq ft) which is about 2.5 times the rate used at the existing Sam Sen and Thonburi plants.

Filtered Water Reservoirs — The filtered water reservoirs will have a volume of about 10 percent of the plant at maximum daily capacity.

Transmission Pump Station—Most of the water produced will be transmitted by conduit to several distribution pump station sites. A total of 12 electric motor driven pumps of

430,000 CMD capacity each will be required by the design year.

Local Distribution Pump Station — Some of the water produced will be distributed locally. For the design year, four electric motor driven pumps and one diesel driven pump of 160,000 CMD capacity each will be provided.

Sludge and Washwater Lagoons — Large shallow earth lagoons will be provided to receive the sludge from the clarifiers and the solids from the filter washwater. A total of four lagoons will be provided by the design year. They will cover an area of 256,000 square meters. The lagoons will have sloping earth sides and a depth of three meters. Effluent from the lagoons will be returned to the influent or wasted to a nearby canal, as desired. Solids collected in the lagoons will be removed periodically.

The continued use of the existing Sam Sen and Thonburi treatment plants is proposed through the design year. The Sam Sen plants will have a capacity of 700,000 CMD and the Thonburi plant will have a capacity of 160,000 CMD.

TRANSMISSION AND DISTRIBUTION

The transmission pump station at the Bang Khen treatment plant will pump water into a system of large diameter conduits. These conduits will deliver the treated water to reservoir-pump station units at various centers of demand. From there, the water will be pumped into the distribution pipelines. The transmission conduits, the reservoir-pump station locations and the major distribution pipelines are shown in Figure 3. These facilities are described briefly as follows:

Transmission Conduits—The transmission conduits are expected to be constructed mostly as tunnels because of their large diameter and the fact that most of them must be constructed in congested areas. A total of about 80 kilometers of conduit, from 1.75 to 4.5 meters in diameter, will be required by the design year. The transmission conduits will terminate in receiving structures which provide control at each reservoir-pump station site.

Distribution Reservoirs — A total of 12 distribution reservoir sites will be required by the design year, in addition to those at the three treatment plant sites (Bang Khen, Sam Sen, and Thonburi). Each site will contain reservoirs constructed as twin concrete tanks. The tanks will be completely enclosed and partially buried with a capacity of about 20,000 cubic meters each, or 40,000 cubic meters per site.

Distribution Pump Stations — A distribution pump station will be constructed at each reservoir site. Five pumps will be provided in each station. One will be diesel driven for use only during power failures. Three of the four electric motor driven variable speed pumps will have a combined capacity equal to the peak hourly demands of the area served by the reservoir-pump station unit.

Distribution Pipelines—Large trunk mains up to 1.5 meters in diameter will carry the water from the pump stations to distribution pipelines throughout the system.

The distribution system was designed utilizing an IBM 360-40 computer for the network analysis.

CONSTRUCTION SCHEDULES AND COSTS

The proposed facilities will be constructed in increments or stages as required. High interest rates and competing uses for the financial resources of Thailand make it unwise to construct facilities much larger than required for immediate needs.

Staging of Construction Programs

As a general rule, it is proposed to construct major facilities so that they will have adequate capacity for about five years after their completion. Before the end of this five year period, a second group of facilities will be completed which also will have sufficient capacity to serve short term future needs.

Facilities such as distribution pipelines will be constructed in continuing annual programs. The "stages" of distribution pipelines presented in the Master Plan only indicate those facilities needed to meet the estimated water requirements for 1975, 1985 and 2000. The transition from the 1975 to the 1985 system will be a gradual one.

The first stage program for most of the major facilities should be completed by about 1975 and should have adequate capacity to serve until about 1980. No single year can be selected for the second stage. In one year, additional treatment units may be required, while the next may see the need for another 10 kilometers of transmission conduit. The following year more raw water pumps may have to be added.

Cost Estimates

The estimated construction cost of all facilities required for the first stage construction program is approximately 100 million US dollars and the total construction cost of the program to the design year is about 500 million US dollars.

FINANCIAL FEASIBILITY

The proposed major improvements and extensions will result in a metropolitan water supply system capable of satisfying the needs of the people of the area. From the beginning, possible designs and alternative plans have been assessed with cost in mind. The goal has been to design a water system which can be completely self-supporting, at water rates not substantially higher than those now in existence in many communities in Thailand and at a total cost to low income families of less than three percent of the total family income. The proposed system is feasible within these terms of reference.

Several possible financing methods and rate structures were studied. The recommended financing plan and a suggested rate structure to generate the required revenue are described.

Financing Plan

Some of the annual costs will be paid directly out of annual revenues. The magnitude of the capital costs required is so great, however, that money must be borrowed to pay these costs.

The amount of money to be borrowed was determined on the basis of the following:

—Annual operating costs will be paid out of current revenue.

—A small portion of the average annual capital costs also will be paid out of current revenue.

—Capital costs for smaller distribution pipelines will be assessed against builders or property owners that benefit directly from the extension of service into streets formerly without pipelines.

—The total cost of service connections to the distribution system will be assessed against the customers.

The remaining capital costs will be financed by borrowing. About 20 percent of the total capital costs will require expenditures in foreign currency to pay for materials and equipment not produced in Thailand. It has been assumed that the foreign exchange component of the capital costs will be financed by an international lending agency. The local currency portion of the capital costs probably will be financed by borrowing from the Government. The estimated repayment terms are as follows:

Foreign Exchange Loan Terms

—Interest rate of 8 percent
—Length of loan: 20 years
—Grace period of 4 years
—Principal repayment in equal installments

Local Currency Loan Terms

—Interest rate of 8 percent
—Length of loan: 30 years
—Grace period of 5 years
—Principal repayment in graduated installments

Revenue and Rate Structures

The costs of some of the distribution pipelines will be financed by charges against developers or land owners who benefit directly from the pipelines which these costs represent. Service connection costs will be paid directly by the customer. All other costs will be paid for out of current revenue from water use charges.

The Master Plan will present several alternative rate structures. One suggested rate structure assumes a higher rate for commercial, institutional and industrial customers, and a lower rate for domestic customers. The rate for the first five years would be about US$ 0.07 per cubic meter ($ 0.20/100 ft^3) for domestic customers and $ 0.09 per cubic meter ($ 0.25 / 100 ft^3) for all other customers. The present rate in Bangkok is $ 0.0 2½ per cubic meter but it is $ 0.07 in Thonburi and $ 0.09½ in Nonthaburi. The suggested new water rates are expected to be adequate to repay the total annual cost of the program.

Assessment of Feasibility

A comparison of total MWWA revenue in 1969 with the expected required revenue in 1971 indicates an increase by a factor of about three. The average low income customer, according to a Government survey in 1962, spent only 0.7 percent of his income for water as opposed to 2.3 percent for electricity and 1.7 percent for cooking fuel. With a rate structure similar to that just described, the low income customer would be paying about 2.5 percent or approximately the same portion of his total income for water as he was paying for electricity eight years ago. The average annual income of a "low income" family is Baht 11,900, at present prices, or about Baht 1,000 per month (US$ 50 per month).

Water services are at least as valuable as fuel and electricity, and improvements in water quality and availability are considered to justify the required increase in family expenses. For the low income family, the estimated portion of total income required to pay for water will vary from a high of 2.5 percent in the early years to 1.5 percent by the design year.

IMPLEMENTATION

Substantial improvements must be made in existing procedures and new actions must be taken in order to provide metropolitan Bangkok with the proposed water system. Organization and management procedures must be improved, financing must be obtained and new laws must be passed. Effective metering must be achieved in order to control wasteful water use habits and generate the required revenue.

Organization and Management

Several reports have been prepared on subjects relating to the organization, administration and financial management of the Authority. In each, the present situation is described, the reasons for change are listed and suggested improvements are recommended. Implementation of these recommendations will provide the Authority with strong operating capabilities and the ability to manage the massive capital development programs to be undertaken during the coming years.

Financing

The Master plan will present four basic methods of financing the costs of the program. Each method probably will require the services of an international lending agency to finance the foreign exchange portion of the costs. An early start is needed to secure the necessary financing.

Legislation

Legislative action will be required in several matters to permit the effective implementation of the Master Plan recommendations. Amendments to existing laws and the enactment of new legislation both may be necessary. Legislative action will be required to provide the Authority with greater powers than it now has. Legislation also will be required to establish a national water resources authority, with power to control the flow and allocate the use of water from the Chao Phrya River.

Effective Metering

Meters are provided to serve as an equitable method of assessing the costs of the system among the users and to minimize water waste. The condition of the present metering system is such that neither of these requirements is being met. The Master Plan will present recommendations on how effective metering can be achieved.

BENEFITS OF PROPOSED SYSTEM

The actual cost to Thailand and the inhabitants of metropolitan Bangkok caused by the lack of an adequate water supply system is not known. It is entirely possible that the value of the savings from the benefits of the proposed system will exceed the cost necessary to provide it. Some approximations are presented to show that this appears to be true.

List of Benefits

The importance of water to man's health is the fundamental benefit received from an adequate water supply. There are many other benefits, however, of varying importance. LOGAN (1960) has presented a partial list of benefits:

Health	*Economic Development*
—Basic physiologic need for water	—Attraction and growth of commerce and industry
—Reduction in costs of medical care	—Contribution to production efficiency
—Increased efficiencies in human energy utilization due to reduction in illness and debility	—Tourism —Increased food production
—Reduction in time losses due to illness	
—Increased man-power availability	
Encouragement of Stable Development	*Public Cleansing* *Fire Protection*
Increase in Property Values	*Savings in Cost and Time over Use of Primitive Water Supply Facilities*

Value of Benefits

It is possible to assess the value of these benefits but it is difficult to do so in a manner which will find ready acceptance of the validity of the estimates. Some of these benefits are more tangible than others, however, and sufficient information is available for the courageous to attempt an evaluation.

Health and fire protection have been selected from the list for review. A third benefit, not included in the list above but very important in Bangkok, is the saving to the people and the Government from the elimination of the present annual subsidy. A self-supporting water system, as proposed for metropolitan Bangkok, will release these funds for other important development projects of the Government.

Savings Related to Public Health

Three categories of public health benefits have been selected for cost evaluation:

—Time lost from work as a result of water-borne illnesses.

Assumption: 15 % of the present served population of 1,800,000 will lose two days from work each year at a wage of $ 2.50 per day per worker.

Annual Cost: $ 1,350,000

—Purchase of medicines to combat water-borne illnesses.

Assumption: 30 % of the present served population of 1,800,000 will require medicine at a cost of $ 2.00 per year per person.

Annual Cost: $ 1,080,000

—Provision of an alternative source of potable water.

Assumption: 5 % of the present served population of 1,800,000 will purchase bottled water or boil tap water; consumption will be one liter per person per day, and the cost of such water will be $ 0.04 per liter.

Annual Cost: $ 1,320,000

The total cost is $ 3,750,000 per year for these three items and these costs are probably underestimated. It is assumed that at least this amount could be saved each year through improvements to public health if an adequate water supply were available.

Savings Related to Fire Protection

In recent years, annual fire losses have been about $ 10,000,000. Discussions with fire officials indicate that these losses could be reduced by 30 to 50 percent if adequate quantities of water for fighting fires were available from the public supply system.

Assumption: present annual fire losses of $ 10,000,000 can be reduced by 40 percent with the provision of an adequate water system.

Annual Saving: $ 4,000,000

Savings in Elimination of Government Subsidy to the MWWA

In 1969 the Government met the MWWA operating deficit of 1.8 million US dollars, and granted 6.8 million dollars for capital expenditures. The Government also paid 6.2 million dollars for the MWWA as the final payment on a capital expenditure loan.

Assumption: Present annual subsidy paid to the MWWA is in the order of $ 10,000,000

Annual Saving: $ 10,000,000

The total value of the benefits which an adequate water system would yield is estimated, very approximately, at $ 18,000,000 per year. The value of these benefits is about $ 10 per person per year, calculated on the basis of the present served population of about 1,800,000.

Benefits vs Costs

The total costs of the program for various years were divided by the expected served population for those years in order to determine the "average per capita annual cost" :

Year	Approximate Served Population	Approximate Total Annual Cost	Approximate Average Per Capita Annual Cost
1971	2,100,000	$ 10,000,000	$ 5.00
1975	2,700,000	20,000,000	7.50
1985	4,600,000	35,000,000	7.50
2000	8,500,000	40,000,000	5.00

These costs are based on present prices in order to make a reasonable comparison. Because of lower water use, per capita annual costs for low income families are about one half the average amount shown. A comparison of the per capita "benefit" of $ 10 *vs* a per capita "cost" of $ 7.50 indicates, even taking into account the roughness of the estimates, that the proposed metropolitan Bangkok water system may well provide benefits which are more tangible than have been anticipated.

REFERENCE

LOGAN, J.A. (1960) The International Municipal Water Supply Program, A Health and Economic Appraisal, *American Journal of Tropical Medicine*, p. 470.

A MUSEUM OF 50 YEARS OF TREATMENT DESIGN

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SAMSEN WATER TREATMENT PLANTS

The Samsen treatment works is a complex grouping of individual treatment plants as shown in Figure 1. Nominally, there are 10 separate plants, but this idea is blurred by duplication of certain facilities and sharing of others. The number of different types of facilities at Samsen is listed as follows:

—Six intake structures

—Nine pumping stations

—Eleven groups of sedimentation units

—Ten filtration plants

—Six filtered water reservoirs

Intakes

Five intakes are equipped only with bar racks. Coarse screening is provided downstream between the intakes and the raw water pump suction pits. The sixth intake, for the latest plant (number 10) has both bar racks and coarse screens. All intakes are connected to pump sumps by pipes of approximately 1 meter diameter.

Pumping Stations

Of the nine pumping stations at the treatment works, one is exclusively for raw water pumps, two are strictly filtered water pumping stations and six serve both functions. Collectively, the nine stations were designed to house 65 major pumps, 27 of which are raw water pumps while 38 are high lift filtered water pumps. Selected information gathered from the name plate data for these pumps is presented in Table 1. This summary indicates that some 10 manufacturers and 17 different models of pumps are represented.

Sedimentation Units

Table 2 lists some of the physical data for the eleven groups of sedimentation units at the water works. The tanks serving filter plants 1, 2 and 3, while nominally rectangular, horizontal flow, sedimentation units, have an unusual flow pattern. For tanks 1, 2 and 3, flow enters the first bay of each compartment at the top and exits from the bay through bottom ports; enters the second bay at the bottom and exits via top ports, etc., such that the flow pattern is in the form of a wave. The flow pattern in tank number 4 is also unusual. Flow through the first three bays of each compartment of the tank is like that of the other tanks but flow through the next three bays is made horizontal by use of 160 small, rectangular diffuser ports distributed evenly throughout the depth and width of the walls terminating these bays. Flow finally exits the seventh bay through top ports. Flow velocities through the top, bottom and diffuser ports can be relatively high. In tanks 1 and 2 it is approximately twenty times the equivalent surface loading velocity for each tank, while for tanks 3 and 4 it is about 30 times as great. None of the tanks has any sludge removal mechanisms and cleaning is effected by draining a compartment and pushing and flushing the sludge through the bays to a drain. The tanks are usually cleaned once a month during the season of high turbidity, and once every two months during the remainder of the year.

Certain physical characteristics for the seven groups of circular sedimentation units are also listed in Table 2. These units directly serve the filtration plants of the same respective number, there being no interconnections between any of the groups. The two Bamag (Germany) circular tanks feeding filtration plant number 5 are not Accelator type units as is the case for plants 4, and 6

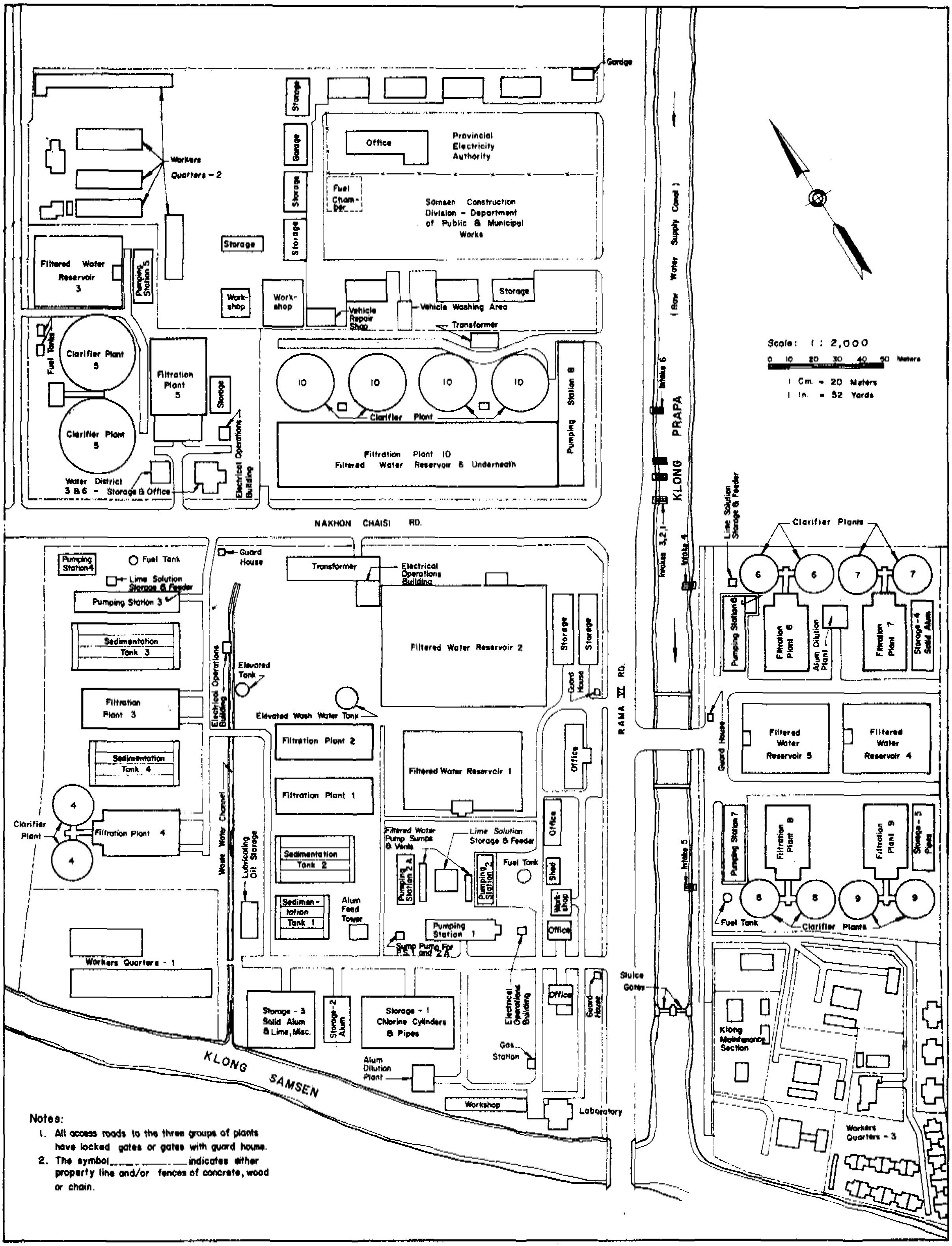

Fig. 1—Location Plan of Samsen Treatment Works.

Table 1—Samsen Pumping Station Data

Pumping Station Number	Manufacturer and Country	Number of Pumps	Raw or Filtered Water	Rated Head, Meters	Rated Discharge, CMH	Comments
1	Sulzer Bros. - Switzerland	2	R	10	1,200	Expected to be replaced
	Sulzer Bros. - Switzerland	1	R	10	1,800	Expected to be replaced
	SW - France	4	F	47	900	-
2	KSB - Germany	5	F	47	900	Installed January, 2512 (1968)
2A	KSB - Germany	2	R	15	1,800	Installed in 2511 (1968)
	KSB - Germany	3	F	47	900	Installed in 2511 (1968)
3	Halberg - Germany	2	R	12	1,800	
	Mather & Platt - England	2	R	10	1,300	
	Dia - Germany	1	R	12	1,800	
	Dia - Germany	1	R	40	900	
	Balcke U	1	F	40	900	
	SW - France	3	F	47	810	
4	Mather & Platt - England	2	R	10	1,300	Only 1 of 3 pumps operable (at wrong speed)
	Dia - Germany	1	R	12	1,800	All expected to be replaced
5	Dia - Germany	5	F	40	900	Only 3 pumps operable
6	A.C.E.G.	1	R	16	1,300	-
	Nyhuis - Holland	2	R	15	1,800	Installed in 2511 (1968)
	Dia - Germany	1	R	12	1,800	-
	SW - France	4	F	52	720	-
7	Dia - Germany	2	R	13	1,620	
	Dia - Germany	1	R	12	1,800	
	SW - France	4	F	47	810	
8	Worthington	6	R	12	1,800	
	Worthington	6	F	52	1,800	
	Worthington	3	F	52	1,080	

through 10, but rather are radial, horizontal flow units without any sludge recirculation possibilities. Raw water already containing alum enters a cylindrical chamber in the center of this tank, is subjected to further mixing by four stirring units, exits from the top of the chamber and is then deflected to the bottom of the tank by a baffle wall. The flow then proceeds radially across the tank and exits over a circumferential, saw-toothed weir. The tanks are equipped with rotating bridge-suspended sludge scrapers to move deposited material to the center of the tanks where it can be flushed out through the main drains.

The upflow clarifiers are all equipped with radial, rectangular cross-section, collector launders, which discharge their flow to a central collector launder and thence to the effluent launder. The Patterson (England) clarifiers in plants 4, 6, 7 and 8 are identical, having 12 radial launders, including the effluent launder, each of which has nineteen free discharging 32 mm (1¼ inch) orifices in each side of the launder. The Degremont (France) clarifiers of plants 9 and 10 are equipped with 16 radial launders per unit and have 40 mm (1 9/16 inch) submerged discharge orifices. Each of the upflow clarifiers is equipped with a variable speed turbine for sludge recirculation within the reaction zone. Sludge removal is supposed to be by automatic blowoff from the sludge concentrating hoppers and by manual operation of the main drain. The automatic sludge blowoff systems of plants 9

Table 2 — Samsen Sedimentation Tank and Solids Contact Clarifier Data

Sedimentation Tank No.	No. of Compartments	No. of Bays per Compartment	Compartment Dimensions W×L×D, m	Total Surface Area m^2	Total Volume m^3	Design Loading CMD/m^2	Design Loading gpd/ft^2	Ideal Detention Time hours	Date Constructed
1	4	4	5.0×21.1×6.5	421	2,750	-	-	-	1914
2	4	6	4.9×31.6×6.5	618	4,140	-	-	-	1930
3	4	8	4.9×42.4×6.5	831	5,430	-	-	-	1952
4	4	7	5.0×37.1×6.5	742	4,830	-	-	-	1953
Total	16			2,612	17,150 Avg.	110	1,083	3.6	

Up Flow Clarifier Group No.	No. of Basins	Clarifier Diameter m	Inner Section Diameter m	Total Surface Area m^2	Total Volume m^3	Design Loading CMD/m^2	Design Loading gpd/ft^2	Ideal Detention Time hours	Date Constructed
4	2	18.22	6.7	453	2,302	96	2,340	1.3	1954
5(1)	2	31.00	12.0	1,288	9,110	34	825	5.1	1958
6	2	18.22	6.7	453	2,302	96	2,340	1.3	1959
7	2	18.22	6.7	453	2,302	96	2,340	1.3	1959
8	2	18.22	6.7	453	2,302	96	2,340	1.3	1961
9	2	18.60	8.4	434	2,352	100	2,440	1.3	1963
10	4	26.20	11.9	1,708	10,564	101	2,480	1.5	1963
Total	16			5,242	31,234 Avg.	82	2,025	1.7	

(1) Actually a horizontal flow, circular tank rather than an upflow clarifier.

and 10 are the only ones that function at the present time. Table 2 indicates that the average surface loading of the upflow solids contact clarifiers is 98 CMD/m^2 (2,415 gpd/ft^2). This is quite high, particularly when contrasted with the loadings of the sedimentation tanks and the sedimentation units of plant 5. In spite of the relatively high loading, the upflow clarifiers usually produce a satisfactory effluent for filtration. These clarifiers are usually drained and cleaned once every three months.

Filtration Plants

The rapid sand filters in the various treatment plants at Samsen are of a variety of designs. However, all are designed to operate at a filtration rate of approximately 117 CMD/m^2 (about 2 gpm/ft^2). Except for plant number 1, which is equipped with rotating rakes within cylindrical tub filters, all have both air and water backwash for cleaning the sand. Although almost all of the plants initially were equipped with loss of head gauges and rate of flow controllers, much of this equipment does not work except at plant number 10. At this latter plant, filters are generally backwashed when the loss of head across a filter approaches 1.4 to 1.5 meters. At the other plants, backwashing is done on a time schedule that varies with the season. At none of the plants is effluent quality used as the basis for determination of the length of filter runs.

Table 3 shows some of the basic physical data and design filtration rates of the Samsen filter

Table 3 — Samsen Filter Plant Data

Filter Plant No.	Type	Filter Beds	Size of Bed m	Total Filter Area m²	Plant Design Filter Rate CMD	Design Loadings		Date Constructed
						CMD/m²	gpm/ft²	
1	Jewell	12	5.2 dia.	256	28,800	113	1.92	1914
2	Jewell	12	5.3×6.06	385	43,200	113	1.92	1930
3	Jewell	12	5.3×6.06	385	43,200	113	1.92	1952
4	Jewell	6	7.48×9.87	449	43,200	96	1.63	1954
5	Bamag	8	2(3.0×8.0)	384	43,200	113	1.92	1958
6	Patterson	6	7.5×9.25	416	43,200	104	1.78	1959
7	Patterson	6	7.5×9.25	416	43,200	104	1.78	1959
8	Patterson	6	7.5×9.25	416	43,200	104	1.78	1961
9	Degremont	10	4.8×7.52	362	43,200	120	2.03	1963
10	Degremont	24	4.84×12.6	1,464	172,800	118	2.02	1963
	Total	102		4,933	547,200 Avg.	111	1.90	

plants. All the Jewell plants have flow rate controllers which, if functioning, are usually set full open. In addition, plants 2 through 4 have float operated control valves. The intent of this dual filter control system is to limit the range in elevation of the water surface on the filter up to the maximum flow rate set on the flow rate controller.

Plant 5 has float operated control valves for maintaining the filter water level and depends upon weir boxes at the head of the filters for presumed equal flow splitting among the filters. The Patterson plants 6 through 8 have diaphragm type flow rate controllers and no water level controllers. The Patterson plants are also unique in that the filter operating controls are located in the filter gallery such that backwashing operations are conducted without the possibility of viewing the filters. The Degremont plants have a float-actuated, siphon flow controller. The float places a very narrow limit on the range of water level in the filter and controls the negative air pressure at the top of the concentric siphon to allow for the variability of head loss through the filter during its run. Essentially equal flow splitting among the filters is effected by the close control of the water level in the filters and the use of a common supply channel to the filters with little variation in its water level.

Table 4 summarizes the results of analyses of sand samples taken from the various plants at Samsen on 30 September and 1 October 1968. The sand in filter plants 1, 3, 6 and 10 is relatively clean while that in the other plants is substantially dirtier. In plants 3 and 5 there is some evidence of stratification of the sand size, while in the others the sand appears to be relatively well mixed. In plants 4, 8, 9 and 10 the media are significantly larger and more uniform in size than in the other plants. The sand recently installed in plant 6 has a much higher uniformity coefficient, 2.19, than is desirable. Chemical analyses of the material deposited on some of the sand samples shows a high concentration of manganese in a few of the samples and a concentration of aluminum which varied with the amount of dirt on the sand.

Further information characterizing the different filter plants is shown in Table 5. Comparison between media design depths and those measured

Table 4 — Results of Sampling and Analyses of Filter Sand at Samsen Treatment Plants

Filter Plant No.	Bed No.	Location of Sample in Bed	Sand Depth cm	Year Sand Installed	Weight Loss, Per Cent of Original			Sand Size, mm				Uniformity Coefficient	Chemical Analysis Per Cent by Weight		
					Water Washing	Caustic Washing 5%NaOH	Acid Washing 5%H_2SO_4	Count & Weigh Method	Sieve Analysis 10% Size	50% Size	90% size		Mn	Fe	Al
1	9	Composite	79	1965	0.2	1.5	1.8	1.13	0.75	1.21	1.67	1.75			
2	11	Composite	86	1967	0.7	2.1	2.4	1.20	0.79	1.29	2.12	1.81	0.026	0.50	0.38
3	12	Top	56	1966	0.2	2.0	2.1	1.09	0.64	1.11	1.84	1.94			
3	12	Middle			0.2	0.9	0.9	1.13	0.74	1.24	1.99	1.81			
3	12	Bottom			0.3	0.7	0.9	1.27	0.96	1.49	4.10	1.75			
4	1	Composite	78	1966	1.9	9.8	9.7	1.43	1.14	1.50	2.15	1.40	1.08	0.55	1.43
5	5	Top	122	1966	0.7	4.6	4.6	1.30	0.76	1.17	1.64	1.70	0.32	0.53	0.82
5	5	Middle			1.3	2.4	2.5	1.48	0.85	1.23	1.68	1.55			
5	5	Bottom			0.4	1.8	1.8	1.35	0.95	1.30	1.79	1.45			
6	6	Composite	70	1968	0.2	0.3	0.6	1.32	0.63	1.22	2.04	2.19			
7	6	Top	60	1960	1.3	6.8	7.9	0.95	0.52	0.86	1.19	1.76	0.80	0.53	1.52
7	6	Middle			0.7	3.8	4.7	1.01	0.62	0.98	1.64	1.75			
7	6	Bottom			0.7	3.5	4.2	0.96	0.59	1.04	1.70	1.96			
8	1	Composite	80	1961	1.2	5.5	6.6	1.33	0.97	1.36	1.90	1.50	0.50	0.45	1.14
9	1	Top	88	1963	1.5	3.9	3.5	1.47	1.00	1.32	1.63	1.39	0.32	0.55	0.90
9	1	Middle			0.5	3.4	4.0	1.50	0.98	1.28	1.53	1.36			
9	1	Bottom			0.8	3.9	4.3	1.38	0.99	1.30	1.60	1.38			
10	9	Top	90	1963	0.2	2.1	2.5	1.47	1.02	1.32	1.70	1.37	0.36	0.80	0.51
10	9	Middle			0.3	1.7	2.3	1.38	0.97	1.29	1.60	1.41			
10	9	Bottom			0.7	1.8	2.2	1.30	0.99	1.28	1.64	1.34			

Table 5 — Additional Samsen Filter Plant Data

Filter Plant No.	Media Depths		Depth of Water Over Media, Range		Approximate Maximum Allowable Filter Head Loss	
	Design cm	Measured cm	From cm	To cm	Meters	Feet
1	-	79	46	82	-	-
2	70	86	80	87	1.2	3.9
3	70	56	96	109	1.2	3.9
4	-	78	90	114	2.0	6.6
5	120	122	10	72	2.1	6.9
6	64	70	73	100	1.5	4.9
7	64	60	97	124	1.5	4.9
8	64	80	89	119	1.5	4.9
9	-	88	21	30	2.0	6.6
10	75	90	38	65	1.6	5.2

in the field usually indicated surplus media, leading to lowered water depth over the media. Water depths over the media are generally shallow in plants 1, 5, 9 and 10 and about a meter in the other plants. The maximum allowable filter head loss, which is related to the length of filter runs, can be as little as 1.2 meters for plants 2 and 3 and as large as 2 meters for plants 4, 5 and 9.

Waste backwash water from the filters is disposed of in several ways at the different plants. The filters of plant 1 have a circumferential collector trough around the tank periphery. Plants 2 through 4 and 6 through 8 have a system of wash water gutters within the interior of the filters. Plants 5, 9 and 10 have a trough parallel and exterior to the two long sides of each filter.

Table 6 shows the results of measurements of water backwash rates and velocities at the Samsen plants made during October 1968. Eight of the plants are backwashed directly from lines feeding the distribution system. At plants 5 and 10 backwash pumps are used. At the time of flow measurement, distribution system pressures were much below what could be expected if the water system were operating the way it should. For those plants drawing wash water from the distribution systems, therefore, computations were performed to indicate the magnitude of wash water to be expected when

Table 6—Backwash Water Rate Measurements For Samsen Treatment Plants

Filter Plant		Pipe Size	Measured Velocity		Measured Flow	Measured Static Pressure		Flow per Unit Area		Quantities Corrected to Standard Conditions(1)		
										Flow	Flow per Unit Area	
No.	Bed No.	mm	m/sec	ft/sec	CMD	Kg/cm²	psi	CMD/m²	gpm/ft²	CMD	CMD/m²	gpm/ft²
	6	248	2.4	7.8	9,670	1.5	21	452	7.7	15,000	705	12.0
1	1	248	2.5	8.3	10,280	1.7	24	490	8.2	14,920	703	12.0
2	6	308	2.4	8.0	14,780	1.6	23	458	7.9	21,800	673	11.6
	2		Incomplete record					455	7.8			
3	6	298	3.5	11.4	20,400	1.7	24	638	10.9	29,700	928	15.9
	3	298	3.7	12.2	21,800	1.7	24	681	11.6	31,700	961	16.8
4	1	305	4.2	13.9	26,000	1.8	25	698	11.9	37,100	993	17.0
	3	305	4.1	13.5	25,400	1.8	26	680	11.6	33,400	970	16.2
5	1	391	2.1	7.0	21,600	-	-	449	7.7	-	-	-
	6	391	2.1	6.9	21,300	-	-	443	7.6	-	-	-
6	4	305	2.6	8.6	16,100	1.8	26	466	8.0	22,600	784	11.2
	6	305	2.7	8.8	16,580	1.8	25	478	8.2	23,270	806	11.5
7	4	298	2.5	8.4	15,020	1.8	25	434	7.4	21,700	629	10.7
	6	298	2.6	8.7	15,520	1.6	23	450	7.7	23,200	670	11.5
8	5	309	3.0	9.7	18,630	1.5	21	538	9.2	29,540	851	14.5
	6	309	3.4	11.3	21,600	1.5	21	625	10.7	34,470	997	14.7
9	7	298	2.5	8.1	14,500	1.7	24	402	6.8	20,300	561	9.6
	4	298	2.4	7.9	14,230	1.7	24	394	6.7	20,080	555	9.5
10	2	451	2.2	7.2	29,800	-	-	488	8.3	-	-	-
	24	451	2.0	6.6	27,400	-	-	450	7.7	-	-	-

(1) Based on pressures considered obtainable once improvements are completed.

the system is improved. This table shows the relatively low wash water rates used at Samsen as compared with U.S. practice. These rates would be quite inadequate to permit the use of dual media (sand and anthracite coal) filters of the type commonly used in the U.S. Such filters would be completely mixed by the air wash and would have to be completely suspended by water to separate the media after air washing. Wash water rates of more than 1,170 CMD/m^2 (20 gpm/ft^2) would be required to do this at the water temperature prevailing in Bangkok (28-30°C or 82-86°F). To obtain such rates it would not only be necessary to increase the size of wash water lines but, at most plants, it would be necessary to enlarge filter bottoms, wash water gutters and wash water drains. Such changes are uneconomical and disruptive of regular plant operation.

Clear Water Reservoirs

There are six clear water reservoirs located within the Samsen complex and Table 7 indicates some of the characteristics of these reservoirs. At the present time reservoirs 1 and 2 are interconnected with each other, and reservoirs 4 and 5 are interconnected. The total nominal filtered water storage for the Samsen plants is 49,700 cubic meters (13.1 million U.S. gallons). Information on how much of this storage can be effectively utilized is lacking. However, it is known it is not possible to draw the water level in most of the reservoirs down very close to their bottoms without causing severe reductions in filtered water pumping capabilities.

Waste Water Facilities

The three components of waste water from all the Samsen plants, namely, sludge from the sedimentation units, wash water from the filters, and drainage of sedimentation units and filters, makes its way by one path or another to Klong (canal) Samsen, located just south of the treatment works.

Metering Facilities

Except for the orifice plates located on the two raw water mains serving plant 10, raw water is not metered at the Samsen plants. In general, wash water usage is also not metered. Filtered water

Table 7—Samsen Clear Water Reservoir Data

Reservoir No.	Rated Volume m^3	Bottom Elevation m	Top Elevation m	Overflow Elevation m	Length m	Width m	Date Constructed
1	5,700	34.95*	38.18*	37.90	54.3	36.2	1914
2	15,000	34.86	38.17*	-	84.2	60.2	1949
3	3,000	33.19	36.27	36.19	38*	29*	1958
4	4,000	34.32	37.87	37.80	39*	29*	1959
5	4,000	34.31	37.93	37.85	39*	29*	1959
6	18,000	34.25	39.15	-	133	29	1963
Total Volume	49,700						
	(13.1 million gallons)						

Note

Elevations referenced to Bangkok Datum, 35.03 is mean sea level.

*Information uncertain.

production is metered, but by pumping station rather than by individual plant.

Chemicals and Chemical Feeders

Three different chemicals are used for water treatment at the Samsen plants: alum, lime and chlorine. Alum is procured from the Ministry of Industry through its Department of Science which operates an alum plant. The Ministry produces both solid and liquid alum, the latter at a strength of 36° Baume. While some solid alum is purchased by the water works, most of that procured is in liquid form which the MWWA further dilutes to 12° to 15° Baume at three dilution plants within the Samsen ground.

Bagged lime is procured locally. Lime addition to the raw water up to the end of May 1968 was effected, when required, at the various raw water pump sumps located throughout the compound. Because of difficulties with lime encrustation on various pump parts, lime is no longer added to the pump sumps. It is presently added, when needed, on the discharge side of the Bang Sue pumping station ahead of the Bang Sue siphon. Feeding at this latter location is accomplished by dumping a certain number of bags of lime per hour into the supply canal.

Up until 1967 chlorine gas was imported, but since that time it has been produced locally. Chlorine cylinders of 90 and 148 kilograms (200 and 325 pounds) capacity are in use throughout the treatment works. Ton cylinders are not used. Table 8 gives information about the number, capacity, location and maximum design flow dosage rates for all known chlorinators at the Samsen and Thonburi treatment works.

Table 8—Chlorinator Capacities at Samsen and Thonburi Water Treatment Works

Chlorinator Location	Chlorinator Identification Number	Associated With P.S. No.	Associated With Plant No.	Maximum Feed Rate Kg/hr	Total Plant Design Capacities CMD	Dosage Rate mg/1	Comments
Reservoir 1	1	1	1,2,3,4	2.8			-
Reservoir 1	2	3	1,2,3,4	2.8			-
Reservoir 1	3	3	1,2,3,4	2.8			-
Reservoir 1	4	2A	1,2,3,4	2.8			-
Reservoir 1	5	1	1,2,3,4	2.8			-
Reservoir 2	6	-	1,2,3,4	(1.6)			Inoperative
Reservoir 1	7	1	1,2,3,4	2.8			-
				16.8	158,100	2.55	-
Reservoir 3	-	5	5	2.8	43,200	1.56	Pumped to Reservoir 6
Plant 10	Integral set of 6	8	10	6(2.0)	172,800	1.67	-
				14.8	216,000	1.64	
Reservoir 4	-	6,7	6,7,8,9	2(2.8)			-
Reservoir 5	-	6,7	6,7,8,9	2(2.8)			-
				11.2	172,800	1.56	
Plant 9	Integral set of 2	6,7	9	2(2.0)	43,200	2.22	Inoperative, parts used for Plant 10
Thonburi	Integral set of 6	-	-	6(2.0)	172,800	1.67	Full capability not available. Some parts used for Plant 10

Approximate prices for alum, lime and chlorine per ton of chemical are 1,450, 400, and 10,000 baht, respectively. Indicative of the amounts of chemicals used are the figures for the year 1967:

Alum

Samsen	8,128,100 kg	(dry equivalent)
Thonburi	907,139 kg	(dry equivalent)

Lime

Samsen	524,429 kg

Chlorine

Bangkok	228,088 kg	(Samsen and Wells)

Considering figures for quoted production during the year, 38 mg/1 of alum were used at Samsen; 29 mg/1 of alum at Thonburi; 2.8 mg/1 of lime at Samsen; and 0.9 mg/1 of chlorine for water delivered from both Samsen and Bangkok's public supply wells.

DESIGN AND PRODUCTION CAPACITIES OF EXISTING FACILITIES

Design capacities

Design capacity is a rather ambiguous term. As used in this report it reflects an assessment as to what a facility is capable of producing, the assessment being made by a design engineer, a plant manufacturer, or an MWWA official. On the one hand, it can be considered a goal that should be obtained; on the other hand, it can be considered as a limit that is difficult to exceed. The quoted design capacities for the 11 MWWA treatment plants are as follows:

Thonburi	172,800 CMD	(45.6 mgd)
Samsen		
Plant 1	28,500 CMD	(7.5 mgd)
Plant 2 through 9	43,200 CMD	(11.4 mgd) each
Plant 10	172,800 CMD	(45.6 mgd)

The design capacity of the Thonburi facility is 172,800 CMD (45.6 mgd) while that of the Samsen plants is 547,200 CMD (144.6 mgd).

Production Capacities

Production capacity is defined here as the maximum flow rate that can be maintained fairly reliably for long periods of time for delivery to the distribution system. Because of the reliability requirement, production capacity is less than the maximum short-term flows pumped to the distribution system which do not include inplant process losses, losses due to equipment breakdown, and preventive and routine maintenance.

Thonburi Treatment Works — The production capacity of the Thonburi treatment plant is about 86,400 CMD (22.8 mgd), or approximately 50 per cent of the design rate. This severe reduction below the design capacity is a consequence of the limitation on the amount of raw water that the Bang Sue pumping station can deliver to this treatment plant. Two raw water force mains of 900 mm diameter from Bang Sue to Thonburi were originally planned for, only one of which has been constructed.

During the period 1 October 1967 to 30 September 1968 the average raw water flow to Thonburi was reported to be 86,500 CMD, while that to the distribution system was reported to be 84,600 CMD. On the other hand, inplant process losses were estimated by the MWWA to be 5.9 per cent of the total amount of water processed.

Samsen Water Treatment Works—Determining production capacity for any single treatment plant at Samsen is not possible. However, it is possible to get a fair idea of production capacities for certain groupings of the 10 plants. Production from plants 1 through 4 tends to run between 100 and 120 per cent of their combined design capacities, with the average for a three month period, from 1 November 1968 to 31 January 1969, being 113 per cent. Plants 6 through 9, on the other hand, are underproducing. Their production has ranged from 60 to 80 per cent of their total design capacity.

Further, production for these 4 plants appears to be declining, having averaged 74, 68 and 65 per cent for the months of November, December and January, respectively. Production from plants 5 and 10 has ranged from 85 per cent to almost 110 per cent of their combined design capacities during the three month period. Periods where the flow exceeds 100 per cent result from the fact that half of plant 10 has been operating above its normal rate by using a standby raw water pump as suggested by the Consultants. Production from all 10 plants combined has ranged from a low of 88 per cent of the total design capacity to a high of 102 per cent, with the three month average being 94 per cent. During the water year 1 October 1967 to 30 September 1968 the average filtered water delivered to the distribution system was reported to be 512,000 CMD (135 mgd), or 93.5 per cent of the total design capacity.

Reliable estimates of the amount of raw water delivered to the Samsen complex are not available. Inplant process losses were reported to be 2.4 per cent of finished water production.

Water Quality

Table 9 gives raw and treated water quality data.

Table 9 — Water Quality : Raw, Filtered, Clarified and Recommended Limits

Constituent[3]	Raw Water[1]		Clarified Water[1]		Filtered Water[1]		Thai Drinking Water Standards[2]	
	Min.	Max.	Min.	Max.	Min.	Max.	Maximum Acceptable	Maximum Allowable
Turbidity (mg/l SiO_2)	5	250	0	20	0	7	5	20
Alkalinity (mg/l as $CaCO_3$)	5	226	6	134	6	128	-	-
pH	6.4	8.9	5.8	8.3	6.3	8.3	6.5-8.5	9.2
Iron (mg/l Fe)	0.3	6.5	0	0.7	0	1.2	0.3	1.0
Chloride (mg/l Cl)	4	94	0	40	1	42	250	600
Nitrate (mg/l NO_3)	0	4	0	4	0	4	45	45
Total Hardness (mg/l as $CaCO_3$)		144	48	140	39	152	200	300
Total Solids (mg/l)	117	524	95	274	92	271	500	1.500
Dissolved Oxygen (mg/l)	2.6	6.7	6.5	8.1	5.6	7.8	-	-
Fluoride (mg/l F)	0	0.3	0	0.2	0	0.2	0.7	1,0
Coliform Organisms (MPN)	Median = 39,000/100 ml.				Median = 0.1/100 ml[4]			2.2/100 ml.

Notes:

1. Based on about 80 samples at Samsen.
2. These standards have not yet been adopted but are similar to W.H.O. International Standards for Drinking Water.
3. Raw and filtered water analyses for Copper, Lead, Zinc and Sulfate show concentrations of zero for all samples.
4. Based on 187 samples from distribution system at 8 locations near Rajdamnern. 15 per cent of samples in excess of 2.2/100 ml and 10 per cent of samples in excess of 15/100 ml. Filtered water chlorine residuals at Samsen vary from 0.05 to 1.6 milligrams per liter.

INVESTIGATIONS FOR SEA DISPOSAL OF WASTEWATER FROM METROPOLITAN MANILA

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INTRODUCTION

Reason for Study

Manila is the largest city in the Philippines, and is the seat of government. The ideal anchorage of landlocked Manila Bay has encouraged marine trade so that a large proportion of the Republic's industry is centered in the area. The 1970 population of the Metropolitan Area is estimated to be 3.9 million; by the end of this century, Metropolitan Manila is expected to have a population of over 10 million. This tremendous population growth, in excess of 5 percent per year, has already outstripped the utilities of the area, and a great effort is underway at present to catch up in almost every phase of urban service.

One of the most sorely neglected utilities has been sewerage. Early in the American occupation of the Philippines, when the Metropolitan population was a little over a third of a million, a comprehensive sewerage system for Manila was constructed. It consisted of seven pump stations serving a separate sanitary sewerage system. Because of the extremely flat topography of the coastal plain on which Manila stands, these pump stations were in series, in two different systems divided by the Pasig River which flows west across the center of the city. All flow was eventually to the main pump station just north of the river at what was then the shoreline. Wastewater was pumped nearly two kilometers out to sea through a 42 inch diameter cast-iron (C.I.) outfall.

The original sewerage system is still in a remarkably good state of repair. However, relatively little has been done to expand the system and at present only about 10 percent of the Metropolitan Area population is served with sewers. Due to reclamation, the main pump station is over one kilometer from the shore and the outfall has been broken and now discharges within 10 meters of the waters edge. Multiple overflows have been made from the sewers to the creeks to prevent wastewater overflowing onto the streets when the pump stations are not operating; at high tide, a large volume of seawater enters and surcharges the sewers. Apart from several sewered government and private housing subdivisions generally discharging to the inadequate treatment of septic or Imhoff tanks, the rest of the Metropolitan Area is served by individual house septic tanks. Discharge from these is directly to storm drains or ditches without any sort of tile seepage field.

The potential hazard to health is enormous. Thus, in 1967 the World Health Organization, with finances provided by the Special Fund of the United Nations Development Programme, engaged a consulting engineering firm to prepare a Master

Plan for Sanitary Sewerage for Metropolitan Manila. Counterpart staff and facilities were provided by the Philippines Government through the National Waterworks and Sewerage Authority. The draft of this report was finalized in December 1969.

Sewerage Study

The limits of the study area were set in part by natural boundaries and in part by logical limits of urban growth in the next 40 years. A total area of nearly 50,000 hectares was considered and included most of 4 cities and 16 municipalities. Figure 1 shows a general map of the Study Area. Being national in concept, the NWSA can operate on drainage basin or regional concept with a minimum of inter-agency conflict. The practical task of serving this large area is immense, and well beyond the country's immediate financial resources. Neglect of sewerage construction for 30 years has meant that to serve 40 years into the future, a 70 year sewerage improvement program has to be financed.

Streams and rivers in the inland basins have virtually no assimilative capacity in the dry season. The Pasig River during that time is almost entirely tide responsive; in fact at high tide flow is reversed, carrying polluted and saline water into Laguna de Bay. Thus, although interim facilities of secondary treatment standard are recommended for inland areas where interceptors will not be available for many years, the Master Plan ultimately recommends a series of interceptors to carry all Study Area wastewater to the bayshore. The isolated basins to the north and south of the Pasig River would be treated in much the same way, with inland interim treatment facilities recommended until funds are available to construct interceptors to the shore.

The immense expense of the contemplated construction indicated that a priority construction program should be planned to serve the area in most desperate need of sewers. The area selected was the urban core of the Metropolitan Area, and included nearly all the City of Manila, with parts of adjacent tributary minicipalities. All flow would be brought to a central interceptor along the Pasig River and pumped through a submarine outfall to disposal in Manila Bay.

Once the priniciple of disposal to Manila Bay was established, the importance of detailed marine studies of currents and assimilative capacity was accentuated, particularly in view of the large ultimate flows expected. Preliminary economic studies indicated that it would be less expensive to serve the independent northern and southern basins with individual sea outfalls than to bring the wastewater from the entire Metropolitan Area to the central outfall planned at the mouth of the Pasig River. Assuming the three outfall arrangement, estimated flows from the construction staging proposed are shown in Table 1.

Table 1 — Estimated Average Wastewater Flows from Metropolitan Manila

Year	Proposed Submarine Outfalls					
	North		Central		South	
	m^3/s	cfs	m^3/s	cfs	m^3/s	cfs
1970	-	-	2	70	-	-
1980	-	-	5	180	-	-
1990	1	30	11	390	1	30
2000	2	70	17	600	5	180
2010	7	250	31	1090	6	210

STUDIES OF MANILA BAY

Configuration of Manila Bay

Located near the middle of the major Philippine island of Luzon, Manila Bay has a coastline of about 190 km and an area of approximately 1,800 km^2. Its mouth is about 22 km wide and the historic island of Corregidor divides the entrance into the northern and southern channels. The deepest part of the Bay is at the narrow North Channel, which has a depth of about 90 m. From there the Bay gradually shallows to the north and east, as shown in Figure 2.

Inland from the north-south range of mountains which forms the western edge of the Bay the land

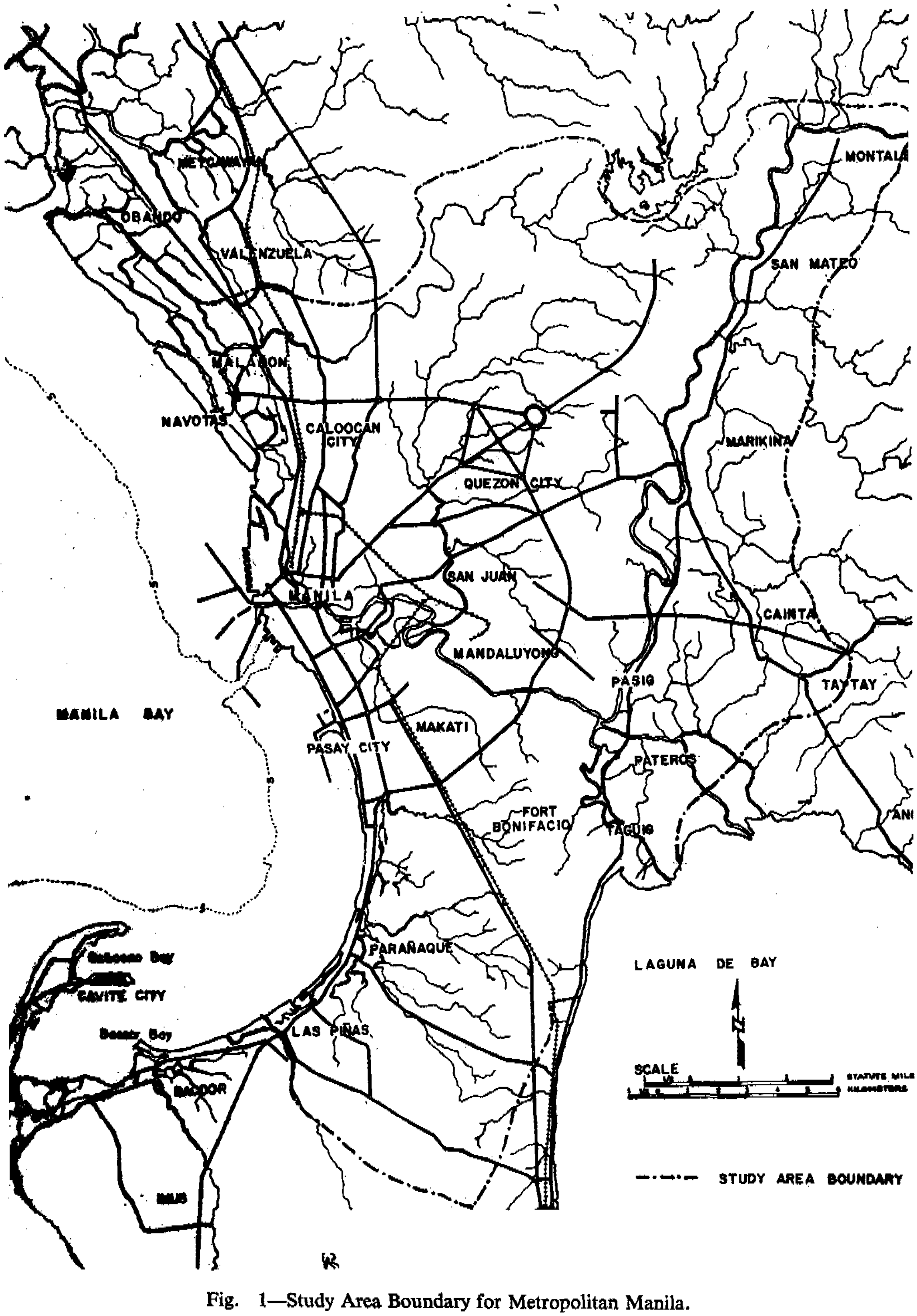

Fig. 1—Study Area Boundary for Metropolitan Manila.

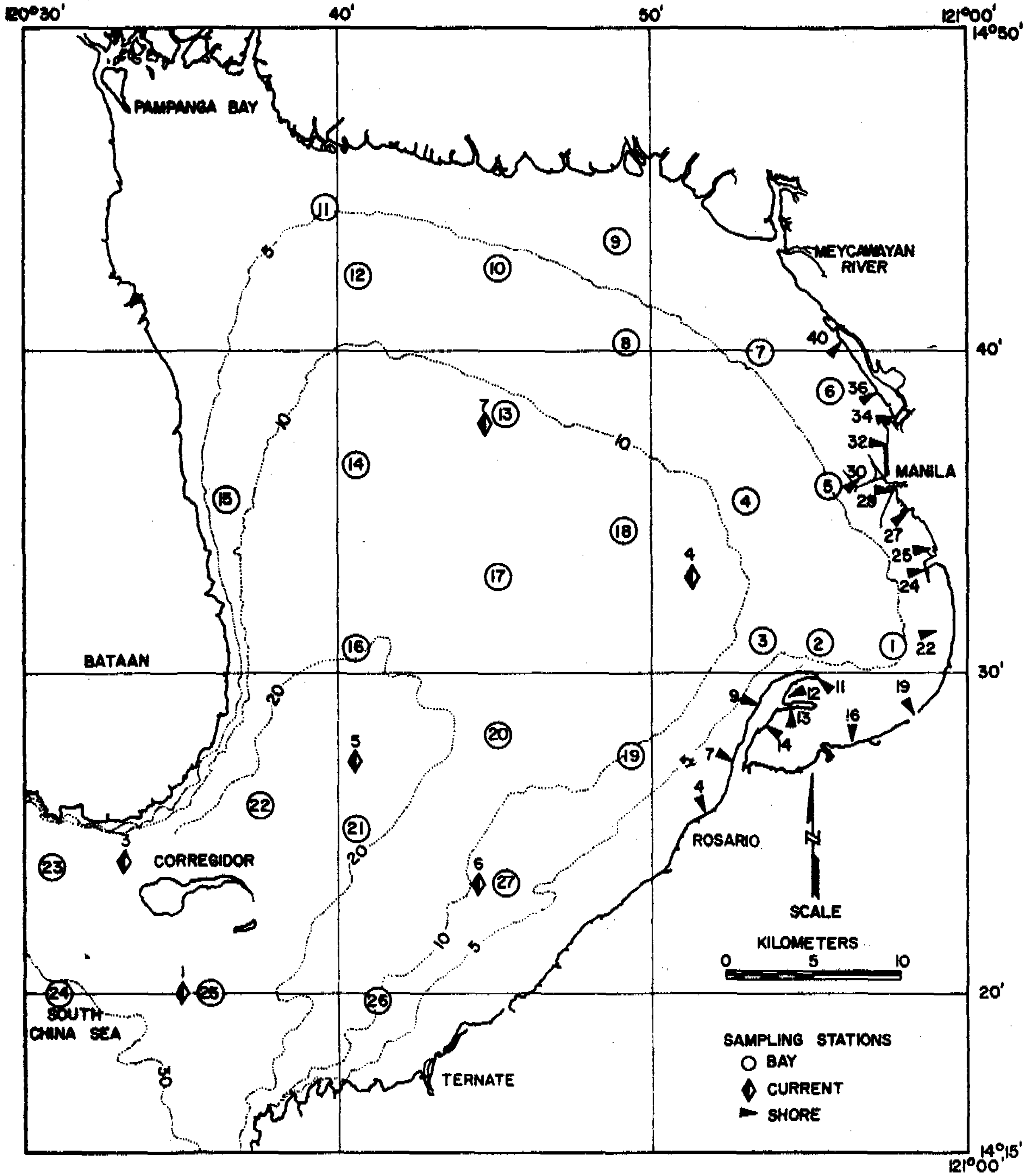

Fig. 2—Manila Bay Sampling Stations.

is generally extremely flat, and at low water the Bay is edged by a low and narrow beach, backed in many places by lagoons, tidal flats, and marsh land. To the north and east the water is very shallow adjacent to the shoreline; there is obviously much siltation occurring from the inflow of fresh water from the northern rivers during the rainy season. Superficially, from the general configuration of Manila Bay, it would appear that the Coriolis effect should have a major influence on currents, but no significant counter-clockwise movement was detected during the study.

Need for Marine Investigation

Despite the vast amount of international, inter-island, and fishing traffic in Manila Bay, relatively little information is available about its characteristics and current movements. However, with the proposal to discharge a major portion of the wastewater from Metropolitan Manila into the Bay, more specific details of current directions and velocities were required. It was also essential to determine the various parameters of present pollution in the Bay so this could be used as a basis of comparison in the future, and so that the capacity of the Bay to assimilate discharged wastewater could be computed. By flow to creeks and thus into the rivers, Manila Bay already is the ultimate receiving point of Metropolitan Manila wastewater. Thus, Manila Bay becomes the logical disposal point for the future wastewater from the area. This paper is primarily intended to describe the practical side of the marine studies that were carried out in Manila Bay.

Meteorological Data

1. *Wind* — Manila is in a markedly seasonal area, with the prevailing winds strongly influenced by the monsoons. October to January are the months of the Northeast monsoon, rainfall is low, and December through February are the coolest months of the year. February to May generally have low precipitation, as the Southeast trade winds are very dry. The rainy season is June to September and the consistent southwest winds bring most of Manila's 2,068 mm of annual rainfall. It is fortunate that during the dry months the wind is fairly consistently off-shore. During the southwest monsoon season recreational activity in the Bay is at a minimum and if the on-shore wind should blow flotables from discharged wastewater to the beaches a minimum amount of nuisance would be caused.

2. *Runoff* — Total yearly runoff to the Bay varies from approximately 50 m^3/s in May to a maximum of about 2,500 m^3/s in August or September. The major portion of this is from the 11,200 km^2 basin of the Pampanga River complex, draining into the northern portion of the Bay. The Pasig-Marikina-Laguna de Bay basin is the other large drainage basin, which covers about 4,000 km^2.

3. *Evaporation* — Recent studies made on the 900 km^2 Laguna de Bay indicated that the average annual evaporation was approximately 1,150 mm with a maximum of about 175 mm in April. These figures would probably apply equally to Manila Bay, which would give a maximum evaporation in April from the entire Bay of approximately 135 m^3/s or almost three times the fresh water entering the Bay.

4. *Tides* — The Tidal range in Manila Bay averages approximately one meter, with extreme tides of almost two meters. Tides are semi-diurnal about one third of the time changing to diurnal at maximum north and south declinations of the moon.

Scope of Studies

1. *Organization and Methods* — Studies of Manila Bay were divided into three distinct phases. First was the collection of data from the littoral water off the Metropolitan Area, second was the gathering of current data, and third was the overall sampling of Manila Bay. Each of these phases depended to a greater or lesser extent on the support facilities of the project laboratory. Techniques for analysis of oceanographic samples are not different enough to cause a competent analyst any problems. However, the great number of samples that come in simultaneously can cause an organizational problem. Extra numbers of BOD and sampling bottles are required, excess incubator space is necessary and a means of refrigerating bacteriological and

biological samples prior to analysis, both aboard the vessel and at the laboratory, is required.

In any project of this scope and magnitude, it would be most desirable to have a full time vessel available for marine sampling. This was not the case in the Manila Bay studies. Thus, an arrangement was made with the Philippine Coast and Geodetic Survey to provide the 90-foot survey vessel "Arinya" for four quarterly cruises and for extended current metering cruises. Both the C&GS and the Philippine Navy provided launches and patrol type craft for other marine work, and although the cooperation was excellent, these departments had other assignments and could not provide vessels at all times, or at short notice.

2. *Shore Sampling* — To obtain some indication of the degree of pollution along the Metropolitan shore, a series of sampling stations was established, starting at Rosario at the base of the Cavite peninsula and extending along the shoreline to the mouth of the Navotas River in the north, as shown on Figure 2. Ideally, shore sampling stations should be visited by boat. However, due to the difficulty of obtaining a vessel, it was decided to find stations that were accessible by land. Once a month one of the project vehicles would visit 17 stations, the sampler would wade out to about 1 meter depth and collect samples from 20 cm below the surface.

Initially, samples were analyzed for coliform MPN, salinity, BOD_5, pH, and sometimes for phosphate. Latterly it was decided that the important parameters were only the coliform concentration and the BOD_5. Also the number of sampling stations was reduced to eliminate those giving atypical results. Considerable difficulty was experienced in obtaining satisfactory sampling sites. Quite often where there was vehicular access to the beach, this was also a convenient garbage dumping point. The very shallow waters often meant that the sampler had to wade out more than 100 meters from the shore before he was as deep as one meter.

The coliform sample was invariably taken first with the sterilized bottle filled with a forward sweeping stroke. Coliform and BOD samples were stored in a cooler full of ice in the project vehicle and transferred to a 5° C refrigerator when they reached the laboratory. Salinity samples were not refrigerated but were stored in a covered box. Phosphate samples were frozen in a small styrofoam cooler of dry ice.

Compared with coliform concentration standards generally acceptable in the United States (70 MPN /ml for shellfish harvesting and 1,000 MPN/ml for bathing beaches), the Manila shoreline is grossly polluted. Figure 3 shows a plot of seasonal average coliform concentrations, as well as the 80 per cent confidence limit graph for all results obtained. Major peaks occurred at stations with easily identifiable local pollution sources. Only stations 7 and 19 were actually at bathing beaches.

3. *Currents* — Four completely separate approaches were made towards the evaluation of currents in Manila Bay.

a. *Current Metering*—As part of the arrangement with the C&GS, the "Arinya" remained for a lunar month anchored at the mouth of the Bay taking current readings in the dry season. After that she visited the five other secondary currents stations shown on Figure 2, for 100 hours each. She then returned to the primary current station in the wet season for a period of 5 days. Currents were observed every hour at the 0.2, 0.5, and 0.8 depth points by current meter and at the surface using a log line and pole (which had an average depth of two meters). In addition, for much of the time a bathythermograph was lowered at four-hourly intervals. The Ekman-Merz current meter used was a comparatively unsophisticated instrument. This type of current meter is frequently provided with two propeller sizes, one for low and the other for high velocity currents. In this particular case, the lower speed propeller would have been preferable because only in a few cases were current velocities higher than 0.5 m/s found; thus low velocities shown are probably not too reliable.

b. *Drogues* — Although it entailed considerable effort to follow and to fix position, the drogue proved to be a reliable method for tracking currents.

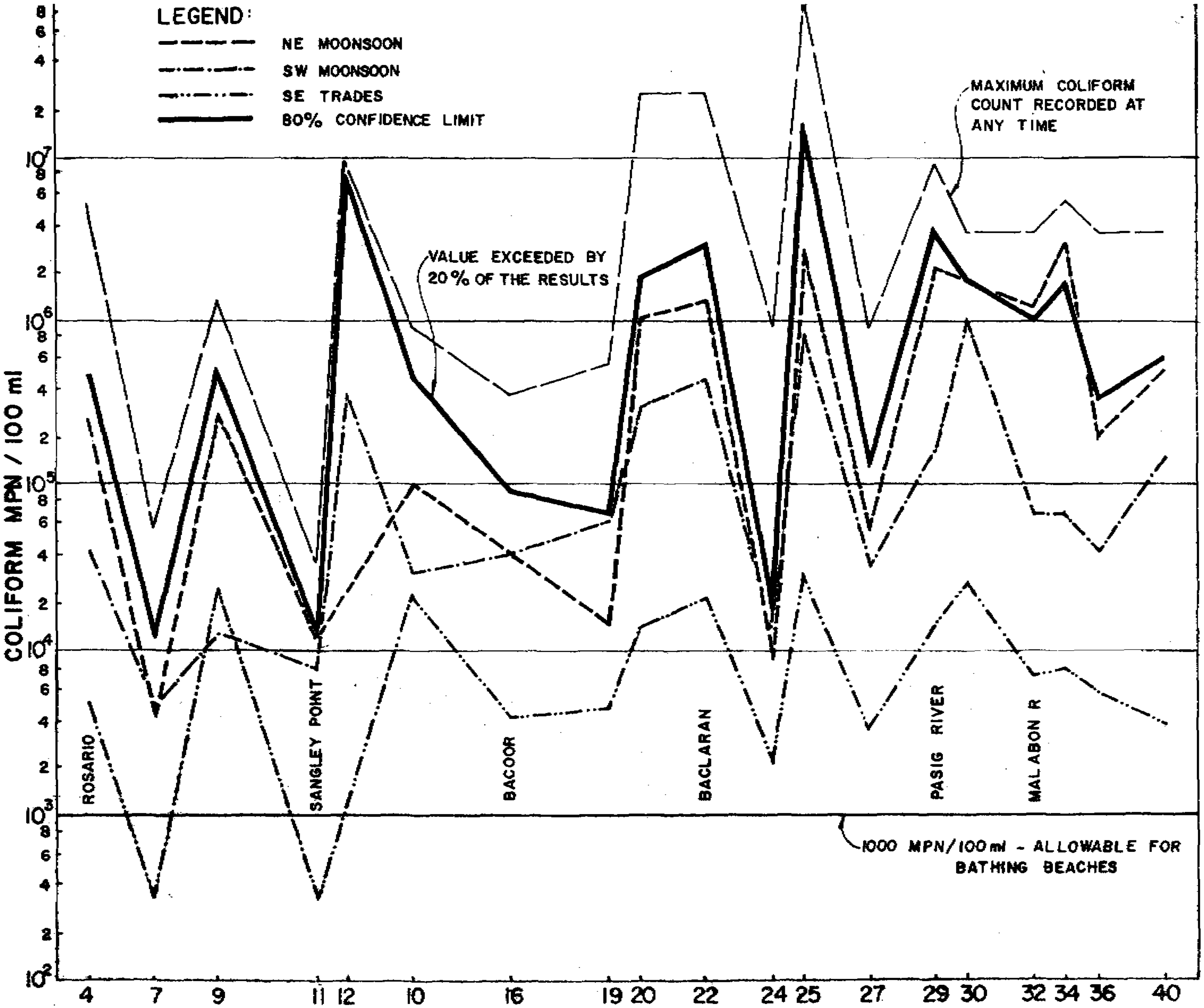

Fig. 3—Coliform Concentrations at Shore Sampling Stations.

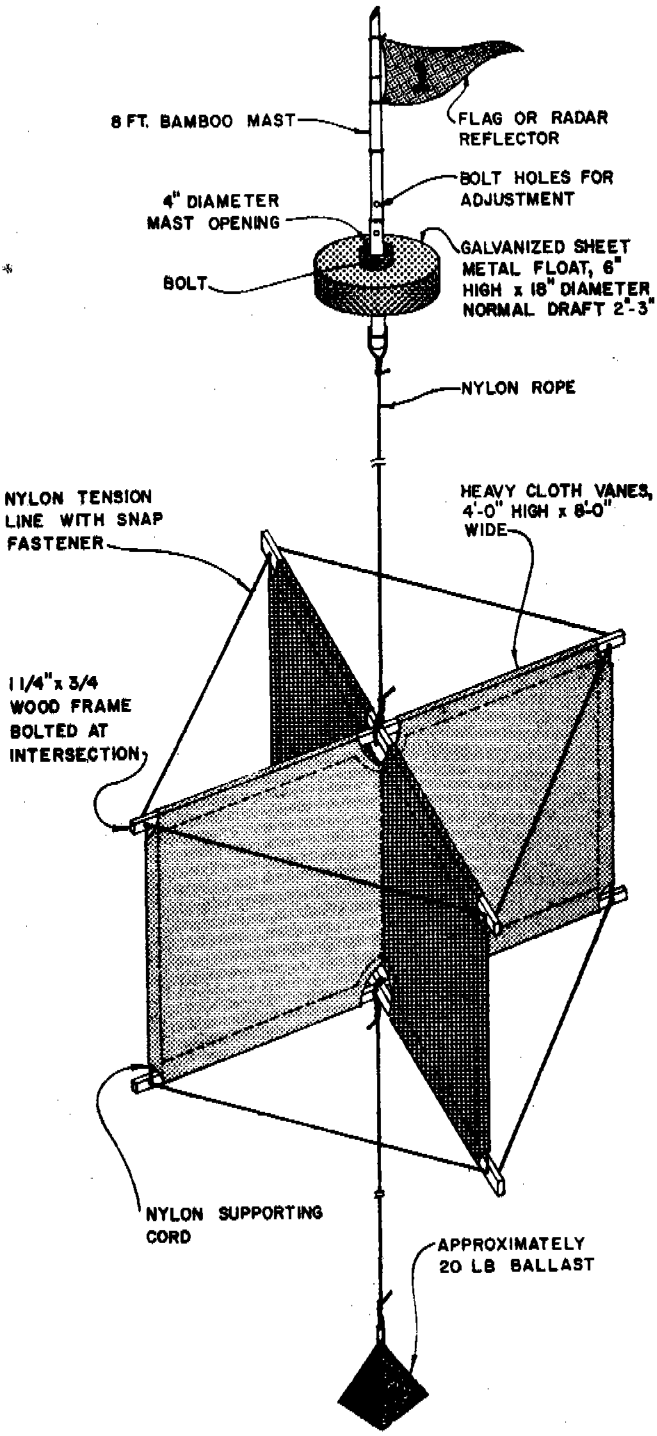

Fig. 4—Typical Drogue.

As shown in Figure 4, the drogues used consisted of a small galvanized float from which was suspended a large cruciform cloth vane, which could be adjusted to be at an average depth of 2 meters or lower.

Manila Bay is much too extensive to attempt to fix position by triangulation from shore stations and the only practical way of plotting the movement of a drogue was to come alongside in a launch and fix the position with a sextant, or to track the drogue by radar from a vessel whose position was known. It was decided that two drogues were the maximum that could be tracked by a single launch and then when the drogues drifted too far apart the one showing the least movement, generally the deep drogue, was lifted and placed closer to the other. Drogues appeared to be cherished prizes amongst fishermen, and had to be carefully guarded.

When the "Arinya" was anchored at the various currents stations a drogue would be dropped over the side and followed by radar. For this purpose, special corner reflectors were made for the drogues. These gave an excellent radar image but had considerable wind resistance, even when 10 cm diameter holes were cut in the faces. When three of these corner reflector type drogues had been lost, a "Christmas tree" type was made. Although this did not have as good an image on the radar screen, it was easy to make and had very little wind resistance. Cross arms at the top of the pole had strings festooned from them; to these strings were attached 3.2 cm squares of aluminum sheet (3.2 cm was the wave length of the radar).

Figure 5 shows the results of all current tracking at depths of two meters or less in the area of possible wastewater discharge in the eastern portion of the Bay. Full lines indicate movement during flood tide, and dashed lines during ebb tide.

c. *Drift Cards*—In an attempt to establish what would happen to the flotables discharged from a submarine wastewater outfall in Manila Bay, a series of tests using drift cards was made. The cards were 5 by 3 inches; on one side the function

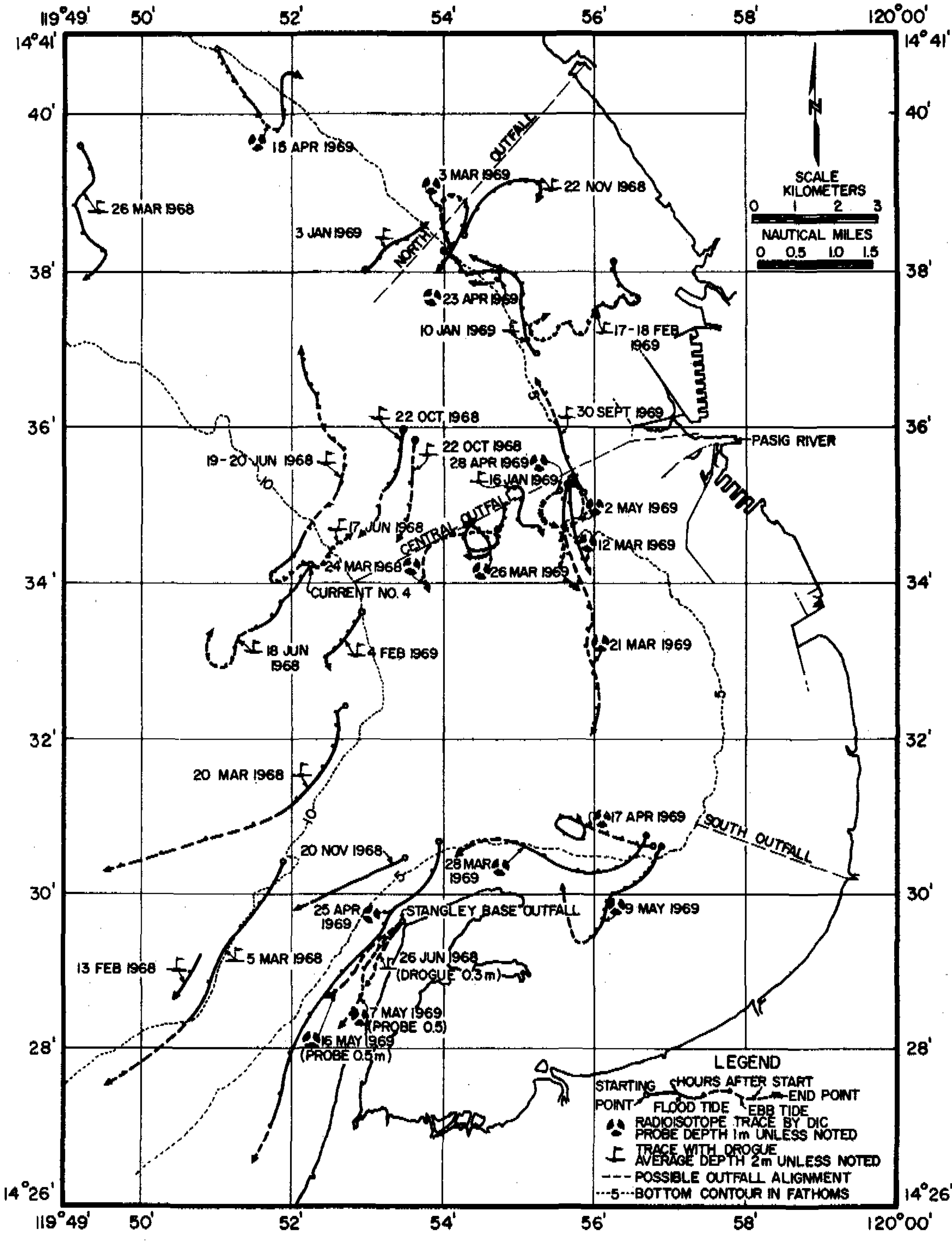

Fig. 5—Typical Current Meter Results.

of the cards was described with a request that a card be returned to the nearest health center, while on the reverse side were blank spaces in which the finder was asked to note the date and the place of finding. The card was then sealed in a clear plastic jacket, generally without any sort of weight. However, a certain percentage of the cards had a small lead weight set in one corner so they would float vertically.

At times of rising tide during the rainy season when the wind was predominantly onshore, over 6,000 of these cards were dropped on five different days. Convinced that the cards would show up in a very short while, the accessible Metropolitan shore line was patrolled by foot for several days after each drop. In addition, launches periodically patrolled close to the shore from as far as Ternate in the southwest to the Meycawayan River in the north. These tests, from a statistical point of view, were a complete failure. Of all the cards dropped only two were found on the Manila shoreline, and another one was returned from an island at the mouth of the Bay. However, it did indicate that despite a rising tide and onshore winds, there apparently was no major movement of drift cards onto the Metropolitan Manila shore. This was interpreted to mean that little trouble would be experienced in the future from flotables discharged from a submarine outfall.

d. *Radioisotope Study*—One of the unusual aspects of this investigation was the completely separate but closely coordinated DANISH ISOTOPE CENTRE (1969) study. To test the feasibility of using an isotope tracing technique in this and future investigations, WHO contracted with the Danish Isotope Centre to conduct a study in Manila Bay. The technique is similar to dyes or any other continuously monitored tracer, but by using a radioactive isotope, in this case Bromium 82 with a half life of 36 hours, detection was possible at extremely small concentrations. One of the Philippine Navy's fast patrol craft was used as a platform for the investigation as this vessel was fitted with radar which was essential for the navigational technique used. The general procedure was for the irradiated NH_4Br to be dissolved in about one liter of water using remote handling equipment and the usual precautions employed with radioactive material. The isotope solution would then be poured on the surface of the water at the point to be investigated and a concentrated solution of fluorescein dye discharged at the same time, to give a visual guide to the initial movement of the radioisotope. After the tracer had diffused sufficiently, the patrol craft would criss-cross the isotope cloud in a regular pattern. A probe with a scintillation counter head set at a depth of 1 meter was fitted to the patrol craft and the level of radioactivity was transmitted to a recorder in the cabin. Tracing of the radioisotope cloud was performed approximately hourly until the level of radioactivity no longer was distinguishable above the background level.

Data collection from the days cruise was then presented as a series of iso-concentration curves, made for each criss-crossing of the isotope cloud. A typical iso-concentration plot is shown in Figure 6. Integration of the individual iso-concentration curves were developed into an iso-dilution plot, usually based on a theoretical wastewater discharge of 1 m^3/s. The iso-dilution curves from Figure 6 are shown in Figure 7.

It was found that the vertical density profile in Manila Bay over much of the year is so uniform that it would be impracticable to try and develop a submerged wastewater field at an outfall diffuser. Thus the discharged wastewater would almost invariably rise to the surface, and so the two dimensional plot at one meter depth probably gave an accurate indication of what could be expected in actual practice. This technique has the advantage that there is no float to cause wind or surface current error, and not only gives the direction and speed of the current but also allows a coefficient of diffusion to be evaluated. By connecting the points of maximum concentration for each crossing a current streamline, comparable to a drogue track, was established, and these are also shown on Figure 5. The DIC results only represent findings during the dry season. A similar study for the wet season is planned.

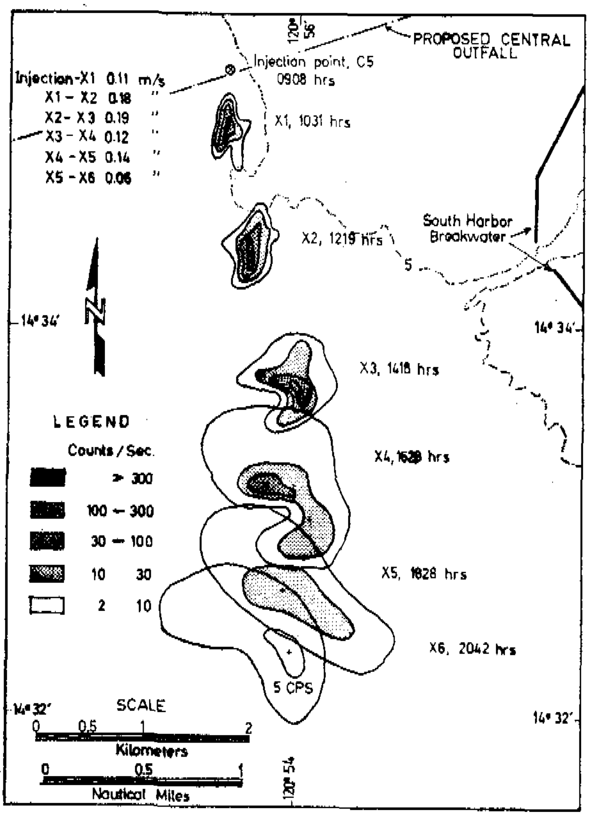

Fig. 6—Typical Isoconcentration Curves Prepared by DIC.

4. *Coliform Die-Away*—One of the parameters frequently used in calculations for the siting of an ocean outfall is the time required for the number of coliform bacteria in the discharged wastewater to decrease by 90 per cent (T_{90} value or die-away time). Although wastewater is not a natural habitat for coliforms, they appear to survive in it, but in the hostile seawater environment their mortality is very much higher. The bactericidal effect of high chlorinity and sunlight, as well as predators in the water and natural flocculation and sedimentation, tend to decrease the numbers comparatively rapidly. The practical determination of the T_{90} value is quite a problem. It is almost a necessity to have an existing ocean outfall for a wastewater source. The only outfall in the study area was the 42 in. C.I. outfall at the mouth of the Pasig River. However, as it now discharged only a few meters from the shore, it was quite unsuitable.

a. *Project Die-Away Studies In-Situ*—A short outfall was found at the southwest corner of the U.S. Navy Base at Sangley Point, Cavite. After several trials, the set-up on the land for the test was as shown in Figure 8. A weighed quantity of Rhodamine dye was mixed with a known volume of water in the large plastic pail and the siphon was connected to the suction side of the pump. Starting at about two minutes before the injection of the dye, samples were collected on the discharge side of the pump at half minute intervals until about 12 samples had been collected. When analyzed for coliform concentration later, the average of these results gave the assumed number of coliforms per 100 ml in the wastewater discharged. In addition, analyzing the dye concentration in these samples gave a check on the original concentration of dye in the tagged wastewater and also allowed a check on the pump discharge quantity.

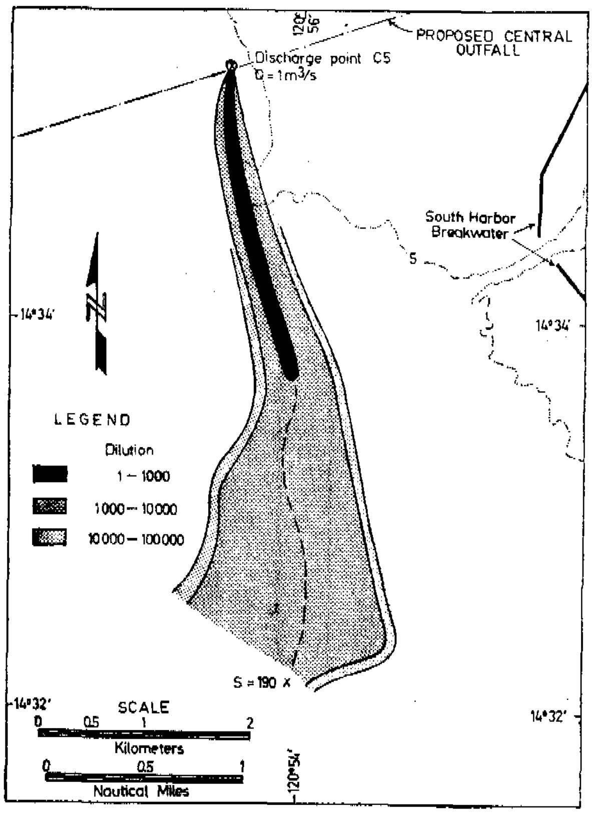

Fig. 7—Typical Isodilution Curves Prepared from the Isoconcentration Curves of Figure 6.

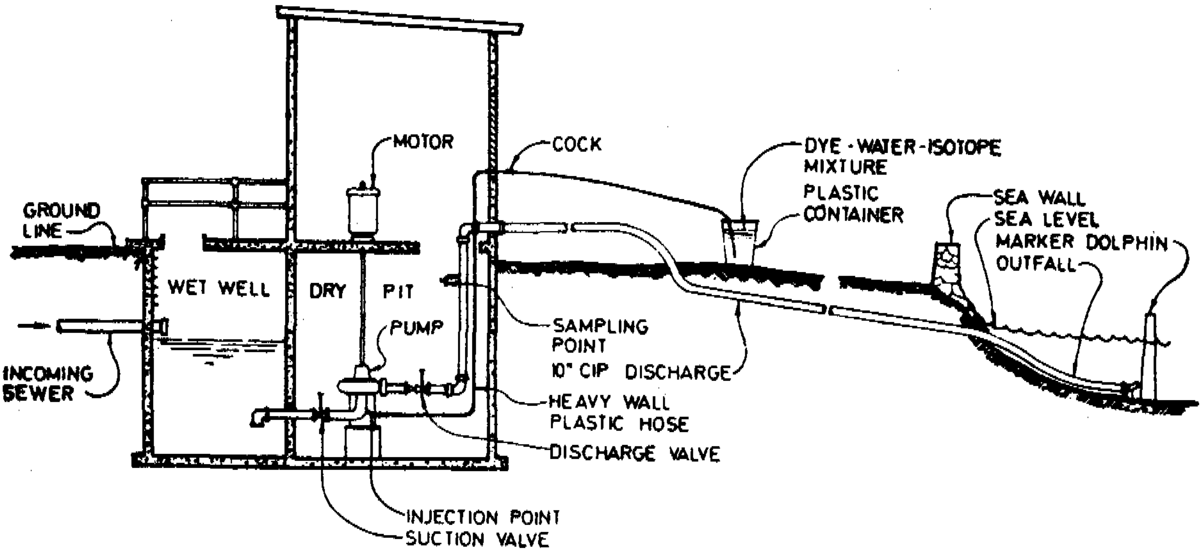

Fig. 8—Sangley Pump Station and Outfall.
(The schematic diagram shows the injection set-up for radioactive tracer with the container remote from the building)

The outfall discharge point was about 50 meters from the shoreline. Usually, as the dye appeared at the outfall, the sea crew would start taking samples in sterilized bottles, from a Van Dorn sampler at 1.5 and 3 meters, and by dipping the sterilized bottles into the water at the surface. A small tee float was launched to follow the surface current, and the intention was to take samples alongside the float. However, a sharp re-entrant angle just adjacent to the discharge point created a severe eddy and many times the test was cut short as the float and the tagged wastewater moved directly to the shore.

The sterilized bottles of seawater were stored in a cooler full of ice and at the end of the test were taken to the project laboratory and analyzed for coliform MPN/100 ml; later the sample remaining in each bottle was tested in a fluorometer and the concentration of dye determined. Comparison of the dye concentration with the original dye concentration injected into the wastewater gave the dilution. The coliform MPN/100 ml multiplied by this dilution should theoretically have equalled the original coliform MPN/100 ml in the discharge wastewater, if there have been no die-away. Thus the decrease in adjusted number of coliforms from the original concentration in the wastewater gave a measure of the die-away from all causes. These results were plotted, and the line of best fit drawn through the points. Results from 3 meters depth were extremely erratic and for practical purposes were meaningless. The results from 1.5 meters were a little better but the most consistent results were from surface samples. In future investigations, sampling at 0.5 meters would probably be a reasonable compromise. The results of several tests are shown in Figure 9. It is interesting to note that within the first 20 or 30 minutes there seems to be almost one order of magnitude of decrease in the concentration of coliforms, judging from the line of best fit through the points. This was attributed to the settling of particles of the sewage as it was discharged from the outfall pipe. After this initial time, the line of best fit seemed to indicate an average T_{90} time in the neighborhood of 180 minutes for Manila conditions.

b. *Laboratory Simulated Die-Away Studies*—Three laboratory coliform die-away simulation tests were made, using fresh, well aerated seawater, mixed

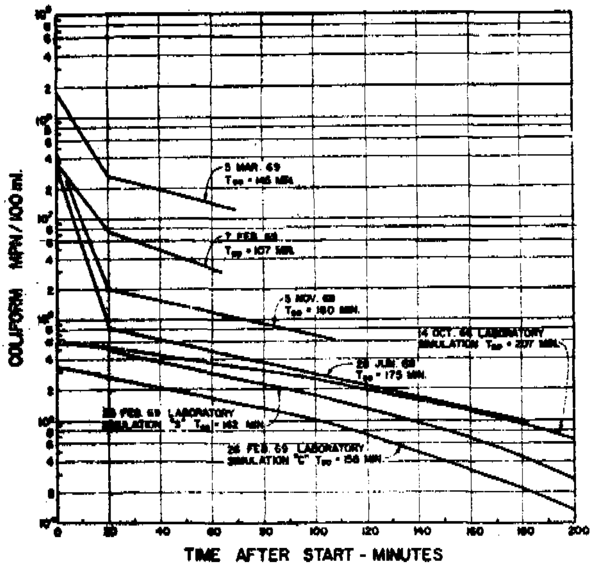

Fig. 9—Coliform Die-Away.
(The graphs show results from four in-situ tests and three laboratory simulations. The in-situ coliform counts determined were multiplied by the dilution to get adjusted coliform MPN/100 ml)

with about 2 percent of domestic sewage. Every half hour, for about three hours, the mixture was thoroughly stirred and several samples drawn into sterilized bottles for coliform concentration determinations. The means of these results were plotted and gave remarkably good confirmation of the 180 minutes die-away time determined in the field, as shown in Figure 9. This method excludes dilution factor from the determination of die-away and does not allow for the effect of sedimentation, as the sea water was stirred prior to each sampling. It was felt essential to have fresh, well-aerated sea water so that the natural predators would still exert their influence but, of course, the bactericidal effect of sunlight was absent

c. *DIC In-Situ Die-Away Studies*—The Danish Isotope Centre study was especially extended for two weeks so that die-away tests using the isotope tracing method could be tried. On the land side the procedure was very much the same as for dye injection, except that the plastic bucket containing the isotope-dye-water mixture was placed about 15 meters away from the station, and careful remote handling techniques were employed for addition and mixing of the isotope with the water. No samples were taken while the isotope slug was being injected into the pump discharge. To check the quantity of sewage being pumped, a Geiger counter was set at a measured distance away from the pump station on the force main, and the time taken for the isotope slug to reach the counter was noted. Knowing the area of the discharge pipe, the quantity discharged per second could readily be calculated.

The navigation and isotope tracing technique was very similar to that used for the regular isotope tracings previously done by the DIC team, except that the probe was set at only 0.5 meters depth. At the point of maximum radioactivity on each crossing of the field, the navigator would give a signal and a sample would be collected in a sterilized bottle from 0.5 meters depth. This sample was stored in a cooler full of ice and later taken to the project laboratory for analysis. In addition, after the criss-crossing of the radioisotope cloud, a single section line was run approximately perpendicular to the direction of the current. Starting in uncontaminated water with only background radiation, the vessel would travel at an even speed across the assumed center of the cloud. At regular intervals, a sample would be taken from 0.5 meters in a sterilized bottle. On analysis of coliform concentration, this would give a section of coliform distribution. The techniques of computation used by the Danish Isotope team were much more sophisticated than used during the project die-away tests. Figure 10 summarizes the navigation and computation techniques used to obtain coliform die-away values. The DIC team reported coliform die-away values of 170 $\pm$ 7 and 130 $\pm$ 15 minutes and suggested that a conservative value of T_{90} for design would be 180 minutes.

A simple, dependable, rapid method of collecting samples for coliform analysis at a depth of 0.5 meters while the vessel was travelling at about 5 knots was essential for this test. Thus the bacterial sampling staff shown in Figure 11 was devised. The sterilized bottle would be fitted in the holder and then the staff lowered into the water in such

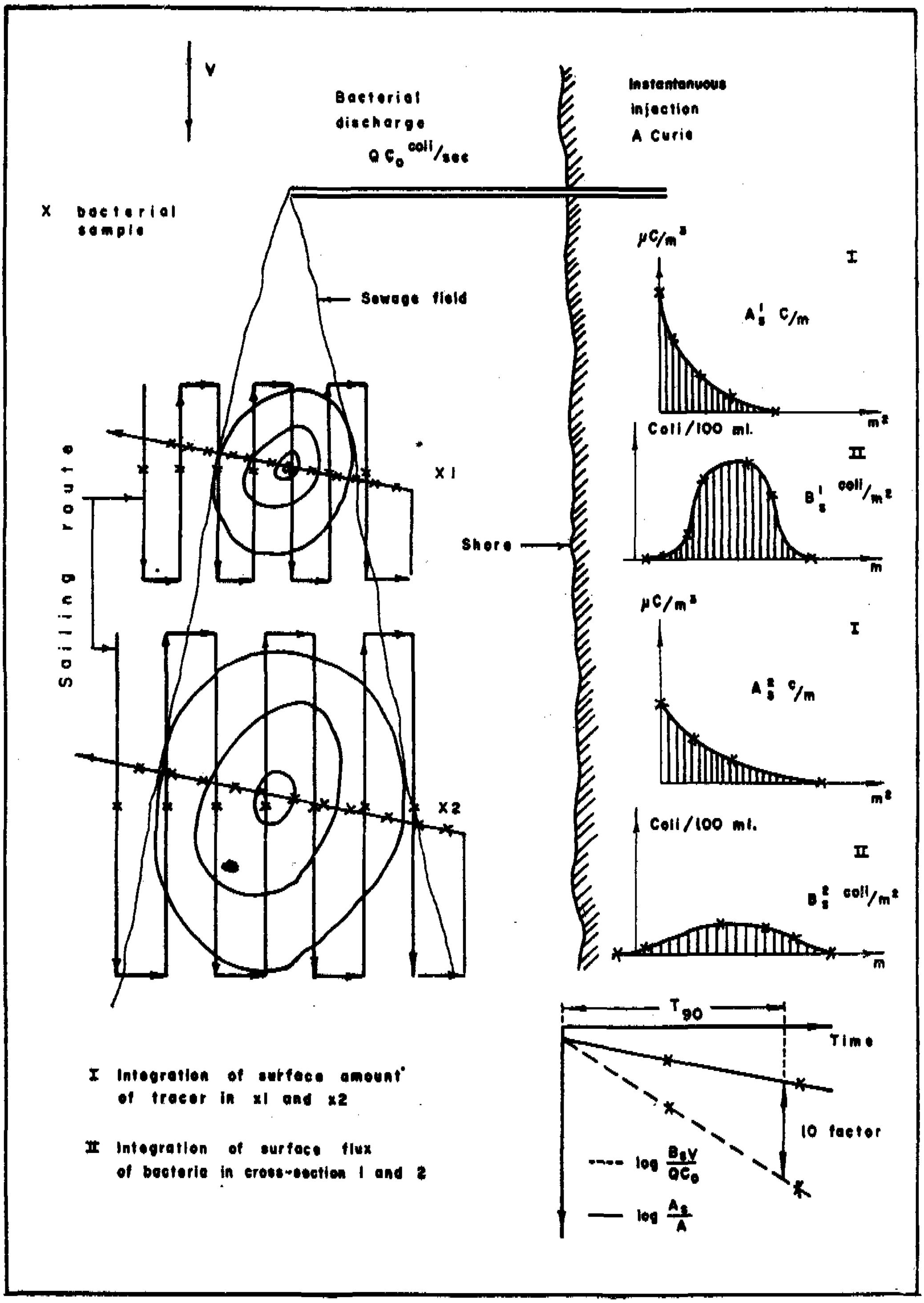

Fig. 10—Navigation and Die-away Computation Techniques Used By the DIC Team.

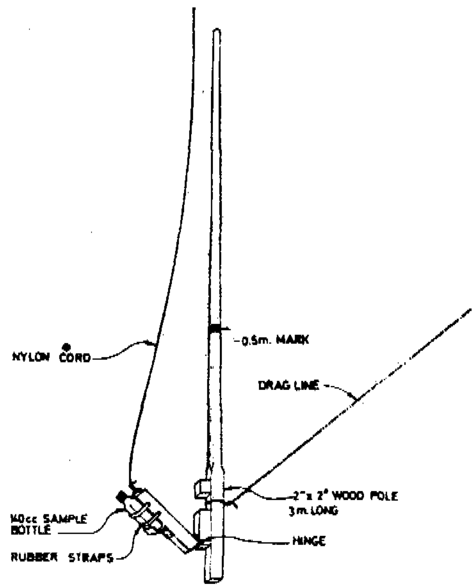

Fig. 11—Bacterial Sampling Staff.
(Staff shown just after it has been rotated 180° and the cord pulled to bring the bottle to an upright position for filling)

a manner that the forward motion of the vessel kept the hinged portion vertical so that the bottle would not fill. On the signal from the navigator, the staff would be rotated 180° and the cord pulled; this would allow the hinged portion to swing vertically and the bottle would fill at a depth of 0.5 meters. While realizing that there was inevitable contamination at the mouth of the bottle by the surface water, the error appeared within an acceptable limit and the technique was rapid enough so that up to five samples per minute could be taken. The drag line was necessary to keep the sampling staff vertical when the vessel was moving.

The number of samples received at the project laboratory for coliform determination vastly overloaded the facilities and sometimes it was three days before dilutions could be made and innoculated and incubated. Thus there was some concern that there might have been error introduced in the coliform determination.

5. *Cruises* — A series of 27 stations were selected, evenly distributed throughout the Bay and its entrance, as shown in Figure 2. These stations were visited in sequence by the "Arinya" on four occasions, approximately once every three months. During each cruise, the regular crew of the "Arinya" had full control of navigation, meteorological observations, setting and lowering of Nansen sampling bottles, reading water temperatures, and casting the bathythermograph. One project chemist and two project engineers accompanied the vessel on sampling cruises. Separate samples were collected for dissolved oxygen, coliform count, salinity, phosphate, and a further sample was put into a large plastic bottle and placed in a cooler full of ice for later BOD and pH analysis in the laboratory. Dissolved oxygen analyses were performed immediately, in a makeshift laboratory aboard the vessel. The standard size reversing Nansen bottle has a volume of approximately 1,300 ml; thus during the first two cruises, two casts of the string of Nansen bottles had to be made at each station. However, special 2 liter Nansen bottles ordered by WHO for the project arrived in time for the last two cruises and then only one cast of the Nansen bottle string was required. At each station a surface sample was collected in a bucket, and then Nansen bottles were attached to the cable to collect samples from a depth of 1 meter, 3 meters, one third, one half and three quarter water depth, and from 2.7 meters from the bottom. In shallow depths some of these bottles were eliminated. After the arrival of the 2 liter Nansen bottles, the time for sampling all 27 stations was less than 5 working days.

RESULTS OF STUDIES

Despite the apparent gross pollution from the Metropolitan Manila Area, results from cruises indicated that pollution of the Bay itself was remarkably low. The BOD_5 of samples collected in the Bay seldom exceeded 3 mg/l and, with a few exceptions, the coliform count within the Bay was generally less than 200 per 100 ml. These coliform results are in remarkable contrast to the excessively high values invariably found along the Metropolitan shores. It appears then that the high coliform counts adjacent to the shores are primarily from local pollution sources, and not from the main discharge of untreated wastewater at the mouth of the Pasig River. The comparatively rapid die-away rate seems to prevent the high shore coliform count appearing in the deeper waters of the Bay.

A better indication of pollution from the Metropolitan Manila Area is the increase in nutrients off the Manila foreshore. Figure 12 shows contours of reactive phosphate for July and October 1968. These very definitely indicate considerably higher concentrations off the Metropolitan Area. This build up of nutrients has apparently stimulated plankton growth to the extent that there are enough phytoplankton to provide dissolved oxygen considerably in excess of saturation at many places in the Bay, particularly towards the eastern shoreline.

Evaluation of all current data led the DIC to theorize a dry weather ebb and flood current pattern in Manila Bay as shown in Figure 13. Not enough studies have been carried out north of the Pasig River to gain any clear concept of what the current pattern in the northeastern portion of the Bay really is. The DIC report suggests that it possibly is merely an in and out motion with the tide, which would not be ideal for disposing of wastewater. However, the southerly current along the Metropolitan shoreline and the southwesterly swing to follow the Cavite peninsula seems to have been well established by drogue and isotope tracks. The northeasterly return at the San Nicolas Shoals has not been clearly demonstrated but appeared possible. If wastewater discharge into this current returned on the flood tide towards Manila it was calculated that the dilution would be so great that the repollution effect would be negligible. Correlation of current data confirmed that velocities were invariably less than 0.5 m/s and frequently on an average as low as 0.1 m/s. Thus while there appeared to be a steady southerly current which would supply fresh water across a diffuser aligned approximately eastwest, the velocity is not so great that wastewater would be swept onto the bathing

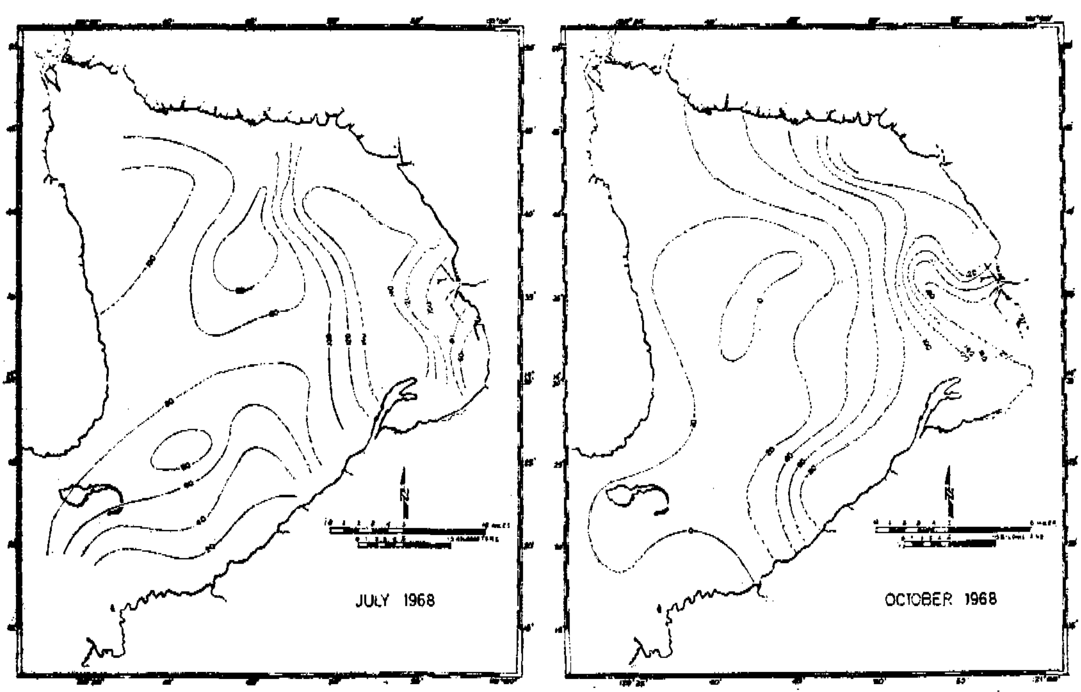

Fig. 12—Phosphate Contours for Cruise II and Cruise III.
(Reactive phosphate results are shown in μg/l, at depth of one meter below the surface)

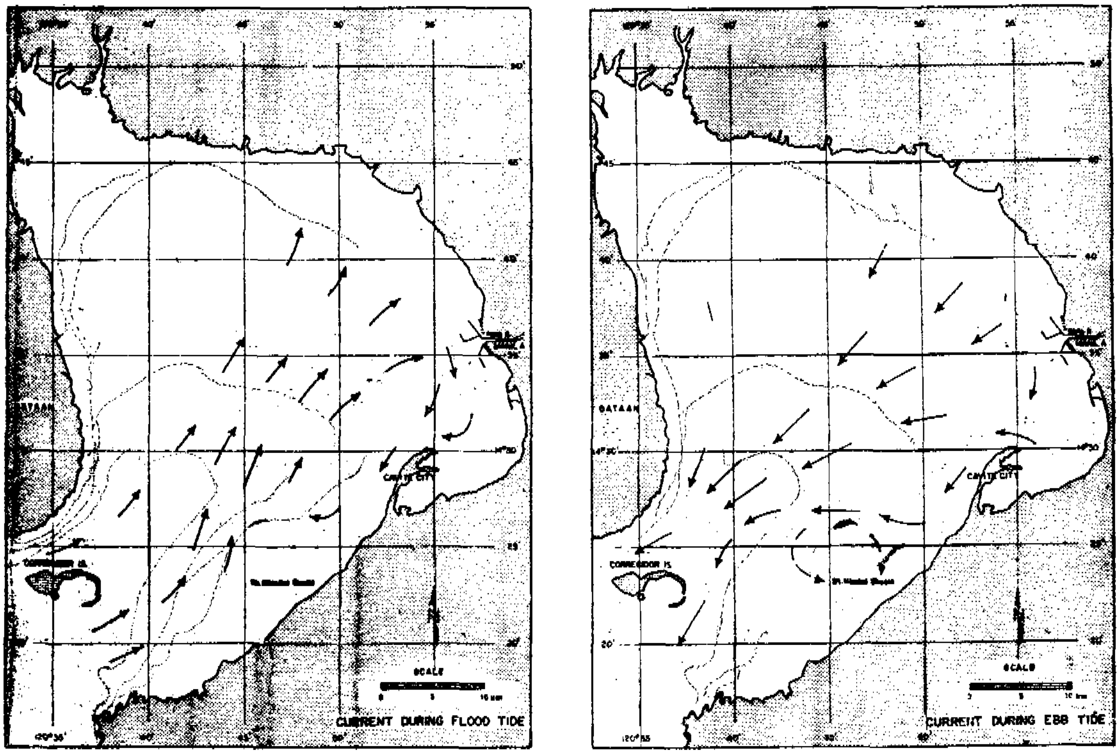

Fig. 13—Currents During Flood and Ebb Tides.
(The diagrams show the currents during flood and ebb tides, as theorized in the DIC report)

beaches or towards the Bacoor Bay oyster beds in less than 9 or 12 hours. By this time the coliform die-away should have decreased the coliform number by at least three orders of magnitude and the physical dilution should be greater than 100. Thus, if the original number of coliforms is assumed to be about 10^8 per 100 ml, five orders of magnitude reduction would bring the level to an acceptable 10^3 per 100 ml.

CONCLUSIONS

Project investigations have indicated that disposal of wastewater from the Metropolitan Area into the prevailing southerly current in eastern Manila Bay is entirely feasible. It appears that to discharge 20 m^3/s would require an outfall from a proposed pump station at the shoreline about 3.5 km to the 10 m depth contour, and then a 1,200 m diffuser aligned about east-west. However, further current studies are desirable off the central and southern urban area in the wet season and off the northern area in all seasons.

It was proposed that the initial outfall should terminate in a temporary point discharge at the 10 m depth for several years while the volume of discharged wastewater was still comparatively low. This would conserve construction capital and allow the effect of the discharged wastewater on the Bay to be monitored. Data gathered would then be used to decide whether or not to extend the outfall, and to design the diffuser. Data from the operation of this outfall would also be invaluable in siting other outfalls.

REFERENCE

DANISH ISOTOPE CENTRE (1969) *Report on a Radioisotope Tracer Investigation of the Marine Evironment of Manila Bay*, August.

WASTEWATER SOLIDS UTILIZATION AND DISPOSAL IN TROPICAL DEVELOPING COUNTRIES

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INTRODUCTION

Wherever modern wastewater treatment plants are installed, many unit processes adopted are for the purposes of solids concentration, conversion and disposal. Initial concentration of solids in a sewage treatment plant is accomplished in primary sedimentation facilities, where up to 75% of the suspended solids in the sewage are removed from the main flow, and an underflow containing about 4% solids (on the dry weight basis) is produced. Subsequent treatment and disposal of this primary sludge in temperate countries might well account for up to 50% of the total cost of treating the sewage. In Asia, where few sewage collection systems exist, let alone treatment plants, wastewater solids are manifest in various forms. Nightsoil collection is practised in most Asian countries, even Japan, but rarely is the collected material treated in a scientific way. Many large cities in this part of the world have relied on septic tanks and cesspools for safe disposal of liquid wastes, but solids accumulate in these units and have to be removed as a sludge. Therefore, even where full-scale treatment plants do not exist, wastewater solids disposal is still a problem. This paper will be concerned mainly with those methods of solids treatment, utilization and disposal which the author considers most appropriate to conditions in tropical developing countries in the immediate future.

NATURE OF WASTEWATER SLUDGES

The composition of wastewater sludges varies with the nature of wastewater discharges and the collection or treatment devices used. Published information on wastewater sludges from Asia is not excessive but Table 1 includes some data from this region. These indicate that nightsoil sludge is similar to a raw primary sludge from a treatment plant and that septic tank sludges in Bangkok are usually not completely stabilized when removed for disposal.

SLUDGE TREATMENT AND DISPOSAL PROCESSES

Unit processes for sludge handling may be conveniently grouped according to purpose under the headings solids concentration, solids conversion, and solids disposal, although some processes fall into more than one category. The result of concentration of a sludge is an increase in solids content and decrease in moisture content. Solids conversion processes accomplish a transformation of the physical and chemical nature of the solids, usually to a more stable and less obnoxious form. The effects of solids conversion and concentration on a typical sewage sludge are shown in Figure 1. Solids disposal implies ultimate discharge with no further handling. Figure 2 shows some processes which have been used for treatment and disposal of sewage sludge. Many of these involve high capital investment on equipment and have been developed for sludge treatment in temperate climates in countries where labour costs are high. The choice of process for any particular location in Asia should be made after an economic comparison of feasible methods has been carried out. It is the author's opinion that those processes marked with an asterisk(*) in Figure 2 will continue to be the most feasible in tropical developing countries in the immediate future. However, a more rational approach to design of installations is necessary if optimum efficiency of land use is to be achieved. Consequently, research on these processes is necessary in Asia to arrive at suitable design criteria. Some work has been done at the Asian Institute of Technology and will be reviewed here.

Table 1—Characteristics of Some Wastewater Sludges from Asia

Type of Sludge	Source	Date Collected	Solids Content, %	Volatile Solids, %	pH	Volatile Acids, mg/l	Reference
Raw Sludge	Ulu Pandan Sewage Treatment Plant, Singapore	March 1965-Mean	4.5	80	5.8	860	Plant Data
	Odai Sewage Treatment Plant, Tokyo, Japan	July 1964-Mean	5.1	43	6.2	-	Plant Data
Night Soil	Unspecified, Japan	1962	1.9-4.2	45-67	7.8	-	IWAI (1962)
	Taipei, Taiwan	1956-7 Summer Mean	2.73	63	9.4	-	ENV. SAN. REPORT(1957)
		Winter Mean	2.87	60	8.9	-	
Night Soil Sludge	Unspecified, Japan	1962	3.7	40	8.6	-	IWAI (1962)
	Bangkok, Thailand	1965-67 Min	1.25	60	6.9	360	AIT Data
		Mean	3.65	67	7.7	750	
		Max	6.40	71	8.5	1700	
Septic Tank Sludge	Bangkok, Thailand	1965-67 Min	1.1	44	7.0	120	AIT Data
		Mean	3.1	71	7.8	320	
		Max	5.6	90	8.5	950	
Digested Sludge	Odai Sewage Treatment Plant, Tokyo, Japan	July 1964 - Mean	5.6	32	7.3	500	Plant Data
	Ulu Pandan Sewage Treatment Plant, Singapore	March 1965 - Mean	9.0	58.5	7.1	83	Plant Data

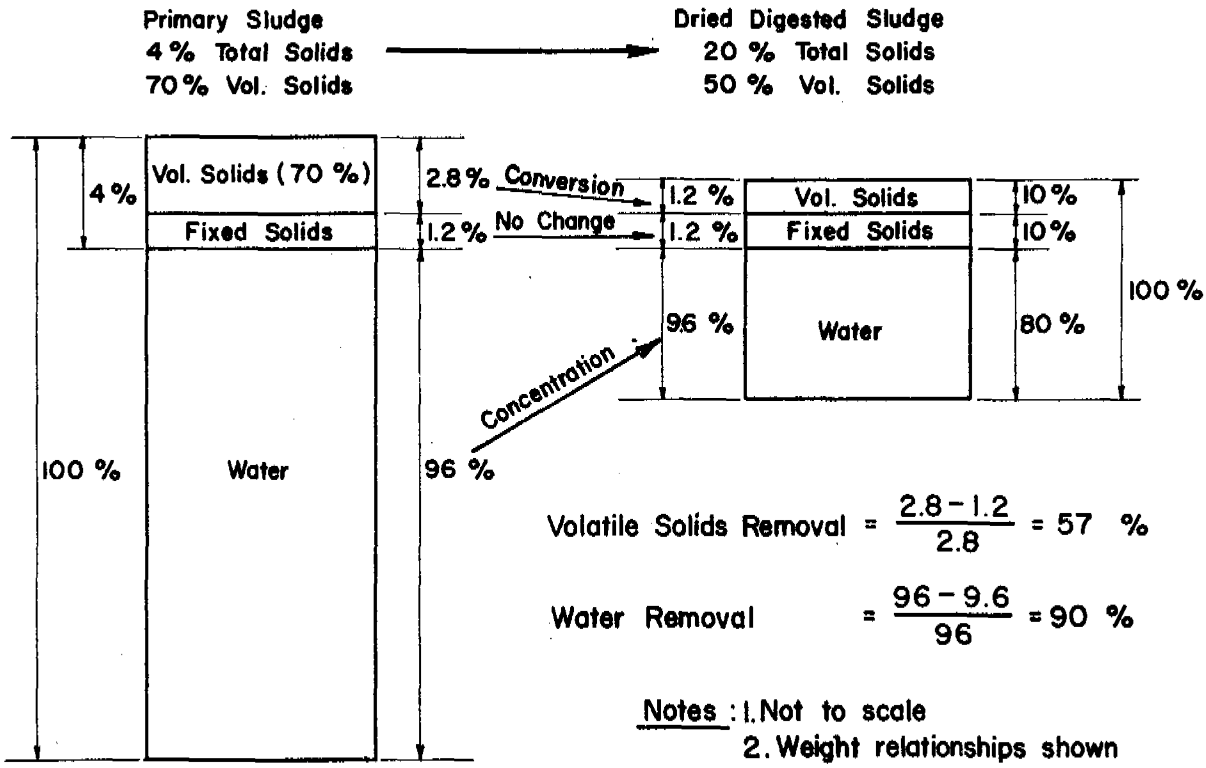

Fig. 1—Effects of Digestion and Drying on Sewage Sludge.

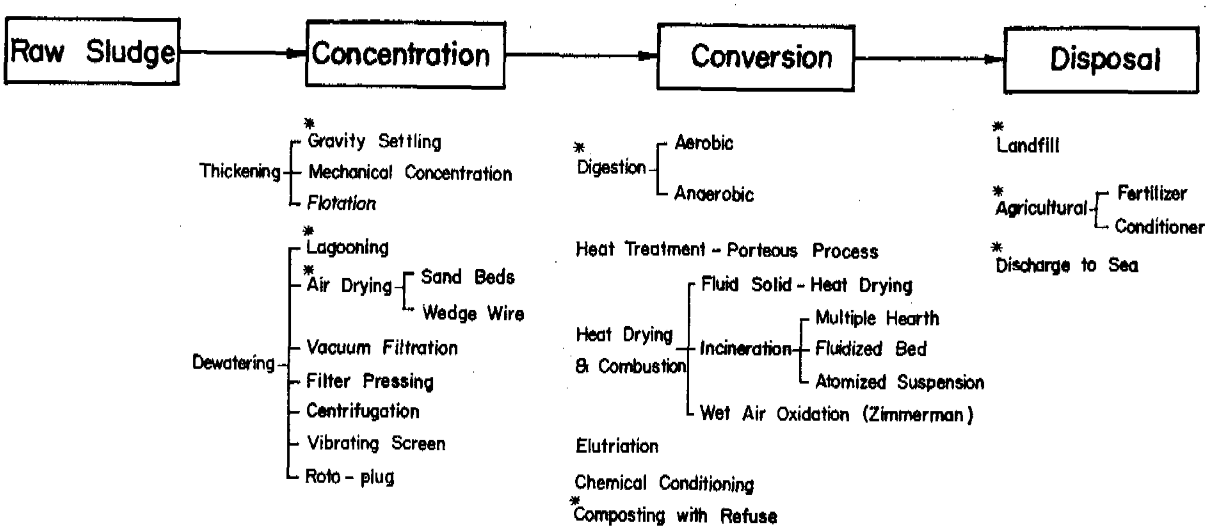

Fig. 2—Some Processes for Treatment and Disposal of Sewage Sludge.

SLUDGE LAGOONING

Sludge lagooning has been the most common method of sludge treatment used in Asia but rarely has it been organized. Although it is not considered entirely satisfactory as a modern treatment process it will continue to be used in the future. However, for optimum use of land lagoons should be operated as drying lagoons, with dried sludge cake removal, rather than as permanent lagoons. Sludge drying in lagoons is brought about by evaporation but some thickening and digestion occur.

Pilot-scale lagoon studies were carried out by LUONG (1968) using septic tank sludge in duplicate lagoons, each 0.44 m^2 in area, and supernatant liquor which separated out was decanted from only one of the lagoons. An initial sludge depth of 22.5 cm was normally used and regular analyses of separated sludge and supernatant layers were carried out. The characteristics of the sludge and supernatant zones for two sludges with initial solids of 2.12 and 1.64% are shown in Figures 3 and 4. Two weeks after the lagoons were set up, mosquito larvae of the species *Culex pipiens* completely covered the surface of the supernatant liquor. This is one problem with lagooning in the tropics which makes the process undesirable for use in cities. The effect of the Bangkok climate on lagooning of the sludge, with and without decantation, is shown in Figures 5 and 6. It is clear that an evaporation rate of approximately 5 mm per day, the only mechanism of water removal in lagoons, was not sufficient to compete with the

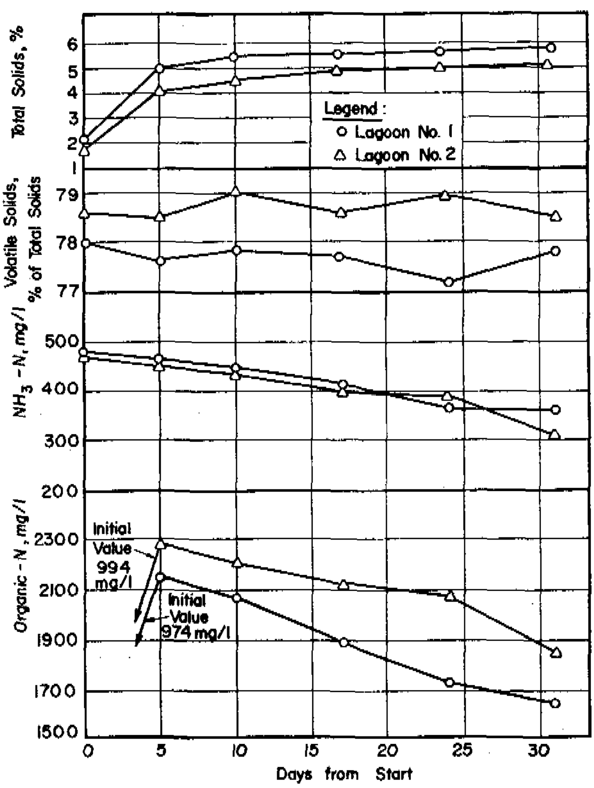

Fig. 3—Characteristics of Sludge Zone in Lagoons.

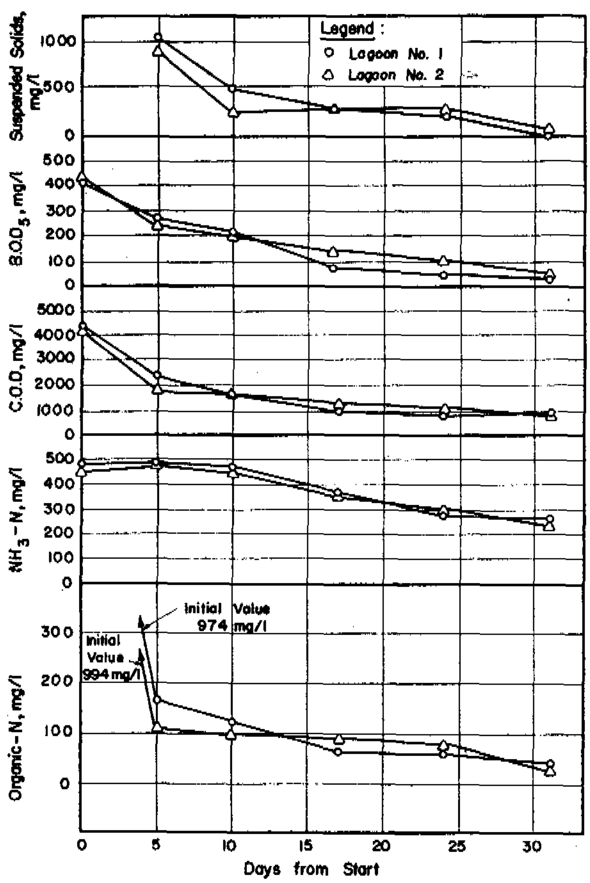

Fig. 4—Characteristics of Supernatant Liquor in Lagoons.

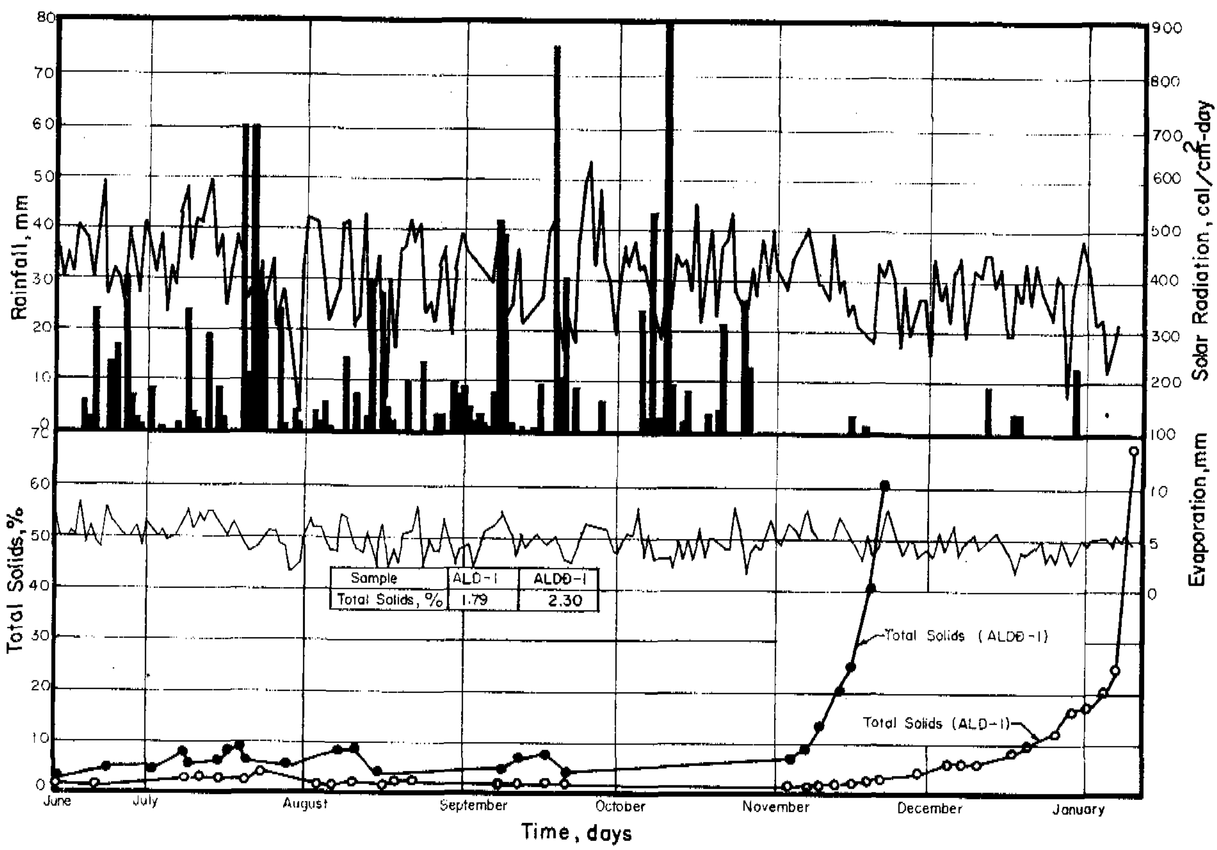

Fig. 5—Sludge Solids Variation in Lagoons.

heavy precipitation during the Thai rainy season, from June to October, even though supernatant liquor (including precipitation) was regularly decanted. However, in the dry season decantation improved the rate of drying and a liftable sludge with mean solids content of 25% was produced in a shorter period. Table 2 summarizes areal loadings obtained in the tests carried out and indicates that lagoons operated during the dry season should be able to handle sludge at a rate of at least 50 kg dry solids/m^2 per year, provided separated supernatant liquor is decanted.

SLUDGE AIR DRYING ON SAND BEDS

Sand bed drying of sludge is widely used in temperate countries and should be most suitable for adoption in tropical countries. Bed construction can be simple and inexpensive, and operation does not require skilled personnel. In this process, advantage is taken of both drainage and evaporation for water removal and land use is more efficient than when lagoons are used. Normally, digested sludge is applied to sand drying beds because it is more readily drainable than primary sludge and less offensive but these may not be significant factors in the tropics.

LUONG (1968) and TSENG (1968) reported on studies carried out with various sludges applied to pilot-scale sand drying beds located outdoors. Sand beds of 0.37 m^2 surface area and 100 cm depth were constructed so as to be weighable. Media as shown in Figure 7 were used, and removable sections of wall allowed a variable depth of sludge to be applied but ensured access of air flow across the sludge surface.

Table 2—Dewatering of 9-inch Layers of Sludge to a Liftable Condition in Open Air Pilot-Scale Lagoons

Samples	Operation	Drying Time: Days	Drying Time: Date	Initial Total Solids %	Specific Resistance 10^9 sec^2/g	Cum. Rainfall mm	Cum. Solar Radiation Cal/cm^2	Loading kg $D.S./m^2$. Yr.	Remarks
ALD-1	Without Decantation	209	Jun. 6 1966 to Jan. 1 1967	1.77	32.2	1047.6	86323.2	6.9	Rainy Season
ALD-2	,,	38	Nov. 5 1966 to Dec. 13 1966	4.85	10.4	12.0	16290.9	108.0	Dry Season
ALD-3	,,	46	Nov. 19 1966 to Jan. 4 1967	1.36	24.8	26.5	17091.4	25.0	
ALDD-1	With Decantation	157	Jun. 6 1966 to Nov. 6 1966	2.30	44.2	1020.2	6662.3	12.4	Rainy Season
ALDD-2	,,	18	Nov. 5-23 1966	1.42	18.8	3.8	9306.5	66.6	Dry Season
ALDD-3	,,	19	Nov. 19 1966 to Dec. 8 1966	1.12	31.9	0	7032.4	49.8	
Average	,,	18.5	—	1.27	—	1.9	8169.5	58.2	

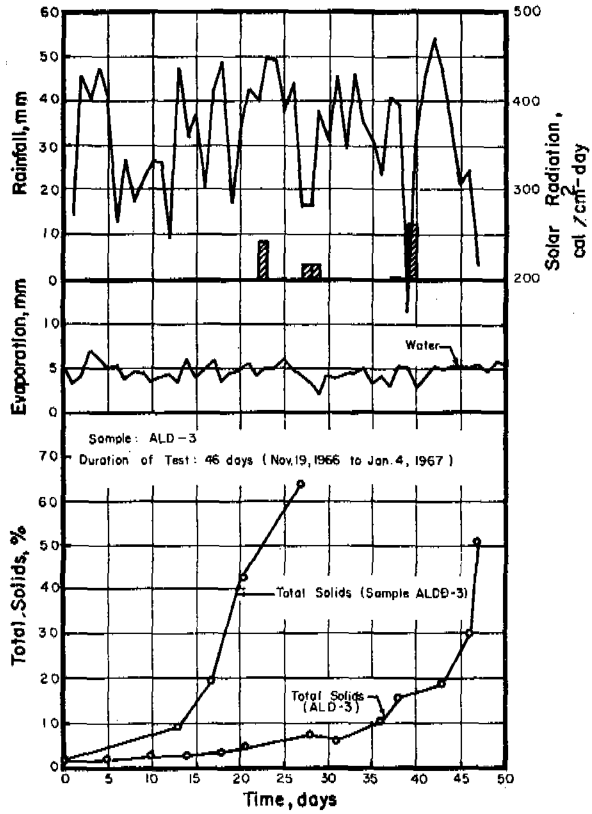

Fig. 6—Sludge Solids Variation in Lagoons.

Applied depths of 20 cm, 30 cm, 40 cm and 50 cm of sludge were used. Drainage from the beds was collected daily and evaporation computed from the total loss in weight, allowing for loss due to drainage.

Figures 8 and 9 show typical sludge drainage curves for dry and wet season conditions in Bangkok. The effect of sludge specific resistance (a measureable parameter of any sludge) on drainability is shown in Figure 8 ; the higher the specific resistance the lower the rate of drainage and hence the longer the time required to drain. It was observed during the wet season that if precipitation occurred before free water in the sludge had drained, the moisture content of the sludge increased and the drainage time was prolonged. If, however, sludge surface cracking, caused by evaporative drying, was deep enough to expose the sand medium, rainfall would pass straight through the sludge and drain directly, causing increases in drainage volume and rate as shown in Figure 9.

The evaporative water losses from sludge samples dried on sand beds are tabulated in Table 3 and compared with water removal by drainage. During the dry season, sludges with low initial solids content drained faster and most water was removed by drainage. Sludges with high initial solids levels took longer to drain and evaporation then became more significant. In the wet season, when precipitation prolonged the drainage time, evaporation was significant regardless of the applied sludge solids content. The ratio of evaporation from drying septic tank sludge to evaporation from a free water surface averaged 0.865 for a one year period.

The effect of sludge application depth on sludge drying time to reach a liftable condition with 25% solids content is shown in Figure 10. For any particular sludge dried under the same weather conditions, an increase in dosing depth of 10 cm increased the necessary drying time by 50 to 100%. The

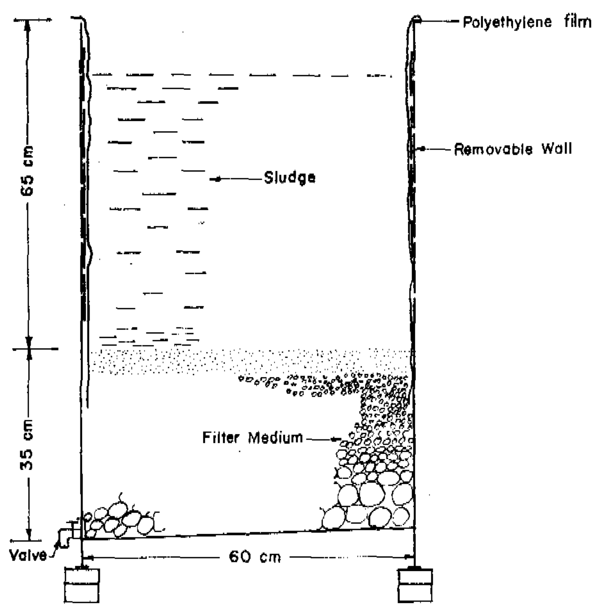

Fig. 7—Sludge Sand Drying Bed.

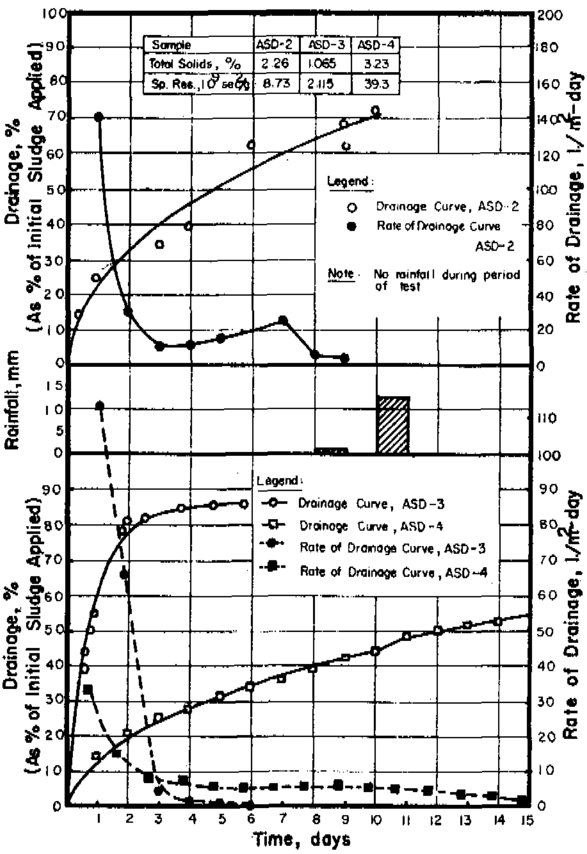

Fig. 8—Drainage from Sand Drying Beds.

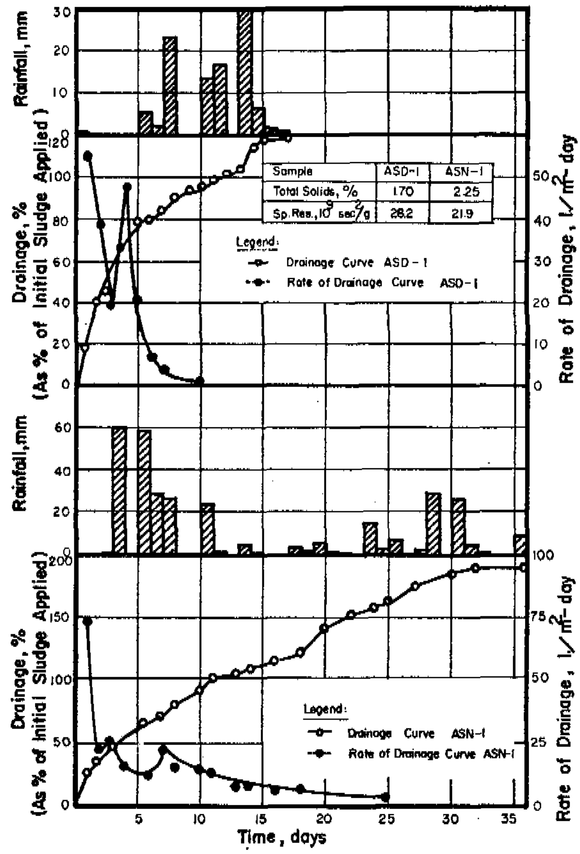

Fig. 9—Drainage from Sand Drying Beds.

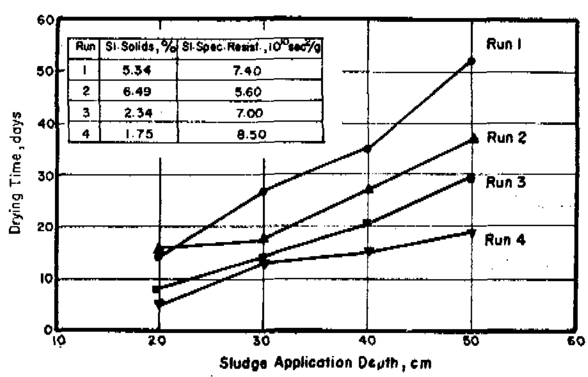

Fig. 10—Relationship Between Drying Time and Sludge Application Depth.

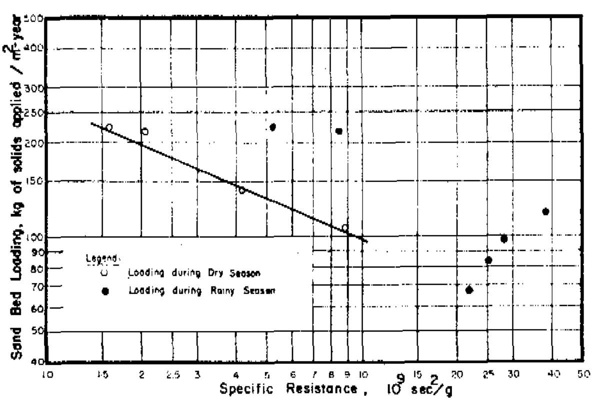

Fig. 11—Relationship between Specific Resistance and Solids Loadings in Pilot-Scale Sand-Drying Beds.

Table 3—Water Removal by Drainage and Evaporation from Sand Drying Beds

	Sample No.	Sludge Characteristics	Dosing Depth, cm	Drying Period (to 25% solids), days	Rain-fall mm	Water Removal, % of initial sl. volume + Rainfall			Proportion of Total Loss, %		
						Drainage	Evapo-ration	Total	Drainage	Evapo-ration	Total
1	Run 1 Bed 2	Total solids 2.35% *Sp. Res. sec²/g 0.93×10¹⁰	26	7	0	79.9	16.4	96.3	83.0	17.0	100
2	Run 2 Bed 1	Total solids 5.5 % *Sp. Res. sec²/g 0.94×10¹⁰	26	12	0	59.4	30.2	89.6	66.4	33.6	100
3	Run 4	Total solids, 1.75% °Sp. Res. sec²/g 8.5×10¹⁰	20	5	0	82.2	14.2	96.4	86.1	13.9	100
			30	13	0	68.8	25.9	94.7	72.1	26.3	100
			40	15	0	71.5	22.9	94.4	75.7	24.3	100
			50	19	0	71.8	22.0	94.0	76.4	23.7	100
4	ASD-1	Total solids, 1.7 % *Sp. Res. sec²/g 2.8×10¹⁰	23	14.5	100	66.0	28.5	94.5	70.0	30.0	100
5	ASN-1	Total solids, 2.25% *Sp. Res. sec²/g 2.19×10¹⁰	23	28	257.85	48.0	46.0	94.0	51.0	49.0	100
6	ASD-4	Total solids, 3.23% *Sp. Res. sec²/g 4.0×10¹⁰	23	14	12.3	45.0	43.0	88.0	51.0	49.0	100
7	CSD-1	Total solids, 2.95% *Sp. Res. sec²/g 0.84×10¹⁰	23	11	46.3	74.0	16.0	90.0	82.2	17.8	100
8	Run 1	Total solids, 5.34% °Sp. Res. sec²/g 7.4×10¹⁰	20	14	21.19	38	37.3	75.3	50.5	49.5	100
			30	27	110.27	47.4	41.7	89.1	53.2	46.8	100
			40	35	130.27	44.6	39.1	83.4	53.4	46.6	100
			50	52	214.52	46.2	35.8	82.0	56.3	43.7	100
9	Run 2	Total solids, 6.49% °Sp. Res. sec²/g 5.6×10¹⁰	20	15	52.8	59.3	26.2	85.5	69.4	30.6	100
			30	17	53.15	56.2	20.9	77.1	73.0	27.0	100
			40	27	100.75	62.0	23.4	85.4	72.6	27.4	100
			50	37	105.95	56.3	24.1	80.5	70.0	30.0	100
10	Run 4	Total solids, 2.37% °Sp. Res. sec²/g 7.0×10¹⁰	20	8	0	73.7	20.4	94.0	78.4	21.6	100
			30	14	10.8	70.9	20.4	91.3	77.4	22.6	100
			40	21	10.8	63.1	28.5	91.6	68.8	31.2	100
			50	30	10.8	57.3	34.4	90.7	63.4	36.6	100

* Measured at 677 g/cm² (50 cm Hg) vacuum, ° Measured at 455 g/cm² vacuum.

highest bed loadings were given by the 20 cm application depth for sludge samples 3 and 8 in Table 4 but inconsistent results were given by sample 9. Bed loadings for the same sludge application depth have been plotted against sludge specific resistance on log-log paper in Figure 11. A geometric relationship between specific resistance and bed loading rate was established for the dry season but wet season results did not conform to the pattern. In general, bed loading or bed yield decreased with increase in sludge specific resistance.

However, even the minimum bed loading obtained during the dry season was more than the maximum lagoon areal loading, even with decantation, and more than twice the loading rate of 50 kg dry solids/m² per year previously suggested for lagoons. The minimum sand bed loading obtained was equivalent to the loading expected in a temperate climate for open sand beds charged with primary sludge.

The effect of sludge conditioning with alum on sand bed drying was also investigated by LUONG (1968) who recommended that conditioning with alum should only be carried out to improve the wet season bed loading if this was necessary. No significant advantage accrued from sludge conditioning during the dry season.

SLUDGE AIR DRYING ON WEDGE WIRE BEDS

The use of a permanent medium, such as wedge-wire, in place of sand in sludge drying beds is said

Table 4—Bed Loadings for Sludge Sand Drying Beds

Sample No.	Sludge Characteristics	Dosing Depth, cm	Cumulative Rainfall, mm	Bed loading, kg D. S./m² yr
1	Total Solids 2.35% Sp. Res. sec²/g 0.93×10^{10}	26	0	330
2	Total Solids 5.5 % Sp. Res. sec²/g 0.94×10^{10}	26	0	475
3	Total Solids 1.75% Sp. Res. sec²/g 8.5×10^{10}	20	0	256
		30	0	148
		40	0	170
		50	0	168
4	Total Solids 1.7 % Sp. Res. sec²/g 2.82×10^{10}	23	100	97.6
5	Total Solids 2.25% Sp. Res. sec²/g 2.19×10^{10}	23	257.85	67.5
6	Total Solids 3.23% Sp. Res. sec²/g 4.0×10^{10}	23	12.3	137
7	Total Solids 2.95% Sp. Res. sec²/g 0.845×10^{10}	23	46.3	215
8	Total Solids 5.34% Sp. Res. sec²/g 7.4×10^{10}	20	21.19	278
		30	110.27	216
		40	130.27	222
		50	214.52	188
9	Total Solids 6.49% Sp. Res. sec²/g 5.6×10^{10}	20	52.80	316
		30	53.15	419
		40	100.75	350
		50	105.95	320
10	Total Solids 2.37% Sp. Res. sec²/g 7.0×10^{10}	20	0	214
		30	10.8	185
		40	10.8	165
		50	10.8	144

to promote a shorter drying period as well as simplifying the process of sludge cake removal. However, use of this particular medium does impose a more complex operating procedure for controlling the rate of drainage. This, together with the high cost of the wedge wire, would mitigate against its use in developing countries unless the sludge drying period was markedly reduced in any particular instance.

LUONG (1968) reported on sludge drying tests carried out using wedge wire as a supporting medium in experimental units placed outdoors. The equipment shown in Figure 12 was used and the drainage rate was controlled by limiting the difference in head across the medium to 2.5 cm until drainage was complete. Thereafter, evaporative drying was allowed to continue until a liftable sludge was produced.

Drainage curves for wedge wire filtration of 36 l sludge samples are shown in Figure 13. It can be seen, by comparing these curves with the drainage curves for sand bed drying in Figures 8 and 9, that drainage through wedge wire medium occurred at a faster rate and was always complete within one day. Evaporative losses occurred over a longer period and accounted for 19 and 12% of applied sludge volume for sludges with initial solids of 2.78% and 2.76% dried to a surface solids content of 30%.

Figure 14 shows the progress of sludge drying for different climatic conditions. Sludges with low initial solids content dried to an average solids content of 25% in a shorter period than those with high solids, regardless of the weather. A summary of experimental results is given in Table 5 where it can be seen that bed loadings from 167 to 287 kg dry solids/m^2 per year were obtained for a range of sludges applied to a depth of 22.5 cm. Alum conditioning only slightly improved bed loading and was not recommended for practical application.

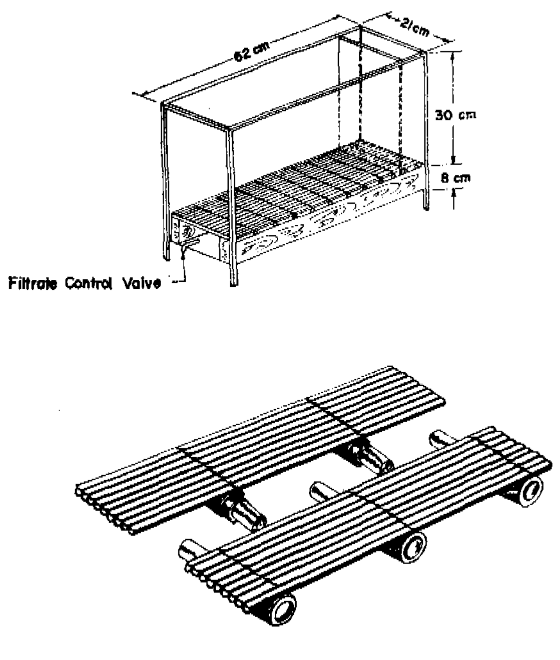

Fig. 12—Wedge Wire Filter and Medium (British Wedge-Wire Co. Ltd.).

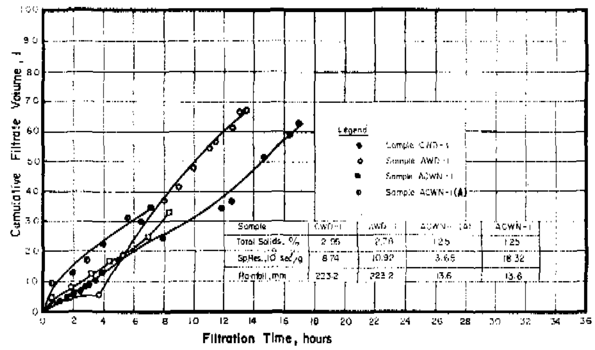

Fig. 13—The Filtrate from Wedge-Wire Filter.

ANAEROBIC SLUDGE DIGESTION

Anaerobic digestion has been by far the most popular method of solids conversion used in sewage treatment plants. The process brings about a reduction of volatile solids (organic material) in sludges, makes sludges less odorous, and liberates methane, a hydrocarbon gas which can be used as a fuel for heating or power production. It is a biological process depending on the activities of mesophilic bacteria in the temperature range from 16 to 38° C. At lower temperatures in this range, mesophilic digestion is slow and plant capacity would need to be high. However, ambient temperatures in tropical countries are usually near the upper end of the range and digestion should proceed at a rapid rate, making the process economical if solids conversion is desirable.

Unheated anaerobic digestion studies have been carried out by SUCHINT (1967) on both septic tank and nightsoil sludges. Table 6 gives analyses of fed septic tank sludges and digested sludges withdrawn from the laboratory digesters after 42 days, and Table 7 shows digester loading rates. Volatile solids destruction was very low, indicating that septic tank sludge had undergone digestion to a high degree. Gas production followed the curves shown in Figure 15 for a mean digestion temperature of 31°C, and it was estimated that a constant gas production rate of 53 ml/l active volume per day would have been established with sludge 5 at 20 days detention time. The rate of

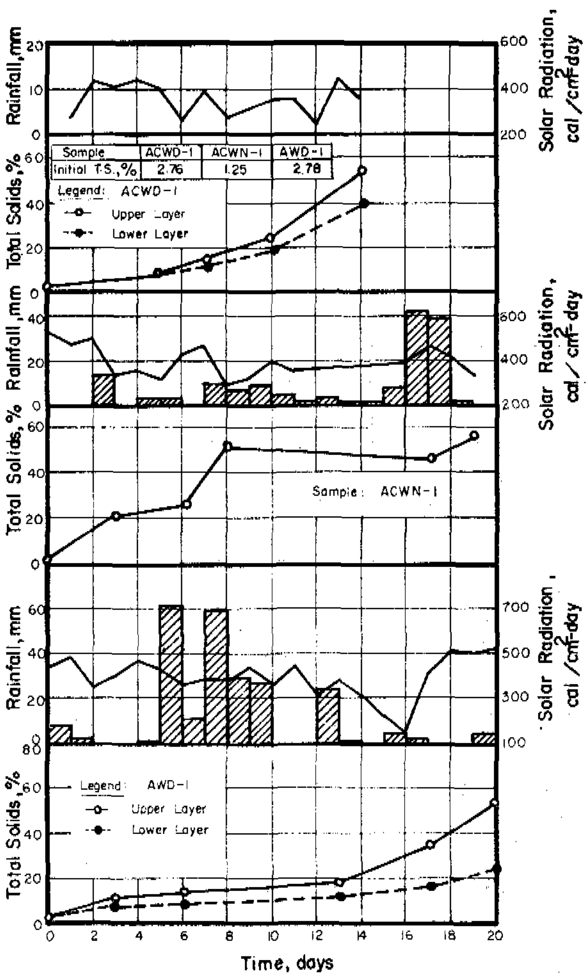

Fig. 14—Sludge Solids Variation on Wedge-Wire Filters.

gas production in the 20 days detention digester dropped after 25 days of operation when sludge 6 was fed, showing the effect of lower volatile solids loading. The results of this phase of the study confirmed that further digestion of septic tank sludge was possible without heating or continuous mixing but that volatile solids destruction and gas production were low compared with normal primary sludge digestion. Under these conditions a detention time of 10 days was optimum.

Table 8 gives analyses of fed nightsoil sludges and digested sludges withdrawn from the laboratory digesters after 42 days, and Table 9 shows digester loading rates. Volatile solids destruction was much higher than in the case of septic tank sludge digestion. Gas production was as shown in Figure 16 for a mean digester temperature of 32°C. It can be seen that much more gas was produced from nightsoil sludge than from septic tank sludge. During the fed period of digestion, the digester with 10 day detention time produced the greatest total volume of gas. Gas production in the 10 and 20 day detention time digesters worked out to be 3,340 and 5,600 ml/g volatile solids fed per day which is higher than the normal production from primary sludge. These may be compared with 68 and 128 ml gas/g volatile solids fed per day during fed digestion of septic tank sludge at the same detention periods. The results indicate that anaerobic digestion was a suitable method for treating nightsoil sludge and that a 10 day detention time was optimum for design of a digester without heating or continuous mixing. This applied to loading rates up to 4.5 g volatile solids/1 active digester volume per day, which is higher than the normal loading

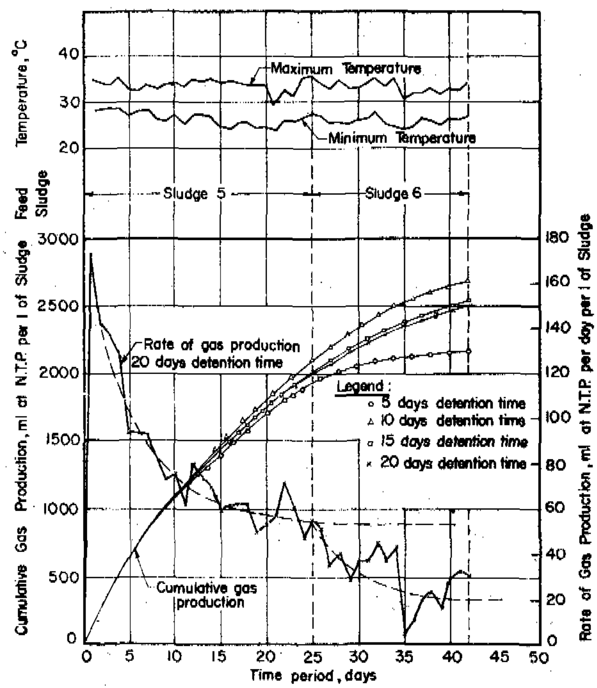

Fig. 15—Gas Production in Phase 2 Digestion Studies.

Table 5—Dewatering of 8-inch Layers of Sludge to a Liftable Condition (25% Solids) on Open Air Pilot-Scale Wedge-Wire Filters

Sample	Treatment	Duration of Test	Initial Total Solids %	Drying Time, Days	Sp.Res. 10^9 Sec^2/g	Cum. Rainfall mm	Cum. Solar Radiation Cal/cm^2	Average Rate of Drainage l/m^2 hr.	Time Req. to Drain off Sup. Days	Loading kg of D. S./m^2.Yr.	Remarks
AWD-1	Without Alum	July 15-29,1966	2.78	14	10.92	219.6	5,392.7	30.3	0.54	167	Rainy Season
ACWN-1	"	Aug. 21-27, 1966	1.25	6	18.33	19.6	2,872.6	46.2	0.30	177	
ACWD-1	"	Nov. 23-29,1966	2.76	9	2.05	0	3,187.0	36.2	0.40	287	Dry Season
Average	"	-	2.30	9.7	-	80.0	3,817.4	37.6	0.41	210	
CWD-1	With Alum	Jul. 23-Aug. 7'66	2.95	14	8.74	70.7	6,077.3	31.9	0.9	168	Rainy Season
ACWN-1	"	Aug. 21-27,1966	1.25	6	3.65	19.6	2,872.6	33.4	0.3	177	
ACWD-1	"	Nov. 21-28, 1966	2.76	8	1.25	0	2,832.0	38.2	0.4	335	Dry Season
Average	"	-	2.31	9.3	-	30.1	3,927.2	34.5	0.8	226	

rate of 1.2 g volatile solids/l per day for conventional digestion of primary sludge. In practice, this loading rate can rarely be achieved without high solids content in the input sludge to the process and continuous and thorough mixing of reactor contents.

COMPOSTING SLUDGE WITH REFUSE

Composting of sewage sludge with refuse is practised at a few plants throughout the world and has the advantage of disposing of two types of waste solids by the same process. The fact that the

Table 6—Composition of Fed and Final Withdrawn Sludges in Phase 2 Digestion Studies

Characteristics	Fed Sludges		Withdrawn Digested Sludge after 42 days of Digestion			
	Sludge 5 For 25 days	Sludge 6 For 17 days	Detention Time, days			
			5	10	15	20
Total solids, %	4.01	2.22	2.28	2.68	2.29	2.64
Volatile solids, % Total Solids	70.5	75.2	72.6	74.0	71.7	71.5
pH	7.6	7.3	8.1	7.6	8.0	7.9
Alkalinity, mg/l	2,450	2,275	1,700	2,163	2,075	2,625
Volatile acids, mg/l	170	292	515	557	69	283
Ammonia nitrogen, mg/l	665	543	476	595	672	630
Organic nitrogen, mg/l	1,260	1,904	966	1,050	869	980

Table 7—Digester Loading Rates in Phase 2 Studies

Sludge	Total Solids, %	Volatile Solids, % Total Solids	Digester Loading Rate, g volatile solids per 1 active volume per day — Detention Time, days			
			5	10	15	20
5	4.01	70.5	5.65	2.82	1.88	1.41
6	2.22	75.2	3.34	1.67	1.11	0.84

Table 8—Characteristics of Fed and Withdrawn Sludges in Phase 3 Digestion Studies

Characteristics	Fed Sludges			Withdrawn Sludges after 42 days — Detention Time, days	
	Sample 8 for 17 days	Sample 9 for 12 days	Sample • 10 for 13 days	10	20
Total solids, %	6.40	4.17	5.23	4.29	4.56
Volatile solids, % of Total Solids	70.2	68.1	70.9	68.4	66.70
pH	7.4	7.2	6.9	8.0	7.8
Alkalinity, mg/l	6,700	3,870	2,775	3,325	4,100
Volatile acids, mg/l	980	1,055	1,677	1,386	1,115
Ammonia nitrogen, mg/l	1,460	1,400	616	1,050	1,387
Organic nitrogen, mg/l	1,170	2,300	366	1,555	1,570

Table 9—Digester Loading Rates in Phase 3 Studies

Sludge	Total Solids, %	Volatile Solids, %total solids	Loading Rate, g volatile solids/l active volume per day	
			10-day detention time	20-day detention time
8	6.40	70.2	4.50	2.25
9	4.17	68.1	2.84	1.42
10	5.23	70.9	3.70	1.85

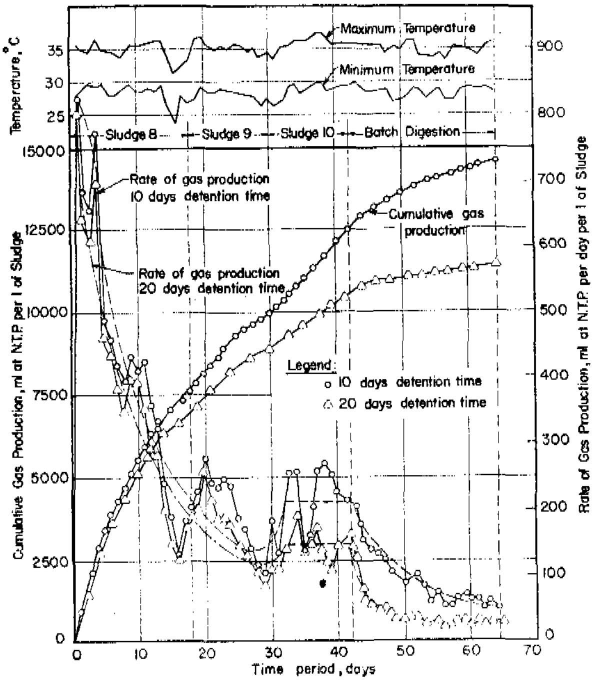

Fig. 16—Gas Production from Digesting Nightsoil Sludge.

process produces an end-product which might be saleable acts as an incentive to evaluation of the possibility of adopting it in any location. When wet sludges are used, the factor controlling the amount of sludge that can be added to refuse is the moisture content of the sludge. Normally a moisture content limit of 60 to 65% is placed on the sludge-refuse mixture but this may not apply to open composting in the tropics where evaporation is high. Compost, the finished product with a carbon to nitrogen (C:N) ratio below 20, can be used as a soil conditioner.

PRANEE (1968) carried out some studies on the composting of sorted and shredded Bangkok refuse with septic tank sludge. Open windrow experiments were carried out over a six week period on mixtures of 24 m^3 of shredded refuse and 8 m^3 of septic tank sludge, with weekly turning of the piles. Temperature and moisture content changes are recorded in Figure 17 where results are also given for composting refuse alone, and Table 10 gives analyses of the raw mixture and finished compost from the process. Using this composting system, thermophilic temperatures were maintained and aerobic conditions prevailed. Moisture content declined throughout the composting period, due to evaporation, and total volatile solids reduction was 13%. The final C:N ratio was within acceptable limits for an organic soil conditioner. Nitrogen, phosphate, and potash concentrations in the compost from the mixture of refuse and sludge were higher than in that produced from refuse.

In addition to open windrow composting, enclosed chamber composting, a mechanized method adopted by the Bangkok Municipality on full scale, was studied. Twelve troughs of the Bangkok Composting Plant, each of $2m^3$ capacity, were filled with shredded refuse and a further twelve at the same level were filled with a mixture of shredded refuse and septic tank sludge in the ratio 4:1. In operation, the troughs were dumped every day, the composting material falling to the next level of the building, and being aerated at the same time. It took six days for the material to reach the ground floor, after which time it was stockpiled for 5 weeks, turning once per week. The temperature and moisture content changes over the composting period for both types of raw waste are shown in Figure. 18 and analyses of raw wastes and finished composts given in Table 11. Again, thermophilic temperatures were maintained and moisture content decreased over the period, but not to the same

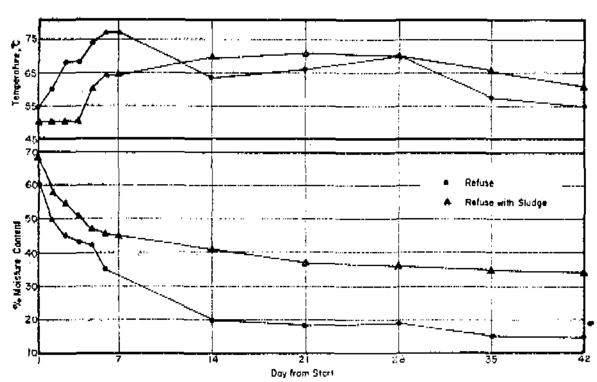

Fig. 17—Temperature and Moisture Content During Open-Windrow Composting.

Table 10—Analyses in Open-Windrow Composting

Constituent	Raw mixture Percent by Weight Dry Basis		Compost Percent by Weight Dry Basis	
	Refuse alone	Refuse + Sludge	Refuse alone	Refuse + Sludge
Moisture*	61.4	68.5	15.0	10.5
Volatile Solids	53.0	55.5	38.0	42.5
Nitrogen (N)	1.21	1.32	0.98	1.32
Carbon (C)	29.1	30.1	21.2	23.4
C/N ratio	24.1	22.9	20.5	17.6
Phosphate (P_2O_5)	0.40	0.47	0.10	0.24
Potash (K_2O)	0.49	0.52	0.29	0.36

* Percent of wet weight.

extent as in open windrows because evaporation from the enclosed troughs was less. Volatile solids reduction in the sludge-refuse mixture was 14.5% and the C:N ratio decreased from 23.7 to 19.6.

The results show that material stabilized faster in the enclosed chamber composting plant than in open windrows. Moisture losses were high and moisture content was low for aerobic composting over the last 4 weeks in open windrows. This suggests that perhaps a higher proportion of wet sludge could have been used. The finished products were harmless materials containing small amounts of the major plant nutrients and as such would be useful as a soil conditioner. Open windrow composting requires large land areas, gives off odours, and attracts vermin and flies. Addition of wet sludge to refuse made the materials-mixing part of

Table 11—Analyses in Mechanical Composting (Composting Plant)

Constituent	Raw Mixture Percent by Weight Dry Basis		Compost Percent by Weight Dry Basis	
	Refuse alone	Refuse + Sludge	Refuse alone	Refuse + Sludge
Moisture*	59.5	69.0	20.5	28.0
Volatile solids	58.9	68.5	45.5	54.0
Nitrogen (N)	1.55	1.60	1.52	1.53
Carbon (C)	32.5	38.0	25.3	30.0
C/N ratio	21.0	23.7	16.6	19.6
Phosphate (P_2O_5)	0.75	0.84	0.60	0.30
Potash (K_2O)	0.60	0.65	0.49	0.51

* Percent of wet weight.

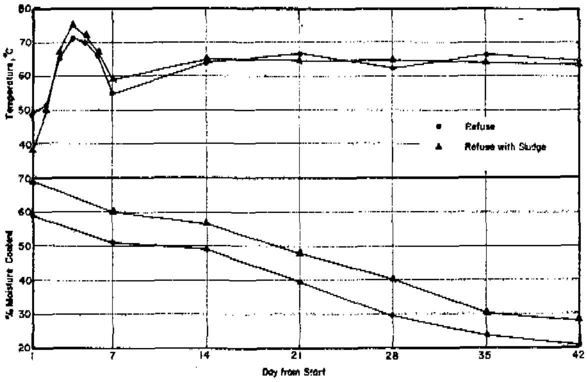

Fig. 18—Temperature and Moisture Content Using Enclosed Chamber Composting.

the process more complex, without markedly improving the finished product. High evaporative losses in open windrow composting in the tropics will allow large quantities of sludge to be disposed of in this manner.

DISPOSAL OF WASTEWATER SOLIDS

In an earlier section, three methods of solids disposal were mentioned, although it must be remembered that both sludge digestion and combustion will remove volatile solids and discharge them ultimately into the atmosphere. Discharge of solids to the sea or ocean is practised wherever there is ready access to this outlet and when the method is found to be economically feasible. Disposal of sewage through pipelines is regularly adopted by coastal towns and is acceptable if the outfalls are properly designed. For sludge discharges of any quantity, such as those from a large city, special vessels are required to transport the sludge (usually digested) to dumping grounds at sea, chosen so that solids will not be carried back to beaches by offshore currents. In developing countries, these methods of disposal will have appeal to coastal cities and to cities located on estuaries and are likely to be most economical if no treatment is given to the sewage or sludge.

Disposal of sludge directly onto agricultural land on a large scale is not expected to compete with other sludge disposal methods in tropical developing countries in the future. Even if the sludge, either wet or dry, is delivered free it will be an unprofitable substitute for artificial fertilizers due to its low phosphate and potash contents. In addition, with increasing industrialization the danger of poisoning the soil or crops by toxic substances in the sludge has to be considered. Final disposal of sludge onto agricultural land after composting in combination with refuse, although desirable from a conservation viewpoint, is unlikely to be widely adopted in Asia. Compost is only a soil conditioner, not a fertilizer, and in terms of performance has little appeal in competition with commercial fertilizers, besides being costly to transport. The compost produced in Bangkok at the present time is very difficult to market mainly because of distribution costs.

For most inland communities, landfill will be the most popular method of wastewater solids disposal. However, more attention is likely to be given to prior treatment of sludge to reduce the volume for disposal and to make its condition innocuous. In the urban context, land disposal of wastewater solids must be carried out in such a manner that the quality of the environment is not deteriorated. It is clear that the practices adopted for treatment and disposal of solids which originated in the water subsystem of the environment are likely to have an impact on both air and land subsystems. The organization of authorities responsible for dealing with solid, liquid and air-borne wastes must reflect the interdependence of the problems which necessitated their formation.

CONCLUSIONS

Disposal of wastewater solids is likely to be a problem even where no sewage collection system exists. In Asian countries, nightsoil and septic tank sludge will continue to be major forms of sewage solids. Of the many processes available for concentration, conversion and disposal of wastewater sludge, those utilizing the simplest equipment and operating procedures and taking advantage of the climatalogical and labour conditions will be most appropriate in tropical developing countries. On the basis of the few studies carried out at the Asian Institute of Technology, air drying on sand beds and unheated digestion seem to have the greatest application in this environment for sludge dewatering and solids conversion. Landfill will become increasingly adopted for disposal of wastewater solids in inland communities because of the widespread use of chemical fertilizers in agriculture. Sludge treatment and disposal practices should be carefully controlled to minimize deterioration of the quality of the environment.

Air drying of sludge on sand beds was found to be an effective means of dewatering, even during the wet season. A 20 cm depth of application was most suitable and gave bed loadings between 214 and 316 kg dry solids/m^2 per year in Bangkok. Sludge conditioning with alum was found to improve bed yield during the wet season but covering the beds would reduce evaporative drying and prove disadvantageous in terms of annual bed turnover. Simple construction of beds and use of local materials for media would make sand bed drying a simple, cheap and effective dewatering process for both raw and digested sludges in Asia. The high loading rates possible in the tropics would keep land use within reasonable limits for most installations.

Unheated anaerobic digestion of primary and nightsoil sludges would be an efficient solids conversion process for use in the tropics. Septic tank sludges are usually stabilized on collection so that further digestion is not necessary. In the experimental digestion of nightsoil sludges, a high gas production in excess of 3,000 ml/g volatile solids fed per day was achieved. A 10 day detention time was found to be optimum even with loading rates as high as 4.5g volatile solids/1 active digester volume per day.

Composting of wastewater sludge with refuse was an effective means of disposing of two community solid wastes simultaneously but it is unlikely that marketing of the product will be profitable. The addition of sewage sludge only slightly improved on the compost produced from refuse alone, in terms of nitrogen, phosphate and potash contents. Open windrows produced a satisfactory compost in 6 weeks but mechanized enclosed-chamber composting was more efficient. This method of sludge treatment and disposal is not likely to be adopted extensively in Asia because it could not compete economically with sand bed drying if the product was not sold.

In this paper no mention has been made of the quantity of wastewater solids or sludge produced by a community. Much data is available in the U.S.A. and in Europe on primary sludge production and characteristics, because most communities have waste treatment plants. Where such a wide diversity of wastewater sludges is produced, such as in Asia, any attempt to suggest working quantities would be meaningless. Both quantity and quality are functions of the diet and habits of the people, the proportion of industrial discharges in the wastewater, and the nature of the collection and treatment systems used. Again, costs of solids treatment and disposal have not been mentioned. Little cost data are available for Asia and, in any case, would be only locally applicable. Use of simple construction, local materials, and unsophisticated operation will minimize costs in any instance. However, it is important if these measures are to be effective that rationald esign criteria be developed and adopted in geographical areas with similar environmental conditions. Research carried out in particular countries and reported freely in international journals is indispensible in building up the background of technological knowledge lacking at the present time in developing regions of the world.

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EFFECTIVE REUSE OF CONTAMINATED WATER

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Just as the turn of the century is the general era credited with having ushered in modern water treatment by filtration, the decade centered on 1970 may well be remembered as the beginning of large-scale reuse of renovated wastewaters. The intense interest in the subject, evidenced by an ever increasing flow of reports describing new treatment techniques and pilot plant operations, has resulted primarily from three factors:

1. the limited supply of new water sources in many areas,
2. the increasing demands for more water by an exploding population, and
3. the emphasis on pollution control and higher requirements for treatment of wastewater.

EARLY REUSE IN THE UNITED STATES

An article by HOMMON (1928) describes reuse at the Grand Canyon National Park in Arizona where water was transported 100 miles (161 km) by tank car. After extensive treatment, wastewaters were reused "in stationary boilers for generating steam for heating purposes and in the locomotives that haul passengers and freight trains on the branch line of the Santa Fe from Williams to the Canyon; for cooling water for diesel engines; for irrigating lawns around the hotel; and for flushing toilets in the public comfort station---". A paper presented by GARTHE and GILBERT in 1966 reports that this sewage reclamation and reuse is still being practiced at the Grand Canyon with very little change from the procedure reported in the earlier paper.

In 1931, Dr. Karl Imhoff in his article "Possibilities and Limits of the Water-Sewage-Water Cycle" reported on his experiments in recycling water and wastes through eleven complete cycles. His conclusion from these experiments was that wastes could be retreated to produce an acceptable quality water for domestic supply until the salt build-up exceeded acceptable limits. In his experiments this had not occurred through the eleventh cycle. He states, "Viewed from the standpoint of water purification and as a result of observations from nature and from experiment, there can be little doubt that city sewage can be purified and reused in rotation as many as ten times".

VEATCH in 1948 presented a compilation of places in the United States where sewage plant effluents were being reused and the type of reuse involved. The uses listed at that time were predominantly for irrigation, but there were also several instances of use for cooling, for railroad engine boilers, and for miscellaneous industrial processes.

During the past twenty years, the number of instances of planned reuse of sewage and industrial waste plant effluents has increased markedly. The tremendous volume of water required for irrigation and for industrial cooling and process water has necessitated consideration of reuse both from the standpoint of water shortage and cost. Where such reuse has been implemented, it has usually consisted of either recycling industrial process water within the same plant or reusing treated industrial wastewaters or sewage plant effluent for purposes other than municipal supply.

DEFINITION OF TERMS

Water reuse must be considered a relative term. Scientists have long recognized and agreed that the water in the earth's environment is a fixed quantity. In the natural hydrologic cycle water is used, purified, and reused over and over again. With the advent of man, pollution of the natural waters has become increasingly severe, and successive reuse of river waters has occurred without having undergone the purifications of the natural hydrologic cycle, each use adding to the degree of pollution. Some waters that are used for cooling, steam generation, and other industrial processes in a closed cycle, are reused continuously with make-up water added only to replace the small fraction which is lost through consumptive use or blow-down. The highest degree of reuse from the water engineer's viewpoint is that of renovating and recycling a city's sewage back into the water system. This has been done to some degree in recent years through recharging underground aquifers by the return of partially treated sewage effluent to the ground. Today we stand on the threshold of the ultimate reuse in direct return of completely treated sewage effluent to the water system.

In recognition of the variances in types and degrees of reuse, it is imperative that the term "reuse" be defined whenever it is used. Inasmuch as our concern today is with intentional reuse rather than natural reuse, perhaps we need consider only two terms: (i) indirect reuse-in which the first user releases or loses control over its wastewaters before subsequent reuse by others, and (ii) direct reuse-in which the wastes are treated and then reused, the degree of treatment depending upon the intended use of the renovated water.

INDIRECT REUSE

The extent to which indirect reuse has occurred has obviously increased as our population has increased. Rivers which were pristine pure prior to man's arrival have been subjected to increasing pollution as cities and industries located in drainage basins and began to discharge their untreated or partially treated wastes. Downstream water users then are reusing part of the water previously used and discharged, the degree of such depending upon the quantity of waste discharged upstream relative to the total flow in the stream. A measure of this type of reuse is provided in a report of the U.S. Federal Water Pollution Control Administration (KOENIG, 1966) which shows that for a group of 155 cities using surface water supply, "the range of upstream municipal wastewater present in the same stream during low flow is from 0 to over 18 percent, with a median, based on population served, of 3.5 percent".

A more startling example of indirect reuse is that of the Neosho River in the State of Kansas from which 12 communities obtain their water supply in a 222 mile (357 km) stretch of the river. SYMONS (1968) reported that under the worst possible drought conditions in a five year period, the water in this stream could be used more than 100 times. Under normal dry weather flow conditions half the stream flow would be used more than once. Use and reuse such as this has necessitated increasingly higher degrees of waste treatment. It has also given impetus to continued improvement in water treatment techniques.

Another well-documented example of indirect reuse (BROWN, 1940) is that which occurred at Ottumwa, Iowa beginning late in 1939. Chlorine dosages of the order of 100 mg/l were required to cope with extensive sewage pollution of the Des Moines River, the raw water source. The citizens appreciated the heroic efforts of the city water utility but abandoned the water for drinking and cooking.

DIRECT REUSE

The most classic and well publicized case of direct reuse within a municipal system is that of the City of Chanute, Kansas as reported by METZLER *et al.* (1968). Chanute is one of the 12 cities previously referred to which obtains its supply from the Neosho River. In 1956, Kansas was in its fifth year of the most severe drought the State has ever experienced. The Neosho River flow during the summer of that year had dropped to near zero and the City of Chanute with a population of 12,000 was virtually out of water. In desperation the City decided to return the effluent from its trickling filter sewage treatment plant to the river channel. The configuration of the river was such that a shallow basin provided about 17 days detention of the returned effluent. The normal water treatment, unchanged except for increased chlorine dosage and closer laboratory control, included plain sedimentation, coagulation with alum, lime-soda softening, recarbonation, rapid sand filtration, and chlorination. The closed system operated five months, during which time the water was calculated to have made 10 complete cycles. The treated water met all bacteriological health standards, but there were serious taste, odor, and color problems. Mineral content resulted in a total solids build-up from a normal 200-500 mg/l to 1,000-1,200 mg/l. Froth from detergents was also a psychologically inhibiting influence on the water users. While the practice got the city through the drought period, the citizens refused to use city water for drinking or cooking. It met accepted bacteriological standards for drinking water, but the color, taste, odor, and froth, coupled with a general psychological barrier were too much to overcome.

INDUSTRIAL REUSE

One area of reuse which is not as dramatic as direct recycling of city sewage, but which has tremendous potential in expanding the usefulness of a limited water supply, is that of direct reuse by industry. A typical example of such use is that of the Maytag Company at Newton, Iowa reported by FOULKE (1963). This manufacturing plant uses in excess of 1 mgd (3,785 m^3/day) in its electroplating processes. Process wastewaters contain chromium and cyanide and must be treated. The chromium wastes are reduced with sulfur dioxide and the cyanide wastes are oxidized with chlorine. Then they are combined for neutralization and pH adjustment for optimum coagulation, after which they are passed through primary and secondary clarification, and discharged to the reclaimed water sump. The water is then returned to the plant through pressure filters and zeolite softeners.

The treatment plant which went into operation in 1955 has made possible the reuse of 70 per cent of the process water. This results in a net savings to the company of about $ 30,000 a year. The reclaimed water is softer (59 mg/l as $CaCo_3$) than the city water (395 mg/l), but the total dissolved solids are considerably higher, 1,200 mg/l as compared with 450 mg/l for the city water. No noticeable bad effects have resulted from the high solids concentration. This direct reuse has materially reduced the total water requirements, eliminated the previous pollution of the stream into which the wastes had been discharged, and reduced operating cost. Any one of these benefits would have justified the reclamation and reuse of the plant's wastewater.

Many industries that require large volumes of water have resorted to treatment and reuse. Oil refineries and petrochemical companies were among the first to institute water reuse facilities and procedures. The paper industry, a notoriously large water user, has found ways to treat and recycle its wastes; one plant reports (ROSS, 1964) a reduction to one-third of its original water requirements and major additional reduction is anticipated. Steel mills have found it desirable and, in some instances, necessary to treat and reuse their water, either from the standpoint of inadequate supply or cost—or both. As a case in point, in 1968 the Armco Steel Mill at Middletown, Ohio put into service a plant designed to treat 144 mgd (545,000 m^3/day) of its plant wastes (BARBER and PETTIT, 1968). This water, after treatment, is recycled through the plant. There is practically no wastewater to be discharged. Even the blow-down is used as primary rinse water at the strip picklers and the cold mill.

In addition to recycling their own treated wastewaters, many industries are also using treated municipal wastewater as their source of supply. An early and classic example of such use is that of the Bethlehem Steel Company which, in 1941, began the use of up to 50 mgd (190,000 m^3/day) of the effluent from the Baltimore, Maryland sewage treatment plant (WOLMAN, 1968). This use had increased to 150 mgd (570,000 m^3/day) in 1967.

Many municipalities have recognized the value of their treated wastewaters and are capitalizing on them through sales to industry and for irrigation. Perhaps the most enterprising of these is the city of Pomona, California where the city is not only selling its own treated wastes, but is also buying wastes from adjacent sanitary districts, treating them, and then selling them for power plant cooling and for irrigation of citrus groves, golf courses, public park lands, and a college campus (PARKHURST, 1967). This type of operation may well be a forerunner of dual water supply systems as proposed by HANEY and HAMANN (1965).

RECHARGE

Direct reuse through recharge of underground aquifers with sewage effluent is gaining acceptance. PETERS and ROSE (1968) have summarized developments in this field. In 1955, tests were made to determine the feasibility of recharge by injecting the Los Angeles Hyperion sewage plant effluent into the water source aquifers. It was concluded that, because of clogging, activated sludge effluent was not of satisfactory quality for injection through a recharge well, and that further treatment of the effluent would be necessary to make the practice feasible. As a result of two years' operating experience of the Whittier Narrows plant, the Los Angeles County Sanitation District announced, in 1963, a program of reclamation and reuse for 100 mgd (378,500 m^3/day) of wastes from the District's several plants. While the plan has never been fully implemented, the District has continued to operate and experiment with the Whittier Narrows plant, discharging the plant effluent mixed with Colorado River water to spreading basins which recharge the subsurface aquifer. No pollution or other adverse effects have been noted in 8 years of operation. Another recharging project in California is that of the Orange County Water District at Santa Ana. The Orange County plan is to inject the effluent from a 7 mgd (26,500m^3/day) tertiary plant into the substrata to form a barrier to prevent salt water intrusion. A pilot plant operation in 1964 has proven the practicality of this plan.

In the eastern part of the United States, specifically in Nassau and Suffolk Counties on Long Island near New York City, similar experimentation in recharge of the underground supply through injection of treated wastes has been conducted. The underground source on Long Island has become increasingly inadequate with the tremendous population growth in the metropolitan New York area on Long Island. Recharge using treated wastes appears to be the best solution to the problem. Standards established for recharge waters by regulatory health agencies are quite restrictive, however, and will require extensive tertiary treatment for the Nassau and Suffolk County recharge operation. Clarification by chemical coagulation, filtration through anthracite and sand filters, and adsorption by activated carbon are planned for this project. A 400 gpm (2,180 m^3/day) demonstration plant was put into operation in the fall of 1967, but at the time of writing this paper, no results have been published. The ultimate Nassau County plan is to inject reclaimed wastewater along the south shore of Long Island to form a barrier to prevent salt water intrusion and the loss of fresh water through waste discharge to the Atlantic Ocean.

SANTEE, CALIFORNIA

A recent wastewater reclamation and reuse project in the United States which has received a great deal of attention is that at Santee, California (MERRELL *et al.*, 1967). Santee is located in Southern California, an area noted for water shortage. The project was initiated in 1962, as a means of providing tertiary treatment for activated sludge plant effluent and to create recreational lakes using the then "polished" reclaimed water. The treatment plant effluent is discharged to an oxidation pond where approximately 30 days retention is provided. Approximately one third of the pond effluent is pumped to the upper end of a canyon to an infiltration area. The water then flows through a relatively shallow natural sand and gravel formation to a series of lakes which, throughout the years of the experiments, have been made available for progressively higher degrees of recreational use, as the quality of the lake water has proven to be satisfactory. In 1965, the first lake in the series was approved for swimming.

A major contribution of the Santee experiment is proof of the cleansing properties of the movement of water through natural sand and gravel beds as it relates to recharge of underground aquifers with sewage effluent. Perhaps an even greater contribution is the knowledge that the public will knowingly accept and intimately use water reclaimed from sewage at least for recreational purposes. The psychological barrier to such use is, after all, likely to be one of the major inhibiting influences on adoption of water-sewage-water recycling.

SOUTH LAKE TAHOE

The design and operation of the South Lake Tahoe wastewater reclamation plant is a milestone in the advancement of treatment of wastes for reuse (CULP, 1968). The objective of this plant was actually not reuse. Lake Tahoe, located high in the Sierra Nevada Mountain Range on the state line between California and Nevada, is one of the three clearest bodies of natural water in the world. There has been considerable concern in recent years that the population growth along the shores of the lake and in basins tributary to the lake would result in nutrient contributions that would promote algae growth and spoil the clarity of the lake. Of particular concern was the effluent discharged from the activated sludge plant serving the City of South Lake Tahoe, a community of some 15,000 population. The South Lake Tahoe treatment plant, placed in operation in 1965, was designed to protect the waters of Lake Tahoe. The original plant of 2.5 mgd (9,450 m^3/day) capacity has produced a consistently high quality effluent that meets not only stringent effluent standards but also most of the U.S. Public Health Service Standards for municipal water systems. Phosphate is almost completely removed eliminating a major nutrient problem. The only remaining problem was an excess of nitrogen. In 1966, the District authorized the expansion of the plant to 7.5 mgd (28,400 m^3/day) capacity and the addition of an ammonia stripping tower for nitrogen removal. Pilot plant tests indicate that the new facilities will remove 95 per cent of the nitrogen.

Treatment of activated sludge plant effluent at the original South Lake Tahoe plant included: (i) addition of alum, (ii) filtration through two mixed media beds in series, (iii) upflow through granulated activated carbon, and (iv) chlorination. The expanded plant, placed in operation in 1968, was revised to include the addition of lime for coagulation and phosphate removal, flocculation and settling basins, recalcining facilities for lime recovery, and the ammonia stripping previously mentioned. The remaining treatment involving upflow filtration through activated carbon, and chlorination was unchanged. The cost of tertiary treatment in the 7.5 mgd (28,400 m^3/day) expanded plant, including fixed charges on the capital investment, are expected to be less than 15 cents per 1,000 gallons(4 cents per m^3).

DIRECT REUSE OF MUNICIPAL WASTES

The first designed direct reuse of reclaimed wastewater for a municipal water supply was at Windhoek, South West Africa. STANDER and Van VUUREN (1968) in their paper titled "The Reclamation of Potable Water from Sewage" state: "Reclamation of effluents, reuse of water and closed circuit water utilization must form the cornerstone of water conservation and pollution control in South Africa in general ---". Based on pilot-plant results, a one mgd (3,785 m^3/day) reclamation plant was constructed to treat biologically oxidized sewage effluent, which has received 14 days detention in a maturation pond. Resulting algae along with the bulk of the residual organic nitrogen and phosphate are removed by aluminum sulfate flocculation-flotation. Synthetic detergents are removed by foam fractionation and activated carbon polishing, incorporated in the otherwise conventional water treatment plant, which processes the wastewater prior to reuse. Residual ammonia nitrogen is oxidized by breakpoint chlorination, which is economically feasible because of the low levels of ammonia remaining after the flocculation-flotation process. This plant reportedly went into service in 1968 and the recycling for municipal reuse is now in practice. The cost of treating sewage plant effluent to a quality acceptable for potable water was found to be 21.5 cents per 1,000 gallons(5.7 cents per m^3) for primary plant effluent, including fixed charges on the capital investment. These costs were based on operation of a one mgd (3,785 m^3/day) demonstration plant and could be expected to be somewhat higher than the costs estimated for the 7.5 mgd (28,400 m^3/day) South Lake Tahoe plant.

Analysis of costs by the U.S. Federal Water Pollution Control Administration indicates that, at present, complete treatment of wastes for direct reuse as a potable supply is perhaps four or five times as high as the cost of waste treatment to a level permissible for discharge to most receiving streams. This cost, however, is still less than the cost of any desalination process in practical use. Furthermore, in considering direct reuse for potable supply, the incremental cost of the higher degree of treatment, beyond that required for discharge to streams, is considerably less than the cost of developing new water sources in some of the more arid regions of the world.

Recognition of the need for reclamation of wastewater was expressed by the WATER POLLUTION CONTROL FEDERATION (1967) in its Statement of Policy on Water Pollution Control adopted in 1967. One of the points of that policy states, "Wastewater represents an increasing fraction of the nation's total water resources and should be reclaimed for beneficial reuse. To this end the development and application of methods for wastewater reclamation must be accelerated."

Recognition of this kind, coupled with technological advances in the art which have brought the cost of treatment to reasonable levels and the indications that psychological barriers to acceptance of treated wastewater for public use are being overcome, will inevitably result in a rapid increase in reclamation and reuse of wastewater throughout the world.

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WATER RECLAMATION AND PROTEIN PRODUCTION THROUGH SEWAGE TREATMENT

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INTRODUCTION

The future of Asia is closely linked with two forms of natural resource—protein and water. Already these are in short supply in many parts of Asia. At best, current programs to check the rising birth rates can only partially solve the problem. If social and political chaos are to be avoided during the coming decades, new techniques of resource conservation must be developed and applied. Re-use of human waste materials is one approach that may be taken. The treatment of water-borne sewage to the point whereby the treated liquid effluent may be used as drinking, irrigation or industrial water supply would effectively combat the urban water shortage. A combination of this process with one which would reduce the human wastage of nitrogen and return it to the population in the form of edible protein would surely be idyllic.

The Asian Institute of Technology (AIT) in cooperation with the Applied Scientific Research Corporation of Thailand (ASRCT) are currently engaged in the study of just such a process whereby nightsoil, or water-borne sewage, is treated using an open ponding technique by which waste nutrients, urea, carbon dioxide and ammonia are utilized to grow algae—a form of high quality edible protein.

PROCESS DESCRIPTION

Two of the major objectives of sewage treatment are the reduction of pathogenic organisms initially present in the sewage and the decomposition of sewage organics prior to disposal of the liquid effluent into a receiving water. The conventional oxidation or stabilization pond has gained wide acceptance through its ability to achieve these objectives at relatively low cost. Aerobic decomposition of sewage organics requires a supply of oxygen, which may be provided by surface absorption from the atmosphere or through plant metabolism.

In the case of the conventional oxidation pond, oxygen is produced by unicellular microscopic plant life—algae. Algae require inorganic nutrients such as ammonia and carbon dioxide for their metabolism and produce oxygen. Bacteria utilize this oxygen to break down sewage organics giving off ammonia and carbon dioxide for the algal metabolism. This natural symbiotic process is similar to the animal-plant symbiosis upon which human life on this planet depends. Most of the algae grown in an oxidation pond are capable of synthesizing the essential amino acids required for human metabolism. The algal cell itself is composed of approximately 50% protein. The conventional oxidation pond is currently designed to treat sewage with a minimum of maintenance and to provide no by-product. The flow through or detention time in these ponds is usually in the order of twenty days at depths of about 1.5 metres (5 ft). As a consequence, algal production is rather limited although the oxygen released by the algae is sufficient to permit decomposition of sewage organics.

The high rate oxidation pond has been developed at the Universities of California (OSWALD and GOLUEKE, 1967) and New South Wales (McGARRY, 1968) and is now being studied at the Asian Institute of Technology to determine the conditions for maximum yield of algae and reduction of sewage organics. As a result the open pond is shallow, being only 45 cm(18 inches), in order to provide the sunlight necessary for algal growth throughout its depth. In the AIT-ASRCT pilot plant pond shown in Figure 1, the detention period is short (1 day),

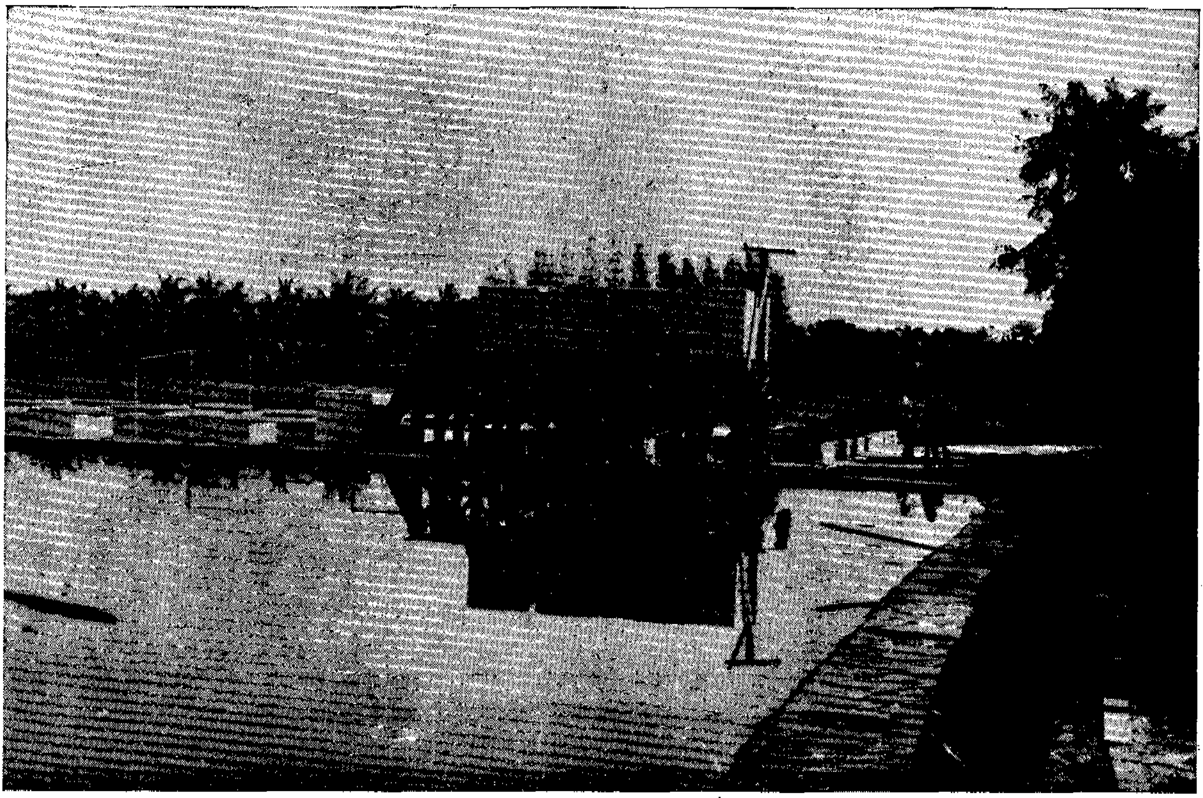

Fig. 1—The AIT-ASRCT High Rate Oxidation Pond and Feeding Units.

permitting a high rate of reproduction and growth by means of a prolific supply of algal nutrients. The process' flow diagram is shown in Figure 2. Influent waste can be of domestic origin or from certain industries. Settleable solids are removed from the influent by conventional sedimentation techniques and treated by unheated anaerobic digestion. The digestion by-product, methane, may be utilized as an energy source for sterilization and heat drying of the final algal product.

The clarified influent to the pond is added on a continuous basis. The pond is mixed daily to keep the settleable solids in suspension where oxygen is abundantly available for their bacterial decomposition. In terms of 5-day 20°C biochemical oxygen demand, the pond may be loaded as heavily as 400 lb BOD/acre day (450 kg BOD/ha day). At this areal loading rate one may expect the effluent to have a BOD of less than 30 mg/1. The daily algal yield from such a pond is as high as 180 kg (400 lb) of dried algae per acre or on a yearly basis 66,000 kg (146,000 lb) per acre.

The unicellular microscopic algae must be concentrated before removal from the liquid medium. This is accomplished by lime or aluminium sulphate addition which causes the algal cells to coalesce as a floc which is then removed from the liquid in the downflow solids contact flotation chamber, shown in Figure 3, as an algal paste containing 8% solids. The other co-product is a clear reusable water. Algal solids are then heat sterilized and dried on open sun drying beds. The algae is then ready for direct feeding to stock (HINTZ *et al.*, 1966) or, after some further processing, to humans (MARIMURA

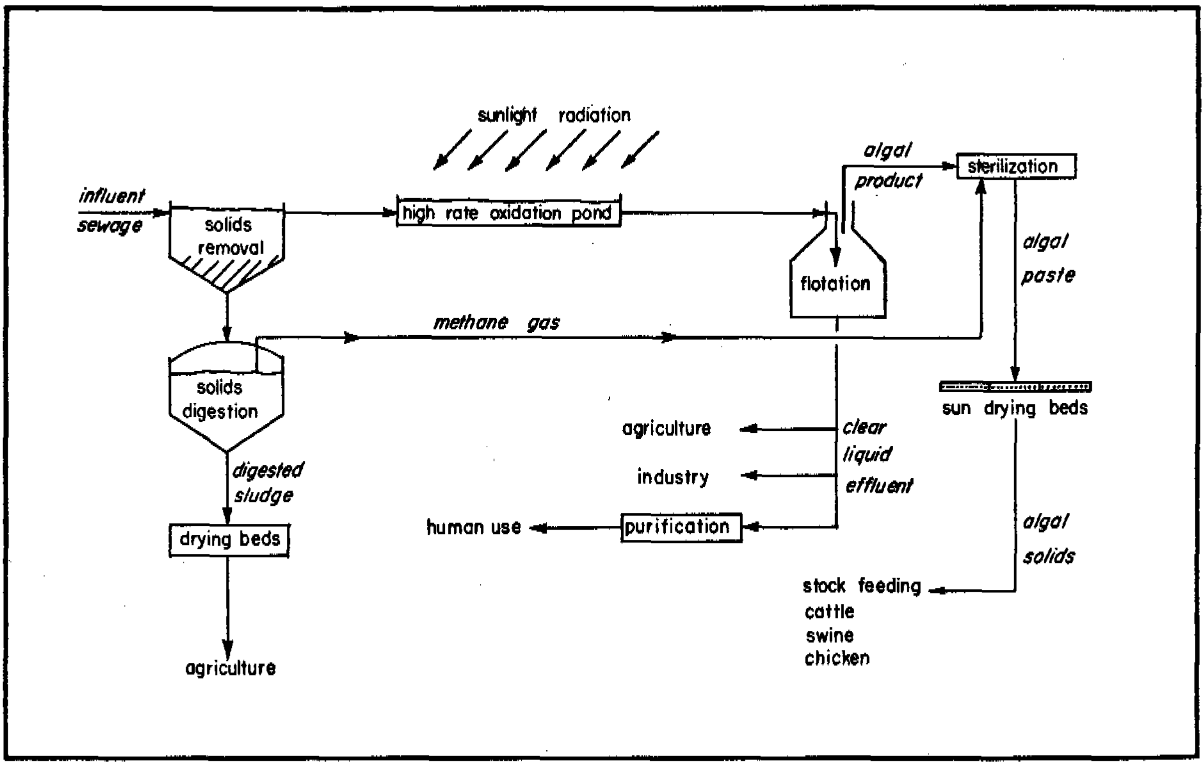

Fig. 2—Mass Algal Culture and Processing Flow Diagram.

Fig. 3—The Downflow Solids Contact Flotation Chamber Used to Harvest the Algal Cells.

and TAMIYA, 1954). The clear water effluent may be reused in industry, agriculture or following further treatment to augment potable water supplies.

COMPARISON OF SEWAGE TREATMENT METHODS

As the need for urban pollution abatement is felt, each city is faced with making the decision of which treatment method to adopt. The choice would normally be made between activated sludge, trickling filters, Pasveer ditch, oxidation ponds or direct ocean disposal. Ocean or marine outfall disposal is often most economic, but its use is limited by such constraints as the city's proximity to the sea, public health, fisheries and aesthetic considerations. The choice between other methods of treatment is largely based on land requirements, construction and mechanical equipment costs. Maintenance, power and operating costs are also given due consideration. Other factors which influence the decision are the reliability and availability of mechanical equipment, reliability and stability of the biological process, and quality of effluent.

Land requirements—The activated sludge process has been preferred in densely populated locations where land is expensive. The Pasveer ditch and trickling filter processes may be chosen where land is less costly and less densely populated. One of the advantages which the oxidation pond system has over other treatment methods is that the land used is reclaimable. Although the initial land requirement is high the ponds may be removed to a more remote location as the city expands and land costs increase. In this way the municipality may realize a profit through real estate.

Construction and mechanical equipment costs—In comparison with other forms of sewage treatment, the conventional oxidation pond construction costs are by far the least. Process units are formed by earthen embankments whereas trickling filter and activated sludge units are of reinforced concrete. The oxidation pond's mechanical equipment is limited to the influent pump. Diffused air activated sludge equipment comprises influent pump, clarifier scraper mechanisms, digester gas collection equipment, gas-driven motors, air pumps, diffusers, sludge treatment devices and piping; a similar situation exists with regard to the trickling filter process and Pasveer ditch but to a less extent.

Maintenance, power and operating costs—These costs are minimal for conventional oxidation ponds in comparison to other forms of treatment. A once per week check of the system and maintenance of the embankments are all that are required. Power costs are limited to those for sewage pumping.

Reliability and stability of the biological process—The activated sludge process is prone to failure under shock loads and sludge bulking conditions. Qualified technical personnel are required for its routine operation, and to a less extent this is true for the trickling filter and Pasveer ditch. The oxidation pond provides storage capacity if failure occurs in any unit. Pond failure has been associated with low temperatures in Canada and the northern United States. Climatological conditions which exist in tropical Asia are ideal for biological treatment by the oxidation pond technique.

Quality of effluent—All conventional secondary treatment methods have drawbacks with regard to effluent quality. Effluents from the activated sludge, Pasveer ditch, and trickling filter processes are relatively high in nitrates, which stimulate undesirable algal growth in receiving water bodies. The conventional oxidation pond's algae-producing nutrients are largely used up by algal growth within the pond. However, if improperly designed, the pond system can give rise to effluents which are heavily laden with algae.

In the light of the above review, it may be concluded that the conventional oxidation pond will play a significant role in pollution control programs in the future. The high rate oxidation pond may be favourably compared with the conventional pond—

land requirements are less and the effluent is free of suspended algal solids. Construction, mechanical equipment, power and maintenance costs are somewhat above those of the conventional pond but are very much below the costs associated with the activated sludge process.

The greatest advantage which the high rate pond has over all the others processes mentioned is the production and possible sale of algae as stock food, which may all but eliminate the costs of sewage treatment if not permit the plant to operate at a net profit. Thus sewage treatment and pollution control need not be a continuing liability to the community but may become an asset.

COMPARISON WITH CONVENTIONAL PROTEIN PRODUCTION METHODS

Asians have used excreta for crop fertilization for centuries. Now, due to their low cost, chemical fertilizers are being utilized in place of human manure. Although the old form of fertilization was an inefficient form of waste reuse it did represent resource conservation at an elementary level. The high rate pond process presents an unusally efficient technique for protein and water reclamation. Using this method man's total waste may be reclaimed and recycled.

Man has relied upon algae as a source of protein for centuries. In Japan, the Philippines, China and Hawaii, algae have been harvested from the continental shelf and eaten, often as delicacies (ZANEVELD, 1959). Fish production represents a form of algal harvesting; algae act as essential ingredients in the relatively inefficient food chain leading to ultimate reclamation of waste nutrients in the form of fish protein. There has been frequent mention in the literature of phytoplankton production of the ocean and the possibilites of direct harvesting, but present harvesting techniques are uneconomic. The greatest difficulty is centred on the minute size of the algal cells and their relatively low concentration in the marine environment. The commercial development of controlled algal farming on land is technologically feasible and is likely to take place far ahead of direct harvesting of marine phytoplankton.

The Economic and Social Council of the UNITED NATIONS in 1968 published a report entitled "International Action to Avert the Impending Protein Crisis" in which it was stated that "while the quantity of food (calories) is already causing concern in many areas throughout the developing world the quality (notably protein) of the food consumption pattern is even more critical. For over one-third of the present population in the developing countries the protein-calorie balance of the diet is inadequate". To accentuate the problem, the areas in which these deficits occur contain the major portion of the world's population. As death rates continue to fall and birth rates remain high, future progress against world protein shortage will tax mankind's every resource and technical capability.

Recent advances in conventional crop production hold some promise but must be implemented on national and regional scales prior to being of significant effect. During 1968 overall production increases were of the order of two to three percent. Future food requirements of the developing countries demand that production increases by three to four percent per annum over the coming two decades.

Conventional crop yields are limited by the very nature of plants themselves. Nutrients must be absorbed from the soil and atmosphere. Relative to the algal cell, an agricultural crop's absorbing surface to plant volume ratio is extremely small. Thus the photosynthetic energy conversion efficiency is normally below 0.5%. On the other hand, algae are not limited by lack of available nutrients and take advantage of their minute size to absorb nutrients and sunlight energy to grow and reproduce rapidly. The normal growth period for algae is one to two days in continuous mass algal culture. Rice, produced on a batch basis, requires three months for growth and is limited by nutrient supply and its dependance upon rainfall. Annual crop and algal protein yields are listed in Table 1 in which the advantages of algal size and the continuous growth process can clearly be seen. On an areal basis, algae are 127 times more productive than soybean and 1,460 times more productive than rice.

Table 1—Comparison of Algal Production with Conventional Crop Yields*

Crop	Annual Protein Yield lb/acre	lb of protein per acre foot of water
Soybean	576	288
Corn	240	120
Wheat	135	90
Rice	50	-
Algae	73,000	135+

*Adapted from OSWALD and GOLUEKE (1967).
+After algal harvest this water may be reclaimed and reused.

A comparison should also be made in terms of quality of protein or amino acid content. The amino acid contents of animal, vegetable and algal protein may be compared and are listed together with the FAO reference protein in Table 2. It may be seen that algae are similar to soybean in protein quality and may compete with soybean particularly for chicken feed markets.

Sewage grown algae have been fed to rats to determine the protein efficiency rate (PER) and to draw comparisons between algae and other sources of protein (OSWALD *et al.*, 1964). PER is the gain in body weight divided by weight of protein consumed. The PER value of the reference instant non-fat dried milk protein was 2.48 and that of protein comprised of 37.5% algae and the remainder fish flour was 2.24. Another important parameter for consideration is algal digestibility, being the percentage of nitrogen consumed during animal feeding trials which is not excreted in the faeces. In

Table 2—Amino Acid Composition of Animal, Vegetable and Algal Protein (g acid/100 g protein)

Amino Acid	1957 FAO Reference	Algae *	Thai Soybean	Hen's Egg
Isoleucine	4.2	3.8	3.8	6.6
Leucine	4.8	7.5	7.3	8.8
Lysine	4.2	5.1	7.0	6.4
Phenylalanine	2.8	4.2	3.2	5.8
Tyrosine	2.8			4.2
Cystine	2.0	0.5	0.8	2.4
Methionine	2.2	1.5	1.6	3.1
Threonine	2.8	4.8		5.1
Tryptophan	1.4	1.0	1.9	1.6
Valine	4.2	5.7	4.4	7.3
Literature Reference	FAO/WHO (1965)	OSWALD *et al.* (1964)	BHUMIRATANA (1968)	FAO/WHO (1965)

* Sample consisting of sewage grown *Scenedesmus and Chlorella—48% protein.*

several test diets with sheep the digestibility of crude protein in diets containing 60% algae and 40% hay (50% alfalfa and 50% oat hay) was observed to be 74% whereas that of the 100% hay diet was 73%.

Swine feeding trials were reported by OSWALD *et al.* (1964) using 15-16% crude protein rations on an air-dried basis. Algae were added at the expense of soybean and cottonseed oil meal protein components of the rations at levels of 0,2½,5 and 10% of protein being replaced by an equivalent amount of sewage grown algal protein. No significant difference in swine weight gain was noted, proving that algae successfully replaced the soybean and cottonseed oil meal dietary components. In a second swine trial algae were used to replace the meat and bone meal protein. There was no significant difference between swine weight gains for all rations. It was concluded that algae have at least the same protein value for swine as does meat and bone meal. Further, the experiment showed that a ration containing only barley and algae with vitamin, salt, and mineral supplements would support adequate growth of swine.

Chemical analyses of sewage grown algae consisting mostly of *Scenedesmus* were reported by OSWALD *et al.* (1964) and are listed in Table 3.

Table 3 — Chemical Analysis and Nutritive Constituents of Sewage Grown Algae*

Component	%
Ash	14.2
Nitrogen	8.5
Ether Extract	6.8
Crude Fibre	4.7
Lignin	4.2
Phosphorus	2.2
Calcium	1.9
Cellulose	3.5
Silica	1.7
Carotene (mg/kg)	77

* After OSWALD *et al.* (1964).

The high protein, carotene and phosphorus contents of the algae indicate their strong potential as food for stock on dry range. The high ash and silica contents were due to non-algal components in the samples acquired during the harvesting and drying processes.

The storage capability of algae was displayed through chicken feeding experiments which were performed using three year old alum-harvested sun drield algae. Laying hens were fed algal diets containing 25% algae and 75% laying mash. The hens readily ate the algal ration. There was little significant difference in egg laying between hens on algae and those on regular laying mash diets.

WATER RECLAMATION

Within the high rate oxidation pond, wastewater constituents are converted to algae through their metabolism and biosynthesis. With the harvest of algae the liquid effluent is clarified and somewhat "stripped" of components such as magnesium, calcium, nitrate, ammonia, phosphorus, carbon and, of course, biochemical oxygen demand. Eutrophication of natural water bodies has gained increased attention during recent years in industrialized nations, particularly in the U.S. The causes of eutrophication are related to algal nutrients as provided by wastewater pollution which promotes unwanted algal growth. The high rate pond is capable of removing these nutrients by algal growth under controlled conditions prior to reuse or discharge of effluents into receiving waters.

It is likely in Asia that reclaimed water will first be used for irrigation purposes. Chemical analyses were performed on a sample taken from an AIT experimental pond and are presented in Table 4. The algae were flocculated using aluminium sulphate and settled prior to testing the supernatant.

Use of irrigation water is constrained by certain quality characteristics, two of the most important being the total concentration of soluble salts and the relative proportion of sodium to other cation concentrations. Irrigation water quality requirements

Table 4—High Rate Pond Effluent Characteristics

mg/l			
pH	7.4	Na^+	101
$SO_4^=$	104	K^+	20
Cl^-	51	Ca^{++}	24
HCO_3^-	166	Mg^{++}	6
Dissolved Solids			
Fixed 344			
Volatile 132			

are governed in turn by the leaching characteristics of a soil. In general, irrigation waters whose total dissolved solids (TDS) are below 500 mg/l may be used on all but the most salt sensitive crops. Provided that leaching and drainage are adequate, TDS concentrations of between 500 and 1,500 mg/l may be and are widely used. The relative concentrations of sodium to those of calcium and magnesium affect the alkaline nature of the soil, because sodium has the tendancy of replacing Ca and Mg in the soil. The sodium adsorption ratio (SAR) is applied as a water quality parameter (WILCOX, 1955). Irrigation waters with low mineral content may be used with SAR values up to 26.0.

With reference to Table 4, the high rate pond's clarified effluent's TDS and SAR values are 476 mg/l and 4.2, respectively. It may be classified as being medium in dissolved solids, low in SAR value and is satisfactory for use on almost all soils. It may be used on practically all vegetables and such crops as rice, oats, wheat, clover, cotton and corn. The reclaimed water should be chlorinated. If the effluent is not chlorinated before use the food should be cooked prior to being eaten.

Reclamation of effluent may be carried out by a wide variety of industries and, following further treatment, may be found acceptable for human consumption. This latter use has its particular advantages in terms of water resource conservation.

SUMMARY

Water and food supplies may be major constraints on future Asian development. Certainly, pollution of our environment will take its toll if the challenge of pollution control is not met. The Asian Institute of Technology and the Applied Scientific Research Corporation of Thailand are currently engaged in a joint research program to meet this challenge.

The process being studied is capable of treating a municipality's sewage and producing a clear reusable water as well as stock food having protein characteristics which are similar to those of soybean. Through this high rate pond process man's total body wastes may be treated and reused. The overall objective of the program is to place sewage treatment on an economic footing in Asia so that pollution control need no longer be a continuing liability on the municipality but rather a commercial asset.

In choosing a sewage treatment method the municipal government is faced with a decision largely based on cost of treatment and effluent water quality characteristics. In locations where land prices are not excessive the conventional oxidation pond or lagoon system has found wide usage. The high rate oxidation pond has been designed to produce a high quality water effluent and protein. Both may be saleable to agriculture and thus bring economic benefits to the municipality. It is felt that through continued research and development within Asia the process may prove itself to be economically viable and be used on a commercial basis.

As a sewage treatment process the high rate pond can handle up to 400 lb BOD/acre day at a detention period of one day and produce an effluent which has a BOD concentration of less than 30 mg/l. The solids and cation characteristics of the effluent are low enough to permit irrigation of nearly all crops and vegetables.

As a protein production process the areal rate of production is 400 lb protein/acre day. This rate is 127 times that of soybean and 1,460 times that of rice. Thus, conservation of land may be effected and, on the other hand, the food production requires no other source of water than the wastewater itself.

The food product consists of approximately 50% protein which has been successfully fed to chickens, swine, sheep and cattle, although long term trials are yet to be performed. In the case of swine, sewage-grown algae have been found to have at least the some protein value as meat and bone meal, an expensive constituent of the swine's diet. Thus a potential market for algae may exist in the pork producer. Likewise chicken, cattle and sheep production represent valuable outlets for the product.

Man is characterized by the large quantity of waste materials which he discards into his environment. Much of this waste has considerable value, particularly in the form of water. The high rate oxidation pond process may be used to reclaim this water and provide a source of inexpensive single-celled protein.

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PACKAGED WASTEWATER TREATMENT PLANTS FOR SMALL COMMUNITIES, INDUSTRIES, INSTITUTIONS, AND CAMPS

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The control or abatement of wastewater pollution from small communities, industries, institutions, and camps has become a serious and major consideration. During the past twenty years, improvements in transportation have allowed the creation of suburban living areas and the location of industries near sources of material, manpower, and market. Sewage collection and treatment involved either conventional systems in towns and cities, or individual disposal methods such as privies, cesspools, and septic tanks for the new areas. However, none of these basic methods was suitable for suburbs. Regulatory agencies, and the higher standard of living of all people, demanded a system capable of achieving a high level of treatment of wastewaters in relatively small volumes. Thus, the "package" treatment plant has come into use.

The term "package" plant in this category is basically a small biological oxidation unit. It is a "package" because it is pre-engineered and fabricated in standardized capacities or units which can be assembled and moved directly to the job site, or from one location to another. The flow capacity of standard plants usually ranges from 5000 to 100,000 US gpm. Smaller units can be transported as one assembled plant, but the larger capacities may be composed of multiple units. Therefore, "package" may refer to a wide variety of fabricated treatment units, from factory built and assembled to factory fabricated but field erected.

Thousands of package wastewater treatment plants have been installed throughout the world since 1950. Application of the process has been made not only on domestic wastewaters, but also on many industrial discharges such as dairy wastes, and in subdivisions, schools, airports, motels, trailer courts, shopping centers, and other outlying locations without municipal sewer facilities.

TREATMENT PROCESS

The process utilized is one of the modifications of the conventional activated sludge process, and is termed "extended aeration". The activated sludge process depends on groups of micro-organisms, primarily bacteria and protozoa, living on sewage solids as a purifying medium. These organisms are maintained in an aerobic environment by introducing air into a mixture of the activated sludge and wastewater, after which the activated sludge is separated by settling. The efficiency of sedimentation depends to a large degree on the weight and density of the sludge developed. The process is a simple one, and can be summarized in the following functional steps:

1. Aeration of a mixture of waste and a biologically active sludge.
2. Separation of the biologically active sludge from its associated treated liquor by sedimentation.
3. Return of the settled biological sludge to be admixed with the raw waste.

It has been established that the efficiency of biological treatment, as measured by BOD removal, is related directly to the weight of biologically active solids in the treatment system and inversely to the applied BOD. A rational expression of the load on the system then is the F/M ratio, the "food" to "microorganism" ratio, expressed as pounds of BOD per pound of biologically-active sludge per day. Suspended solids are a convenient measure of the active solids. Thus, the load on an extended-aeration package plant is rationally expressed as lb BOD_5/lb MLSS per 24 hours, where MLSS signifies mixed-liquor suspended solids. The conventional activated sludge process uses F/M ratios of 0.3 to 0.5 with an aeration period of about 6 hours. The resulting biological solids are not completely oxidized, not stable, and must be disposed of by some means extraneous to the treatment process. With a F/M ratio of 0.15-0.20 and 24 hours aeration aerobic digestion of the solids will occur. The combination of conventional activated sludge plus aerobic digestion provides the basis for the term "extended aeration". The relationship to "total oxidation" should be qualified as there is a build-up of inert organic solids from the process and inert inorganic solids from the raw domestic or industrial wastewaters. Eventually, the system would fill up completely with sludge and the effluent suspended solids would increase unless solids were periodically removed from the aeration tank.

Sludge from the final sedimentation tank is returned constantly to the aeration tank. Even with intermittent flows, provision must be made to return sludge to the aeration tank to prevent septicity. If the sludge in the sedimentation tank should become septic, denitrification could result with nitrogen gas lifting the sludge to the tank surface and creating an odor nuisance and effluent quality deterioration. The removal of 85% of the BOD_5 is generally considered satisfactory. However, with extremely good solids separation, this removal efficiency can be improved.

APPLICATION

There are three persons directly concerned with the planning of a package wastewater treatment plant installation. The owner's engineer determines the waste load the plant will receive and provides the general plan for the installation, including the site preparation, inlet and outlet sewer lines, power facilities, and service building. The equipment manufacturer must then provide the design engineer with information that will permit him to select a plant with the required capacity and operating characteristics. With plans and specifications complete, the final step in the procedure usually is the submittal of the project to the governmental pollution control agency engineer for review and approval.

The greatest responsibility evolves on the design engineer who must determine the plant's capacity. This is often more difficult in a small installation than in a large one, because far greater fluctuations in organic loading and hydraulic flow rates must be anticipated and estimated on the basis of very limited information. Regulatory agencies generally agree on the design criteria for the extended-aeration package plants. The aeration capacity should equal design average daily flow, i.e. provide a 24-hour aeration period. Occasionally, the maximum organic loading rate is stated in terms of pounds BOD_5/ unit volume of aeration tank capacity. With normal wastewaters, the maximum criterion should be about 30 lb BOD_5/1,000 cu.ft. aeration tank capacity. Other aeration tank design criteria generally require that the system be adequate to maintain 1 or 2 mg/l of dissolved oxygen in the aeration tank, that stand-by sources of air be provided, and that air compressors or blowers, when used, be capable of supplying air at a rate between 1500 and 2,000 cu.ft./lb BOD_5.

The capacity of the settling basin should equal the 4-hour flow volume based on the design 24-hour flow rate. Surface loading is used as a supplementary specification. An average overflow rate should be about 500 US gpd/sq.ft. If peak flow is twice the average, the rate during this period would be 1,000 US gpd/sq.ft. A maximum overflow rate should be about 1,000 to 1,200 gpd/sq.ft. for a period not exceeding 30 minutes.

OPERATION

The raw wastewater should be screened or comminuted prior to entering the aeration tank. Depending on the particular waste, attention must be given to either periodically removing the screenings or lubricating the comminuting device. A scum baffle to prevent loss of floating solids over the effluent weir is essential. Scum can be removed from the surface of the clarifier compartment by hand skimming, but devices are available to do a reasonable job automatically. Should foam on the aeration tank become a problem, it is possible to apply spray nozzles utilizing filtered effluent for the spray pump.

A brief check list of the routine maintenance and operations for extended aeration package plants is as follows:

1. Determine that power is being supplied the unit and that all pumps and motors are operating or operational as required.
2. Grease and oil equipment, clean air filters, check pressure relief valves, and perform related work as recommended by the manufacturer.
3. Hose down walkways, sideboard, and splash-spray zones as needed.
4. Check air lift pumps and return lines for clogging.
5. Operate skimming device as needed.
6. Perform recommended simple laboratory procedures and adjust operating variables as indicated.
7. If effluent disinfection (chlorination) is required, insure that an adequate supply of disinfectant is available and that the feed device is operating properly.
8. Scrape down the insides of clarifier hopper at least daily.

Generally, about one man-hour per day is required to keep the extended aeration plants operating at their peak efficiency.

The start-up period of an extended aeration system depends on whether the actual flows and BOD loadings are in accordance with the design. Generally, 30 to 50 days may be required to achieve a mixed liquor suspended solids concentration sufficient to yield consistently high treatment efficiency. Whereas a MLSS of 2,500 mg/l is a minimum desirable concentration, it is sometimes possible to operate below this amount with reasonable efficiency during the early stages of a plant which is operated under design capacity. Experience has indicated that with design conditions, a solids concentration of 4,000 mg/l would appear to be an ideal operational target.

After a period of time at design flow and the establishment of adequate mixed liquor solids concentration, it may be necessary to consider occasional wasting of the sludge solids. Frequent sludge wasting is not desirable from several standpoints. Solids accumulation is less at higher solids levels. Sludge wasting creates an ultimate disposal problem in that it must either be trucked to a suitable disposal site or applied to sand beds which eventually must be cared for. In the case of plants treating domestic waste, it would appear that wasting would be required not more than about twice a year. More frequent wasting will be required for certain industrial wastes or domestic wastewaters containing unusual amounts of inert solids.

SYSTEM OPERATION AND MANAGEMENT

ASSESSING THE ADEQUACY OF A WATER DISTRIBUTION NETWORK

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Full knowledge of the existing conditions is the basis upon which rests any effective engineering planning and design and is as applicable to distribution networks as to any other man made structure or device. The more complex the system the more data are required to provide the necessary base for its satisfactory reinforcement and extension. Sanitary engineers may be interested, in what can certainly be described as a narrow field, to consider briefly the general experience of the authors' firm in the study of water distribution systems, with specific mention of some of the features met with in Bangkok.

Water distribution networks were of course, well developed by ancient peoples in many parts of the globe, but networks under comparatively high pressure with such accessories as valves of many types are of fairly recent evolution. Our history began with the coming of modern high density urban occupation, that is towards the end of the last century when the first high rise structures appeared, bringing with them unit area water demands unknown until then. In this instance the pioneer was Edward S. Cole, who adapted the Pitot tube for field use to measure flow in pipes under pressure, using the traverse method to obtain a velocity coefficient at the gauging point. The instrument proved accurate, easily and economically installed and used.

The first field application was made in Terre Haute, Indiana, in 1896 and later extensively depended upon to study the rapidly growing water demand in New York City, where high rise buildings were being built, with more in the planning stage. Ease of use and the dependability of the results obtained, provided the needed impetus for further development. A photo recorder was produced in 1903, whereby the fluctuations of the manometer liquid column were recorded on a shifting sensitive film. This proved ideal for field use, being light in weight and providing a complete and accurate record of the indicator column at the gauging point, from which water velocity in the pipe could readily be computed for the full time of the measurement.

In effect the Pitometer, together with its photorecorder, proved so valuable a tool, readily and economically usable in any location, that a company was organized to manufacture and sell it to satisfy a growing demand by water works staff people in many parts of the United States. However, all too often the technicians taught how to use the instrument and to interpret and apply the results obtained with its help, soon became so familiar with the functioning of the systems they studied and worked on as to be called to go on to greater responsibilities in the utility where they were employed. The Company organized its own staff to offer expert services as Consultants in the 1920's. A few waterworks have been able to maintain their own effective Pitometer Section to monitor network functioning and/or locate losses contributing to the percentage of their unaccounted for water.

Services are provided under four principal headings: The Water Leakage and Waste Survey; The Trunk Main Survey; The Engineering Study; Teaching and Special Studies.

WATER LEAKAGE AND WASTE SURVEY

The Water Leakage and Waste Survey is an investigation, the basic purpose of which is to reduce to, or maintain at a minimum, a system's percentage of unaccounted for water. It is obvious that before any reinforcements or extensions to a system are planned its present adequacy as regards actual needs must be assessed after eliminating all excessive waste that can be located economically. Each gallon of wasted water found and saved is equivalent to adding a gallon to the capacity at the source of supply. Such a Survey begins by measuring the water delivered daily to the network at the sources. The network is then divided into districts, the water consumption in each of which is measured during twenty-four hours; districts are chosen of convenient size, best advantage being taken of natural boundaries (railroads, bodies of water, throughways, etc.) so that a minimum of valves need be closed to complete the isolation of the area from the surrounding network during the measurement, thus helping assure the maintenance of normal water pressures and flow patterns.

Where the measured minimum night rate is found to be appreciably less than 50 percent of the average consumption rate in the district, there is little probability of excessive leakage in the area. Where the ratio rises above 50 percent, the chances grow with it that substantial leakage or waste of water exists. In some networks, the ratio climbs to 80 percent or more and plotted hourly flow rates make a practically straight line throughout the twenty-four hours. However, considerable variation in ratio may be expected; heavy industries for instance frequently have consistent water demand rates around the clock, while some residential areas may have night rates closer to 20 percent than 50 percent. An experienced engineer, on studying the consumption chart and the area from which it was obtained, can usually make a close estimate of the probable amount of leakage to be expected there. In those districts showing unexplained high night consumption ratios, further measurements are made at night, block by block if the number of valves permit. These final subdivision measurements quickly throw in relief those blocks of high water consumption not explained by use whether industrial, commercial (hotels etc.) or institutional (hospitals), thus allowing detailed sounding of only those blocks of irrational high demand, with consequent rapid location of the causes whether due to underground leakage, unauthorized use of unmetered water, etc. It is axiomatic that the bigger the leak the less noise it may make; for instance an open-end pipe following a break at or near a body of water makes a minimum of noise. Without a measurement of water flow into the area, the chances are minimal of the leak being found by sounding alone. Likewise an abandoned and broken main or service to a former consumer or section may be found leaking hundreds or thousands of meters from its connection to the block of main, the water consumption in which was measured and found excessive. Here again, it is unlikely that sounding alone would locate the leak since the sounding probably would not extend to the point of the break.

A complete Water Leakage and Waste Survey usually will reduce a system's percentage of unaccounted for water to fifteen percent or less, and in systems where work is carried out repeatedly and systematically this percentage between the amount of water delivered daily to the system and the amount registered on meters, or otherwise accounted for, can be and is maintained in several systems at 10-12 percent year after year. The control work is done by remeasuring water consumption in the same districts time after time, further investigations being carried out only in the ones showing unexplained increases in demand compared to figures obtained by previous measurements made after all leaks and waste had been eliminated. In large systems, this type of work is done on a continuous basis throughout the year. In small systems a survey may be made every other year, or every three to five years, depending on the seriousness of the relapse following the most recent survey.

There is of course a wide variety in the type and amount of leakage found in any given system, or even areas within the same network. In terms of percentage of total consumption the underground leakage located and eliminated by a survey has run from a few percent to 50 percent or more of the daily consumption measured at the beginning of the investigations. The higher percentages normally correspond to systems of smaller sizes, since a large city seldom can afford to allow the unaccounted for to reach such proportions either in percentage or total quantity involved. The cost of increasing the supply by such amounts would be prohibitive in all its phases from source through pumping and treatment, transmission and distribution piping. In many systems leakage originates mostly from corroded services such as galvanized steel which in some areas has a useful life of from two to not more than ten years. Aggressive soil may produce electrolytic effects which remove the iron from cast-iron leaving a brittle carbon shell prone to break under even slight pressure changes or traffic-caused vibration. Where earth movements occur, or where a pipe was poorly laid in uneven trenches, many leaking joints or broken pipes may be the principal cause of underground water losses. Not infrequently open blow-off valves are found pouring water into neighboring sewers or water courses, with no hint at the ground surface. These open blow-offs are testimony to some past main break, where after repairs were completed they were forgotten by a tired repair crew. Individual leaks may run from a few cubic meters per day to many thousands. Single breaks on large mains have been located wasting as much as 32,000 m^3/day (8.45 mgd). Leakages in large amounts are sometimes found from reservoirs, especially those where large flows in and out occur daily, thus making it difficult to appreciate even substantial discrepancies, particularly in large reservoirs. A second serious loss of water originates in deficiencies in meter maintenance and in the reading-billing process. In the United States, Water Waste Surveys were often made in unmetered systems to help hasten meter setting so that the areas of highest waste were attended to first. House waste in unmetered systems can assume alarming proportions, bringing per capita consumption to figures well above 400 litres per day, even in low industrial use sections and cities, and this without benefit to the consumer, since the water merely flows through the premises via fixtures that do not shut off or through plumbing with no faucets to shut off. This in turn often makes it impossible to maintain twenty-four hour service in a system, the entire capacity from the sources being wasted away through defective plumbing in a matter of hours. The sheer number of defective fixtures in some systems requires a good tabulator. For instance, in a City of 200,000 (Guayaquil) people, with an unmetered system, 33 percent of the total available supply was found being wasted in a matter of hours through 10,000 defective fixtures. In a city of 800,000 (Havana), 5 percent of the consumption was being wasted by 75,000 leaking faucets, toilets and other fixtures inside consumer premises.

The house waste problem can and does exist also in systems supposedly close to 100 percent metered. This is due to defective meters, poorly maintained and read and deficient billing practices. All too often the material bought for waterworks installations is the cheapest possible with consequent loss in quality. This applied to meters, produces disastrous reductions in the accounted for water column. The meters bought in such cases are usually of the turbine type, which will register correctly for a short period, a few weeks or months, then start to under-register until they stop, often inside the first year of their setting. Inadequate maintenance compounds the trouble and so-called rehabilitated meters will fail to register anything when reset, or stop again a few days later. Finally the practice of flat rate billing on estimates of consumption frequently far below those actually registered by the meters during their brief operational period, further increases the loss of revenue and the amount of unaccounted for water. Little need to mention meter readers who make their readings at home or in a convenient bar, or who regularly skip certain meters because of a muddy location or an unfriendly dog. Then we come to the premises with unregistered and of course unmetered services. These may have been skipped carelessly when they were officially installed, but all too often were put in clandestinely by waterworks personnel during weekends, or holidays, for the benefit of friends, relations, or their own pockets. Surveys have uncovered as many as one thousand such illegal domestic services in one city, and besides these, from time to time, industrial consumers are found using water through unauthorized and unmetered lines. Water registration lost from one large industrial account may come to four or five thousand cubic meters per day, or more. These losses are spectacular, of course, but are relatively infrequent. Much commoner, and a far greater cause of loss in the large consumer category, come from defective metering or meter maintenance on the services to such consumers. Meters are frequently over-sized for the customer's demand rates, or of a type unfitted for that particular service demand rate pattern. In some systems no provision has been made to handle and maintain the large meters. Their weight alone discourages removal and transport to the shop for overhaul and testing. Here again the Water Waste Survey will spot those meters not registering correctly, this being done by direct testing of the meters in place, or indirectly during subdivision measurements. The most effective way to test and appreciate the efficiency of a system's metering, both domestic and industrial or commercial, is to measure actual water consumption in a series of study areas carefully chosen so that the distribution network in each is completely known and mapped and where underground leakage has been eliminated. The measured total flow into each area, over a period of days is compared to the total meter registration during the same period, while actual water use is observed by inspectors examining each consumer premise. Such studies bring into relief the metering deficiencies in all their detail, stopped meters, meters obviously under-registering, unmetered premises, etc. From the results obtained in such test areas, close estimates can be arrived at as to probable total system under-registration.

As useful by-products of a Water Leakage and Waste Survey, we mention the checking, or even revision of the system maps and records, the finding and operating and testing of valves and hydrants and providing the waterworks with lists of the ones found defective so that prompt repairs may be effected. Often valves are found closed partially or entirely, a condition adversely affecting water flow patterns and pressures, as well as chlorine residuals. Pump discharge and efficiency tests are run allowing an appreciation by the waterworks management of just how the various units are functioning.

Outside the United States and Canada, Water Waste Surveys have been made in close to 40 cities in Latin-America, not counting Puerto Rico where each of 126 distribution networks has been studied. In many systems a second and third survey have been made. In the Orient to date, similar studies have been made of the systems in Manila and Bangkok. Results obtained here in Bangkok, in the year and one-half of study show:

> 1,000 underground leaks located wasting about 25,000 m^3/day or less than 3 percent of the measured total consumption.
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> 50-60 percent difference between actual water consumed and water billed for. This was determined from detailed data obtained in five special study areas. The difference was due to meter under-registration and flat rate billing well below actual water consumed.

Further benefits accrued during the Bangkok survey from the map work done, using as a basis the few remaining out-of-date records together with several months of detailed field work locating valves and mains. Forty-six section sheets of maps were made up, scale 1:4,000, on a 1966 photogrammetric base map. This was followed by a valve survey which included hunting for 3,688 reported valves—100 to 1,000 mm in diameter—of which 2,477 were found and records made up for each one. Operating the valves showed that 833 were defective and the list of these was turned over to the repair crews who made the necessary corrections. Twelve hundred (1,200) hydrants, both post and flush, were searched for, 1,035 located, inspected and their individual records prepared. Water discharge from 120 wells was measured and their meters tested.

TRUNK MAIN SURVEY

The Trunk Main Survey is a field study of the actual functioning of a water distribution network in all its phases. Again flow measurements are started at the sources of supply, followed by measurements in each of the feeder mains in the system, section by section. Recording Pitometers are set up at each end of the pipe section under test with recording pressure gauges. One instrument is left set up at the end of each section, serving then as a reference gauging in the succeeding pipe section measurements. From the flow and pressure records obtained, or later by separate tests, head losses per unit of pipe length are derived allowing accurate determination of the friction factors, whether in the Williams & Hazen formula, the Manning or other, as may be specified by the client.

The wealth of data obtained is then tabulated and used to make up maps of the trunk main grid, showing direction of flow, total flow measured at each point, with maximum and minimum flow rates and maximum water velocity. Friction factors are shown along the corresponding pipe sections, and hydraulic gradients across the system, or along various pipe paths, are drawn on graph paper. Water-level contour maps may also be provided. Both the gradient and water-level contour map will highlight areas of deficiency or abnormal conditions. These then form the basis for investigations to discover their underlying causes. In making up the flow data sheets, the total consumption in the system is also noted for each day the measurements were made. Percentage of total system consumption carried by each pipe section the day measured is shown on the hourly flow-rate sheets. These ratios of water carried by a particular pipe in relation to total system consumption, has been found to vary little, hence knowing that ratio allows inferences to be drawn as to what flow a particular pipe would carry under various other demand conditions.

The Trunk Main Survey thus provides a complete picture of network performance, high-lighting both the mains that are overloaded as well as those underloaded or idle, and providing a firm base on which to draw conclusions and make the logical recommendations as to improvements etc. Excessive pressure drops can be directly ascribed to specific feeders overloaded due to insufficient diameter for their length and required flows, or due to low friction factors. Tuberculation of old metallic pipe, has been a condition often found in the past, and of course, still today. But now new cement-lined, or concrete pipes are being found with Williams and Hazen "C" values down around 60 to 70 after only a few years service. This frequently is found due to the water treatment process allowing deposits of aluminum hydroxide to line the interior pipe surfaces. These deposits form in ripples having disastrous results on pipe carrying capacity even though barely paper thin, in fact almost invisible if looked at casually. In raw water lines iron bacteria such as *crenothryx* will produce equally serious reductions in main capacity. These conditions are normally unsuspected and can only be appreciated by actual field testing of a distribution network in the manner here described.

The Trunk Main Survey provides the information required by planners whether in the Waterworks' own organization, or by Consultants it may engage. We have made such Surveys in most of the water systems in the United States and many others from those in Canada to Montevideo, Caracas and Bogota in South America, to Istanbul, Manila and Rangoon.

THE ENGINEERING STUDY

The Engineering Study, using the Trunk Main Survey data, plus many fire flow tests to pinpoint existing network inadequacies, takes the final step into design and cost estimates of specific reinforcements and extensions. These improvements may be made to cover present needs, or with added detailed studies on population and past and present growth tendencies, also to plan future development by stages, taking into account both the economics of the situation as well as the real requirements of the distribution system. Our studies have been made in systems supplying a few thousand people, and in others covering plans to supply millions of inhabitants where requirements include hundreds of kilometers of pipe from 600 to 2,000 mm in diameter together with balancing reservoirs of several hundred thousand cubic meters total storage capacity.

SPECIAL TESTS AND TEACHING

Many types of special tests are made using the Pitometer. These range from water turbine and pump efficiency and acceptance tests, to evaluation of the effect on friction factors of various types of pipe lining.

Teaching has always formed an integral part of our practice. To insure a competent staff at all times, we must keep a teaching staff as a permanent part of our organization.

Water problems are, of course, causes in part of the growing pains and trained engineers are needed, trained not only in the several general disciplines, but specifically trained in narrow fields such as water distribution network operation and development. We routinely carry on such teaching programs and have taught our methods and practice in assessing the adequacy of networks to engineers in several languages and in many places.

WATER SUPPLY DEVELOPMENT AND CHARGES AND RATEMAKING FOR WATER SERVICE IN TAIWAN

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INTRODUCTION

A community water supply is comparable to a manufacturing industry in that the whole water supply system requires competent engineers to plan, design and construct. Similar to an industrial enterprise, even the most perfectly planned, designed and constructed undertaking will run down unless it is adequately maintained and managed by competent operators and managerial staff. Like all manufacturing industries, the production of water and the maintenance of the system involve necessary expenditures. Monies required for production and distribution to the users must be obtained, preferably and logically, from the consumers of the commodity. The present government policy is to achieve a self-sufficient (if not self-liquidating) status of all waterworks. To assist in the accumulation of revenues the government has established a formula for arriving at a reasonable water rate and published rate schedules which have been under application since 1959. Most waterworks have proposed new water rates that follow the promulgated formula to the city council concerned. Concurrence of the council to the proposal, however, has not been obtained on all occasions and accordingly some systems still have insufficient revenue for needed improvements and/or expansion. This paper presents the general trend of water supply development and provides a picture of the approaches to charges and ratemaking for water service in Taiwan.

Taiwan island is leaf-shaped, has an area of about 36,000 square kilometers, is 400 kilometers long and 140 kilometers wide. The spinal mountain range running from north to south and the high foothills comprise approximately three quarters of the total area. The population was estimated as 13,650,000 at the end of 1968. A considerable number of the population is concentrated in urban areas largely on the western and northern plains. Due to the constantly increasing water demand of the growing population, occasioned by the rising standard of living of the people and the rapid urbanization and industrialization of the country, the public water supply problem is becoming more critical. Unless more definite and adequate measures are taken soon the water supply problem will grow in the years to come.

TRENDS IN WATER SUPPLY DEVELOPMENT

Municipal Water Supplies

The first waterworks in Taiwan was installed in 1896 at Tanshui, the most important port of Taiwan at the time. This was followed by the construction of the Keelung waterworks in 1898. Since then, the development of public water supply has received more attention, so that by the year 1944 there were a total of 123 communities served on the island. Unfortunately, most of the systems were damaged during the Second World War and their maintenance has been difficult and inadequate for some time. The government authorities have managed to effect the necessary repairs and eventually placed the water systems in the major cities back in good order. However, it was not until 1949 that the government was able to give more attention to the provision of water supply. This new stimulus was brought about with the help of the JCRR, the United States, and international financing agencies. This stimulation was in the form of grants-in-aid to help the government in increasing its activities in the construction of new systems and expansion of existing facilities. In spite of this assistance, funds were still limited, therefore the development of public water supplies had not been significantly attained during the period of 1950 to 1960. This is shown in Table 1 on the development of water supplies in Taiwan in the last two decades. Government has hopes to channel more development funds to water supply and expects that within the next 10 years Taiwan will have water supply systems in more than 400 communities. About 60% of the total population at that time would be served. This will require an increase in water production from the present 1.26 million tons per day to 3.2 million tons per day in 1980. These expectations are reflected in the last revision (1966) of the ten-year water supply programme.

Table 1—Water Supply Development in Taiwan

Year	Total Population	Total Water Production (cu. meters/day)	Population Served	Percentage of Population Served (%)
1945	5,790,000	100,000	1,035,957	17.89
1946	6,090,860	100,000	1,038,029	17.04
1947	6,495,095	127,400	1,245,221	19.17
1948	6,806,136	154,800	1,556,009	22.86
1949	7,396,931	237,000	1,918,595	25.94
1950	7,554,399	346,600	2,022,191	26.77
1951	7,869,247	374,000	2,160,000	27.45
1952	8,128,374	376,530	2,341,602	28.81
1953	8,438,016	406,195	2,378,472	28.19
1954	8,749,151	441,212	2,410,328	27.55
1955	9,077,643	459,678	2,498,200	27.52
1956	9,390,381	468,665	2,569,258	27.36
1957	9,690,250	477,414	2,642,633	27.27
1958	10,039,435	531,243	2,885,683	28.74
1959	10,431,341	655,987	3,029,927	29.05
1960	10,792,202	689,937	3,201,696	29.67
1961	11,149,139	737,076	3,430,216	30.77
1962	11,511,728	773,290	3,592,076	31.20
1963	11,883,523	801,712	3,883,568	32.68
1964	12,256,682	1,019,328	4,573,734	37.32
1965	12,628,348	1,081,623	4,839,443	38.32
1966	12,992,763	1,115,106	5,017,677	38.62
1967	13,296,571	1,172,573	5,168,497	38.77
1968	13,650,370	1,265,924	5,580,127	40.88

Categories of Water Supplies — 1968

Communities	Population served
7	more than 100,000 each
10	more than 50,000 each
73	more than 10,000 each
240	under 10,000 each

Accumulative efforts of government to the end of 1968 produced 651 public water supply systems, (330 municipal water supplies and 321 simple water supplies) and two industrial water supply systems. Many of the waterworks are quite simple in design and construction. Both surface and ground waters are utilized as sources and are treated for impurities as the case may be.

Of the 330 communities served, about 38 percent derive their supply from ground water sources (producing 395,000 m^3/day) and 45 percent from surface water sources (811,000 m^3/day). The remainder obtain water from both ground and surface sources. Further, of the 133 waterworks in operation 54 systems employ water treatment consisting of flocculation, sedimentation, slow sand filtration and chlorination, 6 rapid sand filtration instead of slow-sand filtration, and 5 both types of filtration. 38 employ aeration for iron removal and other impurities in addition to the above. Chlorination only is necessary in 68 plants. However, because of improper disposal of wastes (domestic and industrial) and uncontrolled use of pesticide and fertilizer, modifications of the treatment processes may come soon.

One might say that the development of public water supply in Taiwan has been relatively slow in comparison with other developing countries. Among the many reasons for the slow development, the shortage of start-up capital and the inadequate service charges and water rates may be counted. The development of water supply schemes requires a sizable capital investment which is not always readily available either on hand or as loans at reasonable interest rates from lending institutions. Moreover, upon their completion a certain amount of operation and maintenance fund must be initially available. To keep the undertaking on a self-supporting and expansive basis, the income from its operation must more than cover the required expenditure and debt obligations. Unfortunately, most water undertakings in Taiwan have difficulty in arriving at this goal because the water rate is generally too low. There are other reasons.

The water supply systems mentioned earlier serve a population of about 5,580,000 which is 41 percent of the present estimated total population. The total headworks output was placed at 1,143, 000 cubic meters per day from community waterworks and 123,000 cubic meters per day from industrial waterworks. All waterworks are publicly owned; five of them are operated and controlled by the provincial government, the others by the local governments.

Simple Water Supplies

Like in many countries the provision of water supply in small communities has not kept pace with those in urban areas. Efforts of government in this regard resulted in the construction of simple water supply systems in 43 communities serving about 7500 people up to 1963. In 1964 the government entered into an agreement wherein UNICEF will provide water supply materials to communities if the communities themselves will contribute their own resources for the completion of the projects. The arrangement was that UNICEF would provide about 1/3 of the cost in kind, the balance to be apportioned to the provincial government, the local governments and the beneficiaries themselves.

As of 1968, 321 simple water supply systems have been installed providing about 65,400 tons of water daily to about 557,000 people in communities with populations ranging from 500 to 2500.

The simple water supply systems are operated either on a self-supporting basis through the sale of water, or administered directly by the local town office and supported by the town budget. It was reported that about 80 percent of the systems were on the self-supporting basis. The water rates range between NT$1.0 (.025 US$) to NT$1.5 (.0375 US$) per cubic meter.

Regionalization of Waterworks

In order to improve the management of the water supply systems and to optimize the use of water resources and employment of technical skills, the regionalization of waterworks is always taken into consideration whenever establishment or expansion of a sizable waterworks is planned. The advantages of regionalization may be summarized as allowing:

1. A coordinated and balanced development of water resources, thereby giving every opportunity to communities within the region to be served with adequate water supply, and
2. The lowering of the cost of water supply installations as a result of coordinated development.

In developing countries, the merits inherent in regionalization may, in addition to the above, include the following:

3. Higher caliber personnel in both the technical and managerial categories to be attracted and employed by the regional waterworks,
4. A higher operating efficiency at lower expenditure,
5. Pooling, and hence an easier apportionment, of capital funds and centralized procurement of supply materials, and
6. Facilitating of emergency repairs.

Sources of Capital Funds

In Taiwan, likewise in other rapidly developing countries, almost all available private funds are being employed in industrial developments and real estate promotion. Consequently no water utilities are, up to now, privately owned. Capital required for water utility development comes from budgetary allocations derived from general revenue and allocated as grants to municipalities by higher level government, loans from international financing agencies such as the IBRD and from the Sino-American fund. The sale of general obligation or special assessment bonds has not been resorted to as it appears impracticable at this time, considering the presence of more profitable investments in the country.

> *Grants*—Before 1964 the government received substantial grants-in-aid funds from the United States Agency for International Development (USAID) and International Development Association (IDA). (These funds amounted to NT$ 76,139,000). Government counterpart contributions were provided as a prerequisite to the aid.
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> *Loans*—Borrowed capital came from the Sino-American Funds, Revolving Funds of the Provincial Government, and loans from the International Bank for Reconstruction and Development (IBRD). Loans from local banks were rarely obtained because of the high interest rates and short duration of repayment periods.

The present provincial government policy on budgetary allocations and/or grants is to concentrate assistance in the form of investments to small town and rural water supplies in preference to municipal water supply development. Table 2 shows the capital expenditures and sources of funds for water supply development from 1964 to 1968:

Table 2—Capital Expenditures & Sources of Funds

Years	Total Amount NT$*	Financial Sources-Amounts in Percent of Total by Year						
		Provin. Funds		Local Funds	Loans			Others
		Invest.	Grant		Sino-Am.	Rev. F	AID	
1964	510,399,000	2.8	2.9	16.0	39.7	-	38.3	0.3
1965	27,256,000	42.8	-	37.2	16.7	-	-	3.3
1966	82,474,000	18.1	-	29.6	27.1	24.8	-	0.4
1967	82,460,000	14.1	0.6	23.1	36.4	24.9	-	0.9
1968	137,151,000	3.6	-	25.7	33.5	37.2	-	-

*1 US$=40 NT$

Community Water Supply Development Foundation—The development foundation on community water supplies was established in 1966. It is in the form of a revolving fund, the repayment of principal of the loans and proceeds from interests are reused as loan fund.

The Taiwan Public Works Bureau was authorized as the competent agency for the overall supervision of development loan projects on community water supplies. The Committee of the Development Foundation was constituted and charged primarily with the duty of loan management. The committee is comprised of representatives from the Taiwan Provincial Government (TPG), Council of International Economic Cooperation and Development (CIECD), and Public Works Bureau.

The development foundation was established with transfer of funds from the Sino-American Fund (NT$150,000,000) and the Taiwan Provincial Government fund (NT$150,000,000). Loan repayments (principal plus interest) have been on the basis of equal installments to be made within ten to fifteen years, beginning one year after the completion of construction, at the rate of interest of 6 percent per annum for township water supplies and 10 percent for larger municipal water supplies. The benefited water undertaking shall be responsible for the repayment of the principal of the loan and interest incurred. A total of NT$109,705,000 has been appropriated during the last three years as follows:

Year	Total Value	No. of Loans
1966	NT$ 22,500,000	14
1967	32,403,000	14
1968	54,798,000	21

A new approach to the repayment of loans is being considered. It is planned that payments shall be on a progressive scale basis taking into consideration the growing period of a new water utility. This arrangement should ease the financial burden of the utility in its early stages.

WATER CHARGES AND RATEMAKING

In Taiwan the water rates are charged on the basis of the quantity of water used for metered connections rather than on the assessed value of the user's property. The water charges presently in force are of three parts namely:

1. A minimum basic charge corresponding to a certain volume of water consumed during the metering period,
2. A graduated rate for all consumption in excess of the basic allowance, and

3. A charge for meter rental and meter maintenance and other services.

Minimum Quantities Charge

The general practice in Taiwan is to charge a monthly rate based on an estimated minimum quantity of water which may be delivered by each size of meter. This minimum charge is collectable from the connected premises even though the amount of water actually consumed as indicated by meter registration does not reach the amount of water stipulated. The concept is to establish a minimum charge based on the water quantity necessary to promote personal hygiene and household sanitation. In Taiwan it has been estimated that about 10 cubic meters per month per family is required (higher in larger cities) for these purposes. The policy that the minimum rate must be paid regardless of actual usage would urge people to make use of the water of the undertaking. This also gives assurance to the water undertaking that each month a certain amount of revenue is forthcoming so that the capital investment will return and the needed maintenance will be paid back. Table 3 summarizes the prevailing practice in billing water for each size of meter in use.

Table 3—Nominal Quantities of Water for Billing Purposes by Size of Meter

Meter Size, mm	Water Quantity, cubic meters per month			
	Max.	Min.	Ave.	Mean.
13	15	6	11.4	10
20	30	10	18.6	20
25	45	15	28.1	30
40	120	25	54.5	50
50	200	35	93.8	80
75	600	40	180	150
100	800	65	324	200
150	1,500	100	578	500

It should be noted that the quantities of water chargeable per meter size were not based on the squares of the diameter of the meter nor on any mathematical assumption of their rated delivery, but rather on assumed figures not necessarily systematically arrived at.

Meter Charge

A meter rental is charged varying with the size of the meter. The cost of installing and maintaining meters, including meter cost, installation, repair, replacement, and renewal, is evenly apportioned to all meter installations of the same size. Table 4 shows the various rentals for meters:

Water Rate Schedules

All of the waterworks in Taiwan are publicly owned. Except in very few cases, most service connections are metered. Where water is supplied without meter, charges are made on the per capita basis ranging from 0.5 (.0125 US$) to 5.5 NT$ (.1375 US$) per capita. Where water is supplied with meter, charges are made on the measured quantities.

There are a number of different rate schedules applicable on metered charges. Those prevailing in Taiwan are:

Table 4 — Meter Rental Charges

Meter Size mm	Meter Rental, NT$/month			Capital Cost of Meter NT$
	Max.	Min.	Ave.	
13	10.0	2.0	5.2	143
20	15.0	3.0	8.0	176
25	25.0	5.0	12.1	400
40	50.0	5.0	23.9	750
50	80.0	12.0	51.3	2,700
75	120.0	15.0	73.6	3,400
100	150.0	50.0	110.3	4,250
150	280.0	60.0	166.5	11,000
200	300.0	226.5	150.0	18,700

Minimum Quantity Charge Rates—Water uses are generally classified into residential, commercial, or industrial supply. The residential use is usually charged the least; the cost of rendering service to heavy water users such as industries is greater than to households. Two rate schedules (single and compound) are being applied to date:

1. Single water rate: Water rate applied equally to all types of customers without regard to demand in relation to use or category of user. This arrangement provides uniformity and simplicity in charging for water consumed and is recommended by the provincial government.

   Schedule:

Max.	5.0 NT$/m^3
Min.	1.0 NT$/m^3
Ave.	2.3 NT$/m^3

2. Compound water rate: Water rate schedule established taking into consideration the class of the customer whether residential, commercial or industrial and shown in Table 5.

Of the 141 rate structures surveyed, 15 cases are applying the single rate schedule while 126 are applying the compound rate. Data given in Table 5 were obtained from the survey of 141 water rate structures. It is shown that the rate on residential use is lower than the other categories of use.

Rates for excess water consumed over the minimum quantities charged—

1. Sliding water charges:

   a. Increasing unit charge—Higher charges are made per unit for larger quantities of water used. Mostly found in communities with water supply shortage. Tends to limit consumption and reduce wastage.

   b. Decreasing unit charge—Lower charges are made per unit for larger quantities of water used. Mostly found in communities with surplus supply. Could be beneficial but on the other hand may be wasteful.

2. Uniform unit charge: Rate similar to the minimum quantities charge but is

Table 5 — *Compound Rate Schedule*

Class	Rate	Residential		Commercial	Industrial
		Private Tap	Public Tap		
	Max.	3.00	4.00	4.00	3.60
Class A*	Avg.	1.94	2.14	2.61	2.93
Waterworks	Min.	1.50	1.50	2.00	1.80
	Max.	5.00	5.00	6.00	5.00
Class B*	Avg.	1.95	1.75	2.44	2.50
Waterworks	Min.	0.80	0.80	1.00	1.20
	Max.	5.00	4.00	5.60	5.50
Class C*	Avg.	1.87	1.72	2.27	2.24
Waterworks	Min.	0.50	0.80	0.70	0.70

* Classified according to plant production:
Class A. Production more than 20,000 m^3/day
B. Production more than 3,000 m^3/day
C. Production less than 3,000 m^3/day

Units: NT$/$m^3$

designed for larger quantities of water used.

Among the 141 rate structures, the decreasing unit charge is being applied to 12 systems, the increasing unit charge to 76 systems while the uniform unit charge to 53 systems. The trend is towards uniform water charges and less on the decreasing unit charge.

WATER RATE FORMULA

The Taiwan Provincial Government has established a water rate formula as the basis for billing water consumption by water utilities with the view to accumulating revenue sufficient to provide adequate service and assure enough funds for the maintenance, operation, capital recovery and development of each system.

Most of the local governments and water utilities recognize the importance of self-liquidating status for waterworks and are, therefore, willing to follow the regulation. However, the municipal or township council is not always pleased to concur with the local government proposal. So, in some instances, the water rate is not enough for the system to be self-liquidating. With the application of the formula the rate of water in one system is not necessarily the same as in other systems, unlike the electric power rate which is uniform throughout the country. Analysis of the formula will bring this out as the amount of each variable is dissimilar in almost all cases. Moreover the assessment of the properties of the utilities does not always produce the correct value of the assets. This is however being remedied.

The established formula is expressed as:

Average Unit Price = (Operation & Maintenance Expenses + Return on Investment + Financial Disbursement) / (Water Sold)

The factors used to determine each item of the formula are:

1. The operation and maintenance expenses which include:

   a. Personnel (salaries and wages),

   b. Maintenance, repairs and/or replacement,

c. Electric power and other power generating fuel,

d. Office supplies and expendable office materials,

e. Postage, telecommunications, stationery and printing matter,

f. General inspection and leakage checks,

g. Chemicals and others,

h. Property insurance,

i. Charges for depreciation,

j. Taxes,

k. Other necessary expenditure (expendables), and

l. Administrative.

It may be noted that revenue from water utilities is taxed. A certain amount of the tax money is returned in the form of a subsidy to water supply systems and the fire protection service.

2. The return on investment: The rate of return of investment is estimated at 4-6% of the net capital amount based upon local conditions. The return on investment shall be used for no other purposes than for expansion work, additional facilities, or repayment of loans obtained for expansion work.

3. Financial disbursements: All expenses incurred for necessary financial arrangements. The interest disbursement is the most important.

4. Water sold: The water sold is the expected (estimated or measured) amount of sales in a year. In arriving at this figure it is extremely important to have close evaluation, good registration of the metering devices, accounting and bookkeeping.

5. Example—Hsin-chuang Waterworks: The municipality has a population of 35,349 of which 33,118 are served by the system, 92% of the connections are metered. In arriving at the water rate for this municipal supply the formula mentioned above was applied. The following is the breakdown of costs:

a. Operation and maintenance expenses. Items 1d. and 1e. in the factors used for determination of this item have been lumped together as item (4) below:

(1)	NT$ 813,504.54
(2)	59,020.00
(3)	411,900.00
(4)	200,125.42
(6)	6,000.00
(7)	9,600.00
(8)	376,885.20
(10)	27,982.19
(11)	92,811.19
(12)	73,724.31
Total	NT$ 2,071,552.85

b. The return on investment calculated at 4% interest applied on the net capital investment—NT$ 125,979.00.

c. The financial disbursements amount to NT$ 238,805.62 for the year under consideration.

d. The water sold corresponding to the period was 1,627,200 m^3. Substituting the values in the formula we have:

$$\text{Water Rate} = \frac{2{,}071{,}552.85 + 125{,}979.00 + 238{,}805.62}{1{,}627{,}200}$$

$$= 1.497 \text{ NT\$/m}^3$$

WATER RATE ADJUSTMENT

It is customary and necessary for water undertakings to adjust the water rate schedule at times in order to provide the required revenue for the operation and maintenance, debt obligations, and the expansion of the utilities. The waterworks management has the responsibility of recommending any rate change. The normal procedure is to submit the proposed change to the municipal or town government council for review and with their concurrence secured, to transmit the same to the Provincial Government for approval. The established new rate is then reported to the Ministry of Interior for recording.

Because the new rate is subject to the approval or concurrence by the town or city council concerned it is sometimes not easy to obtain a change in the rate, especially if the change would increase the cost of water to the consumers. For various reasons some water undertakings have encountered difficulties in obtaining increments to water rates. First, the council may be reluctant to increase the rate for fear of the adverse effects on the chances of its members for re-election. A candidate for election to the council may promise not to change the water rate, which promise could bind his actions after elections. Some of the members of the council may not be too eager to consider the problem of a rate increase. Moreover, the knowledge of members of councils on water supply management in general not to mention the financial requirements of water utilities, is very limited for them to engage in the exercise of rate changing. Secondly, some citizens believe that the provision of water is a government function and therefore expect that expenses for its procurement should come from the government coffers. A programme of public education to establish a rational concept of the public is, therefore, essential for a country in its early years of adopting a democratic system.

Like many other things, the cost of the production of water is not static. The value of money itself fluctuates, the running cost of systems increase with the years, etc. Obviously water rates should increase commensurate with production costs in sufficient amount to allow the water undertakings to operate and to meet all financial obligations. How to effect the needed change in a politically conscious government is a problem of management. Reluctance to make change will result in obsolescence with resultant inadequacy of service, perhaps to the impairment of public health and industrial development. Well conceived and reasonable service charges and water rates which are within the financial capability of the consumers (so that they are enforceable) are essential in providing revenue for the utility and perpetuation of the system.

MANAGEMENT OF COMMUNITY WATER SYSTEMS

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The importance of sound management of community water systems is late to be recognized — and in a relative sense this has been true throughout the world. Generally, it is fair to say that at present community water systems in developed countries are better managed than those in developing countries. However, if we look back to the infancy of the systems in developed countries, we find that attention accorded to management aspects was something less than would now be considered appropriate in those countries.

The characteristics of a successful community water system are only two in number:

- Provides its customers potable water
  - in the quantities needed
  - at the times needed
- Generates revenues required to
  - operate and maintain the system
  - meet commercial and administrative expenses
  - service debt
  - replace worn out plant and equipment
  - finance necessary expansion

Community water systems are expensive and the availability of *CAPITAL* to plan, design and construct a new system (or expand an existing one) is of primary importance. Sales of bonds, general tax revenues, domestic and international loans, or combinations of these sources, have been used. In any event, in estimating capital requirements it is important to include reasonable provision for working capital and, also, to recognize that the system may have to finance its customers to some extent to make it possible to connect to the mains and install the required plumbing.

A prudent businessman, considering investment in a service industry, would first examine the *MARKET* for the service in minute detail—he would want to be sure the demand for the service would be sufficient to provide him a reasonable return on his investment. When the service is the supply of potable water to a community, there can hardly be a question about demand. People need potable water as they need the air they breathe. When it comes to the question of their ability to pay for it, however, the problem gets a little more complex. Many can pay—and many cannot. It seems apparent that the question of whether or not the vital needs of a community for potable water will be fulfilled regardless of individual ability to pay, is one of public policy. If the decision is affirmative, then the organization supplying the water to those unable to pay for it should be paid for the service from the general revenues of the political entity involved. Let us assume, therefore, that any reasonably large community presents demands which warrant a water system and has the means to pay for the water delivered—individuals having service lines to homes or businesses and paying themselves, others receiving more limited services which are defrayed from the public purse.

A MODERN, WELL-ENGINEERED SYSTEM is also of vital importance—not only from the standpoints of service and efficiency, but also from the standpoint of required future expansion. For new or expanding water systems, a feasibility study is required to:

- Identify and evaluate alternative systems and financing plans
- Select the optimal engineering and financing solutions

Next, the system must be designed and financial arrangements for its construction and working capital must be completed. In addition, construction of the system must be supervised. A highly specialized, interdisciplinary approach is involved, and the prudent community usually retains competent consultants to perform these tasks on its behalf.

In summary, therefore, a community which seeks to attain the first characteristic of a successful water system will need:

- *CAPITAL*
- *MARKET*
- *A MODERN, WELL-ENGINEERED SYSTEM*

Turning now to the second characteristic—the generation of required revenues—*SOUND MANAGEMENT* is the basic prerequisite. But *MANAGEMENT* is a broad field which involves much more than the capability to generate revenues. A good manager is one who arranges to hire required talents and applies the talents efficiently. If we accept the generation of revenues to:

- Operate and maintain the system
- Meet commercial and administrative expenses
- Service debt
- Replace worn out plant and equipment
- Finance necessary expansion

as a *basic* indicator of sound management, we can examine what is required to achieve this, and, in the process, we will develop a perspective of the broad implications of the word "*MANAGEMENT*".

First of all, a sound *ORGANIZATION* is required. The organization should be headed by an able administrator armed with sufficient authority and supported by efficient functional units responsible for:

- Operations and Maintenance—reservoirs, canals, pumping stations, transmission mains wells, treatment plants, etc.
- Service—installations, disconnections, meter repairs, plumbing inspection, etc.
- Engineering—planning, design, project management, construction supervision, technical studies, facilities, maps and records, river studies.
- Administration—financial management, billing and collecting, personnel and training, contracting and purchasing, general services.

and appropriate staff elements such as:

- Community Relations
- Legal Affairs

We say "armed with sufficient authority"—and this is important. Under broad policy guidance of a board of directors or its equivalent, the general manager should have authority to:

- Appoint and separate personnel
- Fix compensation as necessary to attract and retain competent personnel
- Adopt efficient systems for performance of assigned functions
- Establish, and require adherence to, performance standards
- Enter into contracts and, within defined limits, to borrow and lend money
- Adjust his budget from time to time, within defined limits
- Deal with the general public and with other governmental bodies
- Withhold or withdraw service for credit reasons

and, of course, the authority to re-delegate certain of these authorities within reasonable limits.

As usual, with authority must go commensurate responsibilities. To achieve the revenue generation requirements, the general manager will be required to insure that a host of functions are performed—and that they are performed well. To cite just a few, he must:

- Select qualified personnel and plan for their development
- Establish service tariffs which relate to the costs of providing service
- Bill for all services performed and collect service charges promptly
- Limit employment to the real requirements for efficient performance of assigned functions
- Foresee increased service demands and meet them in an orderly way
- Keep himself, and the board of directors, currently and accurately informed on financial and operations status, trends and requirements
- Plan and manage capital projects efficiently

The kinds of management problems that face water systems are no different than face other kinds of organizations. They enjoy no special immunities. Several of the more basic problems facing water systems in the developing countries are grouped under several heads—not necessarily in the order of importance.

ORGANIZATION STRUCTURE

Frequently the organization is ill-defined and uncertainties exist concerning the locus of responsibility for specific functions. Almost inevitably, when this is the case, we find a definite tendency at all but the highest level to avoid decision-making. The fuzziness of the organization structure inhibits clear delegation of authority and concensus must be obtained among numerous officials to permit positive action. Usually this situation can be alleviated or eliminated, at least in theory, without great difficulty and within a relatively short time. We say "at least in theory" because the most persuasive motivation, buttressed by organizational charts with functions clearly defined and with key positions and interrelationships described in detail, will not work if the man at the top does not insist upon adherence.

PERSONNEL AND TRAINING

The authorities needed by the general manager include powers:

- To appoint and separate personnel
- To fix compensation as necessary to attract and retain competent personnel

These authorities are *vital* to sound management. In fact, it can be said that without such authorities sound management would be an accident.

One thing is certain. We cannot, on the one hand, point out that water systems are "revenue producing" and should be "self-sustaining" and, on the other hand, bind the hands of the general manager by insisting that personnel practices and pay scales conform with those of other governmental (but non-revenue producing) elements. When we use such terms as "revenue producing" and "self-sustaining", we are talking in business terms—and no business can be run successfully if it cannot compete in the marketplace to attract and retain competent personnel. In one situation we encountered, numerous senior personnel of the water agency were deputed for brief periods from other governmental units. Such personnel:

- Have no long-term identification with the success or failure of the water system
- Require substantial time to familiarize themselves with operations
- Frequently serve out their time avoiding the decision-making process

Water systems should have personnel systems which include realistic pay scales, provision for advancement within and between grades, and other features conducive to "careers". Even with all the desirable features in the personnel system, well-structured personnel training programs are a necessity. This is particularly true in the developing countries, where the supply of personnel with appropriate academic backgrounds may be severely limited. We have found many instances where:

- Inadequate emphasis has been accorded training requirements
- The time required to train personnel has been underestimated
- Training has been ineffective because
  - — the graduate trainee can quickly command higher salary elsewhere, or
  - — his long-term career is *not* with the water system

MANAGEMENT INFORMATION SYSTEMS

The senior management echelons in any organization should be able to engage in decision-making in an informed atmosphere. For any important decision to be correct, except by pure chance, the official making the decision may need accurate and timely information about operations or finances—frequently he needs both. He will have the required data only if a system of management reports, which relate operating statistics and financial information, has been developed. In the absence of such data the manager cannot formulate and execute sound operating budgets. He must have data to forecast work loads and financial requirements and to compare actual performance with forecasts. He should be able to determine whether or not he is

- Losing money
- Breaking even
- Making a profit

and he should know the costs of providing water so that he can establish equitable water rates.

We find, more often than not, that water agencies attempt to struggle along on what we call the "line-item" budget. Such budgets set forth positions and salaries, project expenses, supplies, equipment, utilities and other services line by line, and accounts are established accordingly. While this system will reveal that salaries are (or are not) being paid at levels anticipated, it tells the manager nothing about work progress, and only rarely does it reveal variations among organizational elements. Likewise, in the project area, the manager may know what money has been spent but he is rarely able to judge the reasonableness of the expenditures in relation to physical progress.

It takes both operating data and financial data to manage, and these data should be available on a timely basis so that the decision-making process can be applied before management's options are foreclosed. Before leaving this point, it is important that we note that the data collection job is no small one. A vast amount of data is required. Usually a major, one-time effort to collect basic data such as the analysis of customers by size of ferrule and by number of taps, the valuation of fixed assets, the identification of fixed and variable costs, is required. Then, provision must be made for continuous updating of the data. If such data are not available, water rates will most likely bear no relationship to the cost of providing water service. Like the need for competent and trained personnel, the need for timely and accurate data is vital to sound management.

BILLING AND COLLECTING

Water systems should not *wittingly* provide free service. Our experience has shown, however, that some water systems provide free service *unwittingly.* Billings for water consumed are sometimes substantially below the quantities of water produced, and leak tests do not account for the substantial variations. Partly this is the result of faulty or inoperative meters, but sometimes the discrepancies can be traced to what we call "unauthorized connections"; i.e. customers who have arranged covertly for water service without the knowledge of the supplier. In collaboration with one client, we undertook a connection survey in a selected area of a municipality and found that as many as one out of every four connections was unauthorized. Here was a water agency providing free water *unwittingly.* We have noted failures to:

- Reconcile water produced with water consumed
- Pursue vigorous water meter repair and replacement programs
- Reconcile billings with reported consumption
- Disconnect service to nonpayers

all of which detract from badly needed revenues.

PROJECT MANAGEMENT

Delays in completing capital projects and cost increases are almost universally encountered and—I should hasten to say—the developing countries have no monopoly on this experience. We have noticed, time and time again, that rather extensive studies and analyses are undertaken by water systems in planning new or expansion projects, either because good management is being applied or because it is necessary to proceed in this manner to meet requirements of lending agencies, or both. Curiously, however, once projects are approved and funded, the tendency is to become careless. There seems to be insufficient awareness that it is in the project execution phase that the system is exposed to maximum danger. This is the time when resources are actually spent and the indebtedness becomes real. It is the time when careful, detailed planning is essential. There is a real requirement for substantial improvements in project execution, and it is hoped that some day soon detailed and logical project execution plans will be a prerequisite to funding projects. In this area, we believe, lies the greatest potential for increasing the percentage of "successful" projects—projects which accomplish their purpose in time and within budget.

ESTABLISHMENT OF WATER RATES

From the foregoing, you will not be surprised to learn that we have frequently encountered situations in which the rates charged cannot be rationalized. The data necessary to conduct the analyses are simply not available. It follows that no relationship of the rates charged to the costs of providing water can be established. Until such time as a water system knows precisely:

- Who is using water
- In what quantities
- The costs of providing water

it cannot establish rates which will generate the revenues we have identified as being required.

SUMMARY

In summary, patience, persuasion and persistence are required in developing and implementing solutions. The solutions are critical in developing countries where development demands exceed available resources. In the final analysis, a technically efficient water system can, unfortunately, constitute a continuing drain on limited public resources.

LOCAL VERSUS NATIONAL AUTHORITIES AND THEIR COORDINATION

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INTRODUCTION

This paper discusses the basic legal enactments and organizational structure from which an undertaking derives its powers, formulates its policies and carries out its works. Engineers cannot confine their interests to the strictly engineering aspects of a project; they must, in the final analysis, have the active support of the economists, fiscal analysts, government officials and legislators if their plans are to be translated into reality. The organization of the governing authority gives expression to the underlying philosophy governing the undertaking. Engineers should at least be familiar with this philosophy, and might even exert some influence based upon their knowledge of the physical aspects of the undertaking. Lack of interest can contribute to an unsatisfactory end result, even though the designs may be excellent. The best of projects can become the pawn of partisan politics or fall into unscrupulous management. Also, there are many worthy projects which might never come into being if the proponents were unaware of or indifferent to the importance of water supply and sanitation in the general philosophy of government. Engineers should be competent in matters of economics, law and politics. Unfamiliar as engineers are with the legal and political problems involved, they are conversant with matters of costs, benefits, operational problems and impact on the communities. Their knowledge of these matters can contribute substantially to the deliberations of the people who make the final decisions.

ALTERNATIVES

Historically, water supply and sanitation facilities have been local undertakings, aimed at meeting local needs, financed and built locally. However, present day trends are toward a broader concept of national responsibility for the development of adequate facilities. It may well be argued that only by a national effort can we attain the results so direly needed. It is the purpose of this discussion to examine the basic questions of responsibility and authority in the field of water supply and sanitation and try to determine those functions which properly should be left to the local communities for action, and those activities which are within the scope of national authority. Hopefully, we might be able to perceive the balance between local and national action which will combine the best features of each.

What do we really mean when we speak of authority in the field of water supply and sanitation? Is it not the grant of power, by an exclusive franchise to produce, manage and market an indispensable commodity and service. This is a significant power and carries with it a grave responsibility. It should be handled with care and remain close to the people who are dependent upon the proper exercise of the power—only when we can demonstrate a clear advantage to the community at large can we warrant extension of control of an inherently local situation to a widespread national authority. Obviously, there are such general benefits in today's world of rapidly developing economies. Only through authorities national in scope can we move ahead with water supply and sanitation programs which will keep pace with the planned and accelerated programs of national development in other fields. It is only by this means that we can fully utilize the resources of national and international finance and conserve the limited professional and technical manpower now available. But in extending the essentially local powers to the national level we must beware that the local participation and responsibility does not become diluted to the point where local control is delegated to a national authority both in miles and in interests.

Water supply and sanitation facilities have certain unique characteristics which really demand close local participation; and they are especially liable to abuses by an administration far-removed from the local scene. In the first place, the services rendered are individual in their nature and of importance to every resident. The authority should be quickly responsive to the consumers. Secondly, although the coverage of a given area is quite intense, the areas covered are relatively restricted. Water distribution and sewage collection can never cover the areas such as are served by electrical distribution systems or irrigation networks. Consequently we have many small but highly concentrated areas of service scattered over the entire country. While this undoubtedly calls for a large degree of overall planning, the actual operation is better left as far as possible with the locality. The problems, solutions and costs of operation must vary widely from place to place making a central and standardized operation very difficult. The situation requires a flexibility which can be achieved best through local management. Finally, it is my belief that these services are so vital to the health and well-being of the community that every community should be encouraged to work towards the solution of its own problems. True, the national authority should stand ready to assist communities where their own resources are insufficient but the prime responsibility should remain at the local level.

When we look back on the development of water supply and sanitation facilities in the United States of America we can see both the advantages and the disadvantages of a development stemming from local initiatives. We see an almost unprecedented development, sparked largely by local demand, financed by local bond issues, and until rather recently, largely independent of federal subsidy and control. We can see systems that undoubtedly worked, but often worked to the short-term and narrow interests of the local community. We can see a shocking disregard of the broader public interests as, for example, stream pollution. An earlier entrance of some degree of central control might have avoided many of the abuses which we in the U.S.A. are now seeking to correct at great expense. Can we not benefit from this experience and develop a proper blending of local and national authority which will bring the benefits peculiar to each and eliminate some of the defects found in the unbalanced use of either.

Insofar as the outcome of local operations remain limited to the locality and do not run counter to the public interest, it seems reasonable that responsibility for local operations remain in the community. Where construction and operation of water supply and sanitation facilities impinge upon the national development, the operations should be subject to some degree of national control and, in some circumstances, national participation. Where local resources and abilities are insufficient to cope with serious problems of public health and economic development, assistance from the national government is in the national interest.

Water for potable and industrial uses comes from the total water resource of the nation, and effluents from sewage treatment plants are discharged into the waterways; so water supply and sanitation form a part of the general pattern of water resource use. There has been a tendency, on the national level, to place water supply and sanitation under the control of a national water authority which has jurisdiction over all water uses. On review, this does not appear to be the best organizational procedure. Water supply for human consumption and sanitation works have many unique aspects which sharply differentiate them from other bulk use of the water resource, such as generation of hydro power and irrigation and recreational uses. The volume of water used for human consumption is minute compared to these other uses, but the importance of such water to the health and well-being of the community is inestimable. Volumes of sewage are not great in terms of national water resource but the effect of sewage effluents is out of proportion to their volume.

In national organization, a water supply and sanitation authority should be kept distinct from the operation of hydro-electric power and irrigation projects, although subject to the same considerations of water use policy. The activities of all national agencies dealing with water should come under the review of a water policy board, but this water policy board should have jurisdiction only in matters of water allocation between competing users. Beyond this point the national undertakings in the field of water supply and sanitation should be placed in the hands of a national water supply and sanitation authority, referred to hereinafter simply as the national authority. This national authority should have the full and sole responsibility for all national government activity in this field. The local government should retain the initiative and leadership for each local community.

THE NATIONAL AUTHORITY

The role of the National Authority should be limited to:

1. Consultant and co-ordinator for:
   - Planning on the national level
   - Adherence to national water use policy
   - Establishment of priorities in development
   - Use of national credit
2. Regulatory on:
   - Rates and rate structures
   - Standards of water quality
   - Pollution control
   - Technical and fiscal criteria
3. Service agency to provide:
   - Financial assistance
   - Professional engineering assistance
   - Operational and management guidance

The functions outlined above will be discussed briefly in the following paragraphs.

The problems of water supply and sanitation certainly deserve consideration in the general planning for any nation. The national water supply and sanitation authority would speak for all of the communities in the nation in the counsels of national planning. This is a highly important matter for often in the past sufficient emphasis has not been given to the problems of water supply and sanitation in long range planning. A representative of the national authority should also sit on the water use policy board which allocates water to the various uses of the nation and controls pollution of the water courses.

The national authority also, working in close liaison with the national planning board, should assign priorities in the directions indicated by the planned economic development of the country. This is a most effective tool but must be used with caution. The power granted to the national authority can be positive through the issuance or withholding of licenses and franchises, or it can be persuasive through the granting or withholding of credits or subsidies, the degree of power being a matter of national policy. In any case, the national authority acts to discourage uneconomic development and to encourage development to meet needs anticipated in the general economic planning for the nation. For example, in Uganda the National Planning Board envisioned a heavy industrial development in the city of Jinja. As a result, the national government took steps to use their national credit to accelerate the construction of water and sewerage facilities, anticipating the growth of the city and facilitating the realization of the plan.

The planning staff of the National Water Supply and Sanitation Authority would have the responsibility for preparation of long-range programs to serve as a guideline, in consultation with local authorities, in development of joint undertakings in appropriate situations and in the use of national credit or subsidies. These studies are designed to supplement, not replace the use of local initiative for development and the use of local staff, if it is available, for design. The National Authority can supply certain high level professional services which would ordinarily be beyond the scope of the individual community. The National Authority can foresee the need and encourage the development of water and sanitation districts which cut across political subdivision boundaries. It is not recommended, however, that the prime responsibility for the operation of such joint districts rests with the National Authority. It is to be preferred that the Board of Directors of joint districts have a majority representation from the component municipalities.

The most important and the most potent function of the National Authority would lie in its control of the use of the national credit to finance water supply and sanitation construction. Government might place at the disposal of the National Authority a revolving fund as a source of loans to municipalities. The authority might sponsor and monitor a program of suppliers credits to municipalities. Government might use the National Authority as its agency for loans from international banking institutions, which the authority would in turn lend to the municipalities. Also, the authority might serve as a central clearing house for the co-ordination of all bi-lateral assistance programs.

It is highly important that this planned development be kept up-to-date and responsive to the needs of the communities as well as to needs of the country as a whole. To accomplish this it would be necessary to have an annual review of the plan, with consultations and hearings at all of the important cities, towns and districts. Localities would present their proposed programs for inclusion in the national program and, where needed, they would make application for loan assistance from the National Authority. The National Authority would review these applications and the substantiating data and, where necessary, would supplement the application with studies of their own. Costs of such studies would be met from the budget of the National Authority or from such external sources as might be available. Should the projects materialize, the costs of the preliminary studies would be repayable from the project budget. In my view, these related functions of programming and credit extension are the strongest tools of the national agency and they can be used without undue interference with the local prerogatives of maintaining a self-supporting operation. It is essentially a consultation and co-ordination activity and does not exercie regulatory or executive powers, except through control of funds.

REGULATORY DIVISION

There are certain regulatory functions of the National Authority which should be exercised through a separate division of the authority. The regulatory division should exist to ensure that local water supply and sanitation utilities are operated in the broad public interest as they stem from public grants or franchises. Regulation would be exercised in two fields: compliance with standards of quality water supply, treatment of sewage and services to insure public health and avoidance of nuisance; and standards of fiscal responsibility to properly protect the investments and to prohibit excessive charges or inequitable rate structures.

The technical staff of this division would establish criteria suitable to the locality and the circumstances and provide for inspection and enforcement. In the case of the design of new facilities, enforcement of these standards would not be too difficult, particularly where financing is dependent in any degree on the National Authority. Any release of funds, either loans or grants, would be contingent upon a certificate of compliance from the regulatory division. In the case of new construction which is entirely financed from local sources the enforcement is more difficult. In the case of flagrant violations of reasonable standards, the division might impose a fine, get legal injunction, or as a final resort, take away the license or franchise. Cases of existing installations of substandard design or operation are more difficult to handle. They call for a combination of coercion to get the maximum local effort, coupled with an offer of assistance if the best local effort is still insufficient.

The problem of fiscal control is a very perplexing one. Loan covenants can be drawn to clearly spell out requirements for sound fiscal management, but what recourse is there should mismanagement or unforeseen circumstances bring about a potentially disastrous situation? If the National Authority has made a loan it may be burdened with a defaulting borrower. It is seldom that an outright forcelosure will bring about a good solution, in fact foreclosure might aggravate the situation. It might be more effective if the responsibility were left squarely on the doorstep of the local community. It would seem much better for the National Authority to have safeguards for repayment which do not involve the takeover of the operation. For instance, to cite the example of municipal bonding practice in the United States, the obligations are general obligations of the municipality, and in case of default in payments they constitute a lien against the properties in the municipality. There is no question of the bondowners taking over the operation, but the municipality is forced to either improve the operation or to make up the losses from other sources.

The regulatory division has a further responsibility to review the rate structures to ensure that the burden of costs is being fairly distributed among the consumers. This stems from the general principle that water charges are based primarily upon the volume of water consumed, with a secondary factor of provision of peaking capacity or availability of service (minimum charge). Approval of rate structures must be limited, in all probability, to situations where the National Authority has a financial interest in the undertaking, but it can be justified on the grounds of broad public interest.

PROJECTS DIVISION

We come now to the more positive areas of National Authority. That is providing assistance, in terms of money, rather than consultative or regulatory roles. This assistance is sometimes by means of technical and professional assistance, but more often by the provision of funds. There is a distinction between the major cities in many countries, which have already made a start on water supply and sanitation and in many cases have progressed quite far, and the smaller cities and towns and most particularly the rural regions, which are barely on the threshold of development. Larger cities need not be left out of the jurisdiction of the National Authority, but there is need for a different emphasis in working to meet the needs of the smaller communities and rural agencies. The larger cities have already established well-staffed engineering departments, their principal needs are money, and in some cases co-ordination of efforts with surrounding political units. The small town and rural situation is quite different. Here there is a shortage of trained personnel and inability to staff for the undertaking. Limited sources of trained manpower make it imperative to use the National Authority as a technical agency to carry out planning and design on a regional scale. Many advantages are apparent, design standards and practices can be adopted for general use, interchangeability of equipment and parts is possible, and economies can be realized through bulk purchases and a certain standardization of construction elements. It is only through a central engineering office that small towns and rural facilities can be designed with economy and contracted for construction advantageously. Therefore it is recommended that there be a projects division of the National Authority which will undertake the engineering design and award of contracts for construction for those municipalities which do not have their own engineering staff, and for areas or regions organized for the provision of water supply and sanitation facilities.

This project division would operate as a division of the National Authority, funded by a revolving fund but aimed at becoming self-supporting. The various towns or areas would be charged for engineering services as a part of the project cost. The projects division would be a service division supplying engineering services, but not involved in operation or finance. As a part of its activities it might provide training courses for plant operatives and present certificates for successful completion of such courses.

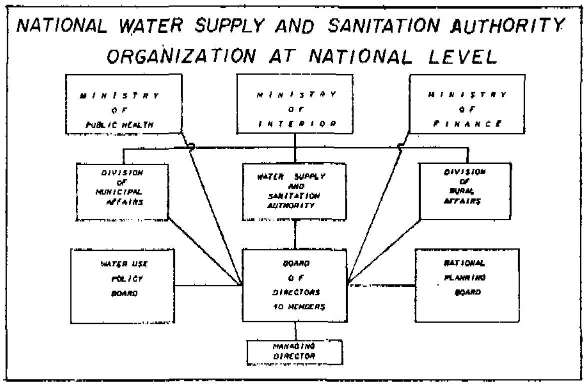
FINANCIAL ASSISTANCE

We now come to the crux of the matter, the provision of financial assistance from the national level to the local level. A fully self-supporting local system is the ideal we seek. However, we must face the reality that in the rapidly developing countries of Southeast Asia, the needs for water supplies and sanitation facilities far outstrip the present capabilities of the localities to finance. There is already too great a gap between the needs and the accomplishment, and it is intolerable to see this gap widen, as it will unless a strong effort is made at the national level. We must recognize that there are demands upon the national treasuries from every quarter. But this makes it all the more important that there be a National Authority for water supply and sanitation, to serve as advocate in the national counsels and to be the agency through which government funnels its financial assistance to water supply and sanitation projects. As discussed previously, much of this assistance can be in the form of bi-lateral aid, a revolving fund for project assistance, use of suppliers credits on a national scale and use of national credit with international lending agencies. In some cases the government must resort to outright grants and subsidies to accomplish urgent improvements required in the public interest but incapable of carrying a commercial type loan. In all of the above situations it is imperative to have a National Authority to act as intermediary, sponsor, or in some instances the executing agency. This does not imply that the National Authority should become the owner, operator or primary executive for the facility. In my view it is of paramount importance that the local people, who are the beneficiaries of the works, be recognized as the owners of the system and bear the primary responsibility for its proper operation. Although national financial resources are often necessary, and should be used where necessary, it would appear best that the national financial interest be that of a lender, rather than a shareholder. Where it is unavoidable that the national government have an equity, it would be preferable that the government equity be less than fifty percent.

ORGANIZATION

The organizational set-up of a National Authority and its interrelation with other national agencies and with the local owner-operator is of interest. The organization charts presented are purely hypothetical, presented merely to illustrate the relationships which might be desireable. In any particular national situation the organization would have to be tailored to fit the circumstances and pattern of existing organization.

Chart I illustrates the place of the national agency in the top governmental organization and its relations with other top-level government agencies.



The National Water Supply and Sanitation Authority might be placed in any one of several ministries, or might be an independent agency. Various ministries have claimed jurisdiction over water supply and sanitation, notably Public Health, Public Works, Water Resources and Interior. Choice will vary from country to country depending upon the characteristics of government. In my opinion, Public Works and Water Resources cover too broad a field to give proper emphasis to the problems of water supply and sanitation. On the other hand, Public Health is somewhat narrow in its concepts. I believe that as water supply and sanitation are primary concerns of municipalities, the National Authority for water supply and sanitation might well be placed in the Ministry of Interior. This ministry is normally responsible for governmental activities in relation to municipalities as well as development of regional interests. I think the essential thing is to have the authority placed where it will be in close contact with community activities both of urban and rural character.

The activities of the National Water Supply and Sanitation Authority are of interest to, and are influenced by four other governmental agencies. These are: The Ministry of Public Health, the Ministry of Finance, the Water Use Policy Board and the National Planning Board. Each of these agencies should have a representative on the Board of Directors of the National Authority. In turn, the National Authority should have its representative on the Water Use Policy Board and the National Planning Board.

Chart 2 illustrates the internal organization of the authority. Activities are placed with five major divisions, as follows:

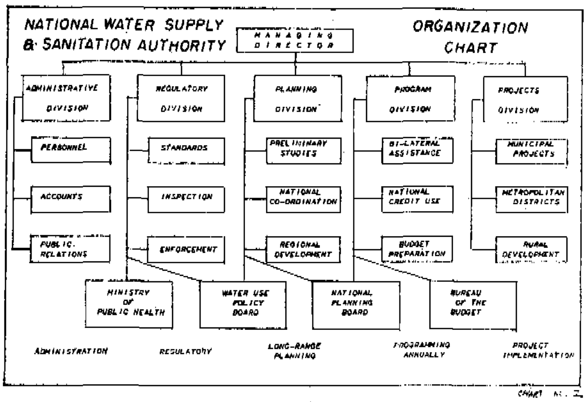


CHART NO. 2

1. Administrative

2. Regulatory—Operating in close co-operation with the Ministry of Public Health and the Water Use Policy Board, and having an engineering and fiscal staff to carry out its responsibilities.

3. Planning Division—The division would operate in close co-operation with the Water Use Policy Board and the National Planning Board. It would have an Engineering Staff and Economic Staff.

4. Program Division—The division would operate in close co-operation with local municipal authorities and representatives from the National Planning Board and the Ministry of Finance. There would be a small engineering section but the section would be comprised chiefly of economists and fiscal people.

5. Projects Division—The staff of this Division is primarily an engineering staff, and its functions will range from almost entirely review and consultative in the case of large municipalities to actual design in case of rural supplies. A training staff is attached to this Division.

As the relationship between the National Authority and the local organization is important, Chart 3 illustrates this relationship. Projects fall into four categories, as follows:

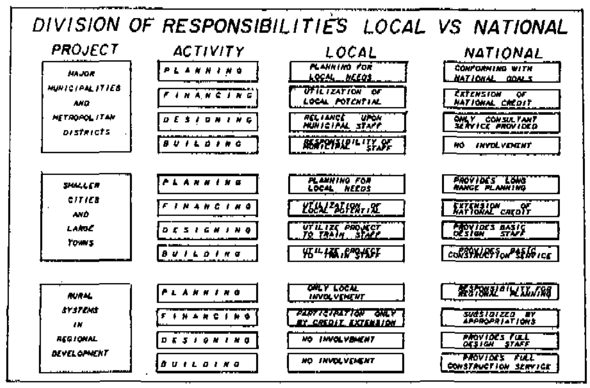


CHART NO. 3.

1. Virtually Independent, Municipally Owned and Operated Systems
2. Jointly Operated Metropolitan Districts
3. Small Projects Requiring Technical Assistance
4. Regional Operations Organized by the Authority

The major municipal systems in the first category primarily require financial assistance. They are usually competent to handle their own engineering design, with some assistance perhaps, on specialized problems. Implementation of the project should be left largely in the hands of the existing organization, but by reason of the financial involvement of the National Authority, it might have a representative on the local Board of Directors, and might retain the veto power on matters of disbursements from the loan or grant funds, and review powers on design standards.

In the second category of metropolitan districts which cross lines of political subdivisions, the National Authority can take the role of catalyst in organizing the districts. It might also provide consulting service, where the components lack such capabilities, or are reluctant to place these activities entirely in the hands of the single major municipality. The National Authority should be represented on the Board of Directors for the project, and the participating areas should have approximately proportionate representation. There will be many small localities which, in addition to financial assistance, will require a large part of their technical advice from the National Authority. The projects division should have a technical section to provide these services. In the fourth category of regional development of rural systems it is probable that the National Authority will have to continue to take the lead in organization, design and construction and quite possibly in operation. For this purpose the National Authority should de-centralize the rural operations into regional offices.

CONCLUSION

In conclusion, the goals we seek can be achieved only through a cooperative effort between national and local authority. We must look to national power and effort to give both technical assistance and financial assistance, but in the final analysis we must look to local ownership and operation to ensure the proper utilization of the facilities. Neither can succeed without the other, together they can do the job.

NEW DEVELOPMENTS

THE ENGINEER LOOKS AT THE COMPUTER AS AN AUTOMATIC DRAFTING TOOL

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Feeling somewhat as pioneers, our consulting engineering firm established in 1962 a data processing group to use whatever applicable programming was then available, and adapt it for use in the engineering of a large water supply project. Although the programming was far less sophisticated than that presently in use, and the rented equipment not nearly as efficient as current hardware, the net result was impressive. Following this achievement we obtained our own equipment, and set out to find new uses for the computer in the field of engineering. In our investigations we discovered many practical applications, the most significant of which is the use of the computer as an automatic drafting tool. The decision to look at this somewhat new application was based on the fact that an estimated 75 percent of the cost of plan preparation is in drafting. Electronic drafting could assume a significant share of this graphical representation work, hopefully resulting in better quality plans as well as savings in time and cost.

Our basic equipment consisted of an IBM 1,130 computer, 8-K with one disc, a line printer, card reader punch, keypunch machine, sorter, and a slow speed Cal-Comp 30 inch drum plotter. We have since doubled our core capacity to 16-K with one disc, and have recently ordered a second disk which will decrease our program running time and increase the versatility of the machine; we have added two keypunch machines and a new Zip-mode (high speed) flat bed plotter which is up to 8 times as fast as the old drum plotter, and we also have a borrowed Zip-Mode drum plotter for some specific applications. We plan to add to our equipment a relatively inexpensive television set that will allow us to show on a screen the compiled data prior to plotting. This will allow us to make changes or corrections without tying up precious minutes of plotter time. We are now using the plotter to plot on plan and profile sheets, ready for the designer, all field topographic data and ground profiles. Everything on this sheet including the lettering is drawn by the computer.

This procedure, while eliminating the major need for drafting personnel up to the design stage, introduced a problem in communication. In the past, draftsmen were familiar with extracting information from field notes that, in some cases, were not of the best quality (draftsmen understood what the note keeper was trying to say, or at least knew when to ask questions). However, with the new procedure the first person to see the notes is a keypunch operator, trained only to translate what she sees into a series of pre-programmed symbols and to give it a descriptive title. These are the basic symbols that are already in the program and are stored in the machine. The keypuncher's interpretation produced some surprising results at first, such as concrete parking bumpers appearing as concrete walls, etc. This problem was easily solved when we revised our field note-taking procedures to a specific format that helps the keypunch operator keep topographical items in order, while at the same time causing the field crew no undue difficulty. On projects without complex topographical items we have switched from the note system to the use of a dictaphone and have reduced the crew from three men to two. This system speeds up both field and keypunching operations. In either method, the field man is expected to review the completed drawing, in most cases by taking it into the field and comparing it with the actual site.

High quality is very important in any engineering work and certainly this is true of engineering drawings. Accurate, legible and neat drawings not only are necessary for official comprehension and approval, but for contractors who must use them to understand the project on which they are bidding. Such drawings also have public and client relations value, for often the eye influences the mind. An otherwise excellent engineering project can appear in a poor light if the lettering or line work is poorly done, actually casting suspicion upon the whole project. Staff engineers have rated the quality of our computer-produced drawings as superior, and have judged the quality by the uniformity of symbols and lettering. Legibility is of greater concern to most users than artistic rendering. Federal and some state and local governmental agencies have accepted computer drawings, have praised the quality, and in a few instances have flexed rules a little to accommodate machine produced drawings. Touch-ups by hand may be needed, but currently there is little handwork required. Continuing research and experimentation keeps reducing this.

We are now training our draftsmen as programmers with these satisfactory results: their positions have been improved; they feel they are contributing to the modern age of technology instead of becoming obsolete; and they are continually coming up with new ideas for use of the computer. One of our newest trainees suggested that since the computer has the information as to the location and first floor elevation of the houses, it might be possible to ask it for the sewer elevations required to pick up house leads. A simple program change was made and the designer now has a visual aid to design. This change eliminates a lot of routine work otherwise necessary in preliminary design stages.

Standard detail sheets can be stored in the computer, and the various details for a particular job can be called out and drawn automatically, thus eliminating the "patched up" sheet made from sepias and other sources. They can be made to conform to the balance of the plans automatically, and there is no longer a need to include detail sheets with many details that are not applicable to the project being designed.

We are developing a paint spray booth by contract with a manufacturer. These booths are made up of standard component parts and the number and kind of these parts which must be assembled into a workable unit depends on the job to be done. The program is being designed to take from the salesman's order book the parts list and configuration and instruct the computer to make the standard shop drawing, parts list and *cost estimate.* Upon instructions the computer can produce an isometric drawing automatically, and from stored information at any angle desired, of the completed unit.

The advantages to computerization in this case are so great as to be almost unbelievable. For example, hundreds of manhours now required to produce a proposal can now be replaced by minutes of computer time. Another significant factor is the ease with which changes could be made in the system, and a complete set of revised drawings obtained. Other graphic applications now being used by our office include plotting of soil borings as a part of the contract drawings.

Some applications which we can visualize, but have not started developing, include a program for updating maps such as conservation maps which show features which change frequently. We believe that base maps could be stored in the computer rather than on tracings. A system of updating could be developed to automatically produce corrected maps within a matter of minutes. We did not originate this idea; the Wisconsin State Highway Department update their maps by use of aerial photographs, a digitizer and a plotter.

Other applications relate to engineering practice. The computer tabulates bids by automatically verifying all mathematics of all contractors bidding on a particular job. The basic line items and quantities are fed to the machine at one time, and the unit prices of all contractors are then entered. The resultant bid tab is then condensed to a summary tab with totals of each bidder in ascending order.

All of our standard specifications have been stored in the computer for retrieval when needed. Corrections are easily made when required and we have eliminated an age-old problem of a designer using an outdated specification.

We have demonstrated some of the applications we have made of the computer plotter; we feel we have only just begun. We hope other engineers will join us in broadening the field of engineering applications, finding new ways to make use of the tools available to us to design better facilities at less cost.

FEASIBILITY OF DESALINATION FOR WATER SUPPLY

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It is proper and desirable that all available alternatives for water supply be considered, including the alternatives that are becoming available through the development of new technology. The desalting process is such an alternative, as a source of fresh water or for improving the quality of existing supplies. Desalting is not a panacea for all water ills, but the cost of producing fresh water from saline sources has been reduced to the point where water supply planners should consider its utilization. Desalting will not offer an economically competitive solution to many water supply problems but its potential should not be ignored.

The problems of providing an adequate water supply of acceptable quality are not limited to the Asian region. It is readily apparent that water problems in one form or another touch every nation in the world. In some areas it is a problem of availability, in others of salinity or quality; it may be a problem of maldistribution, of pollution control, or in some cases of excess. Regardless of the cause, at a time when world population has passed the 3.5 billion mark, no nation can continue to regard with parochial indifference the increasing imbalance between the supply and demand for water.

Several years ago, Paul Hoffman, the Managing Director of the United Nations Special Fund, reported the following:

> "At least 60 of the 100 underdeveloped countries and territories associated with the United Nations face forms of water shortage which in time can be met only from nontraditional sources; that is, from brackish and salt water sources."

By quoting Mr. Hoffman's statement, we do not want to imply that water supply problems are limited to underdeveloped countries, for virtually every nation faces grave challenges to assure the adequacy of present and future supplies of fresh water. As an example of our growing concern about water, just a month ago, eighty-two Representatives to the Congress of the United States joined in a call for an "Environmental Decade." Recommending that the 1970's be designated as the Environmental Decade, they suggested it would be a proper time for all Americans to make the following resolution:

> "I pledge that I shall work to identify and overcome all that degrades our earth, our skies, our water, and the living things therein, so that the end of the Environmental Decade of the 1970's may see our environment immeasurably better than at the beginning."

That same resolution is appropriate for every person attending this seminar and for the people of the Nations which you represent.

THE FEASIBILITY OF DESALINATION FOR WATER SUPPLY

The word "feasibility" implies the consideration of the cost of desalted water as compared to other sources of supply. But considerations other than cost must also be carefully evaluated. For example, in an area where rainfall is seasonal and yearly averages fluctuate widely, is it reasonable to construct huge reservoirs at great investment to assure an adequate supply of water for a drought that may occur only once in a decade, or would it be better to have a standby desalting plant to meet emergency requirements? In answer to that question, I believe we must not only consider cost, we also must consider the reliability of the source of supply, and the volume of water required. Another important part of any feasibility study:

what is the quality of the water available from natural sources of supply? Desalting plants produce high quality water which, while it may cost more, is worth more. In summary, desalting plants give man the opportunity to produce the quantity of water he requires, when he requires it, and at a location of his own choosing. We think these are major advantages offered by desalting plants which water planners should be aware of as they work to develop solutions to water supply problems.

The preface of a bill that was enacted by the Congress of the United States in 1952 reads as follows:

> "In view of the acute shortage of water in the arid areas of the Nation and *elsewhere* and the excessive use of underground waters throughout the Nation, it is the policy of the Congress to provide for the development of practicable low-cost means of producing from sea water, or from other saline waters, water of a quality suitable for agriculture, industrial, municipal, and other beneficial consumptive uses on a scale sufficient to determine the feasibility of the development of such production and distribution on a large-scale basis, for the purpose of conserving and increasing the water resources of the Nation."

The enactment of this legislation marked a turning point in the development of desalting processes. Up to 1952, desalination was considered to be the primary concern of navies and the maritime industry to provide fresh water for ships and crews at sea. There were, at that time, a few small land-based desalting plants located in some of the remote and very arid areas of the world. To work toward the development of large land-based plants to produce fresh water from the sea was a new and exciting concept. To advance desalting technology, the United States Government, through the Office of Saline Water (OSW), has invested more than $200 million. During the current fiscal year alone, we will spend $25 million to carry on research and development activities.

PROGRESS IN DESALINATION

Rewarding progress has been achieved since 1952. The cost of desalting has been sharply reduced. In 1952 it cost upwards of US $4 to produce 1,000 gallons of fresh water from sea water. Today, desalting plants of 1 million gpd are producing fresh water from sea water for about $1 per 1,000 gallons. Plants of 2.5 million gpd are reporting production at a cost of 80c-90c per 1,000 gallons and a new 7.5 million gpd plant in Mexico is expected to produce fresh water for about 65c per 1,000 gallons. In areas where low-cost fossil fuel is available, such as in Kuwait or Saudi Arabia, even lower costs in the same size ranges are being achieved. A new 1.2 million gpd brackish water desalting plant in the U.S. is reporting product water costs of 35c per 1,000 gallons.

Another measure of the progress that has been achieved in desalination is its acceptance as a viable water supply tool. An inventory of desalting plants compiled by OSW reveals that there are now in operation or under construction about 700 desalting plants producing approximately 300 million gallons of fresh water per day. We now estimate, by 1975, world-wide desalting capacity will exceed 1 billion gallons per day. This rapid application of desalting technology is a realistic indication of the feasibility of desalination for water supply.

In the Asian region there are 24 desalting plants in operation: 7 in India, including one on Andaman Island; 3 in Indonesia; 3 in the Phillippine Islands; 2 in Pakistan; 4 in Japan; 1 in South Korea; and 4 in Polynesia (Fr.). These plants range in size from 25,000 gpd up to 700,000 gpd, with a combined total production of more than 3 million gpd. Last month, Esso Standard announced the award of a contract for a 275,000 gpd desalting plant to be constructed at Sriracha, Thailand. It is designed to provide boiler feedwater, fresh processed water and potable water necessary for operation of an asphalt plant. This is an excellent example of how industrial development is being initiated or expanded through the availability of desalted water.

The Office of Saline Water is supporting the development of a number of new or improved desalting processes. Virtually all of the sea water conversion desalting plants in operation today use a distillation cycle, and the specific process that currently is being most widely used is multi-stage flash distillation. At San Diego, California, we have a module of a 50 million gpd multi-stage flash plant. A module is a slice or a portion of a full size plant. The module has a product water capacity of 2.6 million gpd, but it is providing us with design, construction and operating data for a 50 million gpd plant, and thus is enabling us to bridge the technological gap between the plants of 1-10 million gpd that are in existence today and the multi-million gallons per day plants we anticipate will be constructed in the near future. We are interested in providing the technology for the construction of very large desalting plants for two reasons: first, because we are convinced that many areas of the world will require huge volumes of desalted water to meet the increasing demands of growing populations and expanding industry; and second, because our studies indicate that as we go up in size we will be able to further bring down the cost of desalted water.

Results of the research and development activities conducted by the Office of Saline Water are available to any nation that wishes them. We currently are sending, without charge, a copy of every Research and Development Progress Report published by the Office of Saline Water to Bombay, New Delhi, Taipei, Karachi and Manila. We would be glad to extend this list on Official request from individual governments if they are not now receiving these reports and are interested in obtaining them.

CONCLUSION

In conclusion, desalting is not some hoped-for potential source of water to meet future water supply problems. It is here and now technology. It is reliable. It has demonstrated that it is economically feasible in many areas of the world. It offers flexibility in water supply programming. It provides high quality water. It is available to provide an alternate source of supply for cities and industries.

REVERSE OSMOSIS DESALINATION PROCESS AS A VILLAGE WATER SUPPLY SYSTEM

K. CHANNABASAPPA

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The reverse osmosis desalination process has the potential to provide the water supply needs of villages and towns that are the backbones of all Asian nations. The process offers simplicity and can be operated with any locally available energy source. The equipment can be manufactured locally with technical assistance from the U.S. or other countries. Since the welfare and public safety of these villages is so vital to the stability and economic growth of Asian nations, it is imperative that we give serious consideration to desalination technology as an expedient means of providing village water supplies.

PRESENT STATUS OF THE VILLAGE WATER SUPPLY

Over 90 to 95% of the Asian population (except perhaps in Japan and a few other countries) live in small villages, and nearly 60 to 80% of these villages do not have adequate water supplies of potable quality (i.e. water low in mineral content and free from bacterial contamination). In many villages, the only available water supply source is a stagnant pool, a shallow pond, an irrigation ditch, or a shallow brackish well. Most often, the same water supply source is used for drinking, bathing, washing clothes, cleaning animals, and other miscellaneous purposes. Due to this unrestricted use, the water is generally of poor quality and is highly contaminated with bacteria and viruses. The use of such waters for drinking has been the major cause of high infant mortality rates and epidemic diseases.

Another difficulty is the unavailability of adequate surface water supplies throughout the year. Though many regions of Asia receive adequate rainfall, it is seasonal. Because of the lack of adequate surface reservoirs, underground storage facilities, and other flood control measures, many parts of Asia suffer from severe floods during the rainy season and from droughts in the dry season. In dry periods, the villagers haul water for several kilometers for household use. Livestock are often moved to water sources in order to take care of their needs. Typical examples of this situation are found in Northeastern Thailand, in the Mekong Delta in South Vietnam, and along the west coast of India. In the Mekong Delta, the problem is very acute. South Vietnam has a total population of approximately 14 millions. Nearly 10 million of this population live in the delta, and for six months of the year (November to May) the villagers suffer from a serious shortage of potable water. They pay up to US$2 for 1 cubic meter of potable water.

In most of these regions, even the ground water is brackish. This is particularly true of shallow ground waters. A major reason for the high salinity of ground water is that during the rainy season, the agricultural lands become flooded, and due to lack of subsurface drainage systems, the soils become waterlogged. The flood waters during their downward movement to underground areas become enriched with salts by soil leaching. Often the salinity of the groundwater increases with depth. In some locations, fresh water aquifers have been found at shallow depths but they are generally small in size. Thicker aquifers extending over relatively large areas may be found at greater depths but their location requires a detailed investigation of the underground geology and hydrology. Such a study would involve extensive geological mapping and drilling, and monitoring of water quality and quantity. It would also require large capital investment, and manpower utilization. Since the economic and technical resources of many developing nations are somewhat limited, the development of information on reliable underground water resources would probably take 10-20 years to complete. In the meantime, it is necessary to adopt other means to provide village water supplies. The problem is urgent and the need for a practical solution is obvious.

An approach that appears to have great potential as an immediate solution to the village water supply problem is the utilization of membrane desalination processes for conversion of brackish waters to potable waters. As mentioned previously, large quantities of brackish ground waters are readily available at shallow depths in many water shortage areas. Engineering and development work conducted to date in the United States have clearly indicated that membrane processes are very economical for brackish water conversion.

MEMBRANE PROCESSES

Two membrane desalination processes have been proven to be economical for conversion of brackish waters to potable waters. These are: (i) electrodialysis and (ii) reverse osmosis. Both of these processes permit salt removal from saline solutions without a phase change; i.e. unlike distillation, which is also a desalination process, the pure water in the saline solution does not undergo phase changes from liquid to vapor and back to liquid. In addition to ambient temperature operation, the membrane processes offer other additional advantages. These include:

1. Large metallic components such as copper heat exchanger bundles are not required,
2. High capital investment equipment such as tube rolling and milling machines are not needed,
3. Capital and operating costs for the small membrane plants are about 50% of those for distillation plants,
4. Membrane process equipment can be manufactured with local materials and manpower (less dependency on foreign imports),
5. Membrane plants are simple to construct and operate,
6. No corrosion or scale problems.

In both electrodialysis and reverse osmosis processes, thin plastic films called membranes are employed to achieve salt removal from saline solutions. The electrodialysis membranes can be prepared from a mixture of ion exchange resins and a polymeric binder while the reverse osmosis membranes are usually prepared from cellulose acetate-acetone-formamide solutions. The major difference between electrodialysis and reverse osmosis processes is that in electrodialysis, electric potential is used as the driving force to remove salt from the saline solution, whereas in reverse osmosis, hydraulic pressure is used as the driving force.

Though both electrodialysis and reverse osmosis processes are equally applicable and economical for conversion of brackish waters to potable waters, reverse osmosis appears to be better suited as a village water supply system. The process is simple to operate and does not require electricity directly. The only requirement for reverse osmosis operation is an energy source to drive a high pressure pump. This energy source could be steam, electricity, or even animal power. Advantages of the reverse osmosis process over the electrodialysis process include:

1. Lower energy consumption,
2. Removal of bacteria and viruses is complete,
3. The process is not too sensitive to the salinity changes in brackish water,
4. Low maintenance requirement (except for high pressure pump),
5. Highly skilled operators are not required for plant operation.

DESCRIPTION OF REVERSE OSMOSIS PROCESS

When pure water and a salt solution are on opposite sides of a semi-permeable membrane, the pure water diffuses through the membrane and dilutes the salt solution. This phenomenon is known as osmosis. Because of the difference in salt concentration, pure water flows through the membrane as though a pressure were being applied to it. The effective driving force causing the flow is called osmotic pressure. The magnitude of the osmotic pressure depends on the concentration of the salt solution and the temperature of the water. By exerting pressure on the salt solution, the osmosis process can be reversed. When the pressure on the salt solution is greater than the osmotic pressure, fresh water diffuses through the membrane in the opposite direction to normal osmotic flow.

Figure 1 is a schematic diagram of the reverse osmosis process operating on a brackish or saline

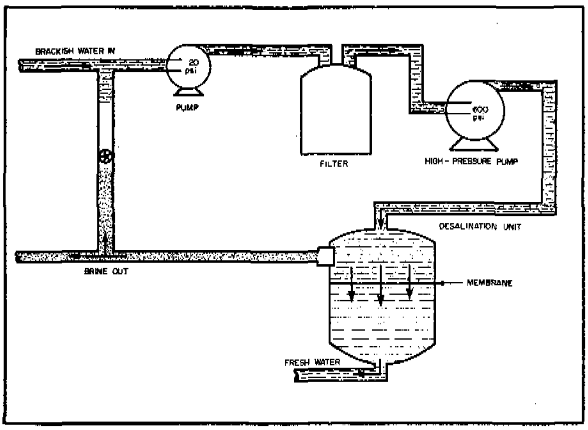

Fig. 1 — Schematic Diagram of the Reverse-Osmosis Process.

water. The salt water is first pumped through a filter where suspended solids that would damage the membrane are removed. The salt water is then raised to the operating pressure by a high pressure pump and introduced into the desalination unit. Fresh water permeates through the membranes and is collected at the bottom of the unit. Brine is discharged at the top of the unit. When desired, some of the brine may be mixed with incoming saline water and recirculated.

It can be readily seen in Figure 1 that the most important component of the reverse osmosis process is the membrane. However, it is also obvious that the membrane alone cannot serve as an operational desalination unit. The membrane is very thin (4 to 6 mils) and has to be supported on a material that is capable of withstanding the high hydraulic pressures required for reverse osmosis. These pressures range from 600 psig for brackish water operation to 1,500 psig for seawater operation. To date, four different configurations of membrane-support systems have been developed. These include plate-and-frame, tubular, spiral, and hollow fine fiber:

Plate-and-Frame: This design is similar to that of a conventional filter press. The membranes are mounted on both sides of solid, reinforced epoxy plates into which product water channels have been cut. A large number of these plates are alternated with brine feeding frames and the entire array is housed in a pressure vessel.

Spiral Wound: The module essentially consists of a number of membrane envelopes, each having two layers of membrane separated by a porous, incompressible backing material. These envelopes, together with brine side spacer screens are wound around a water collection tube. The modules are housed in carbon steel pipes lined with corrosion resistant coatings. The pressurized brine flows axially along the brine side spacer screen; pure water flows through the membrane into the porous backing material and then to the central product collection tube.

Tubular: The tubular design combines two functions in one in that it uses the surface of the tube as a support for the membrane and the tube wall as a pressure vessel. Normally, the membrane is placed on the inner wall of the tube, and the salt water, under pressure, flows inside the tube. Product water passes through the membrane to the tube wall, where arrangements are made to transfer the product water, now at low pressure, to the outside of the tube. This may be done by using a tube which is porous over its full length, thereby permitting direct flow of the product water to the outside of the tube. When a solid tube is employed, small holes are drilled at intervals along the tube, and a porous fabric material is placed between the membrane and the pressure tube to provide a path for the product water to the outlet ports. Figure 2 illustrates the operation of a tubular design reverse osmosis system.

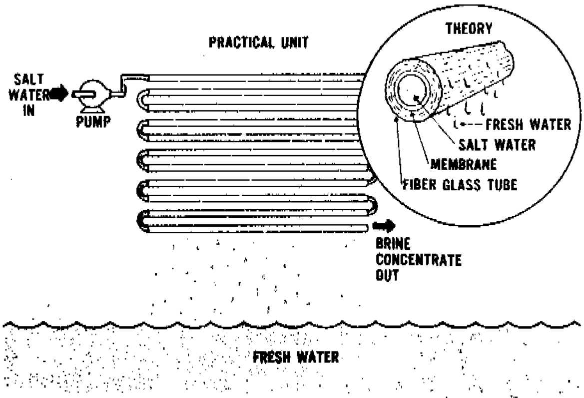

Fig. 2— An Illustration of Tubular Reverse Osmosis.

Hollow Fiber: Modern technology has made possible the preparation of reverse osmosis membranes in the form of fibers. These fibers are hollow and range in diameter from 50 to 200 microns (approximately 0.002 to 0.01 inch). Since they can withstand very high pressures, the fibers function both as desalination barriers and as pressure containers. In an operating hollow-fiber reverse osmosis unit, the fibers are placed in a pressure vessel with one end sealed and the other end open to a product water manifold. The salt water, under pressure, flows on the outside of the fibers, and the product water flows inside the fibers to the open end where it is collected outside the vessel as shown in Figure 3.

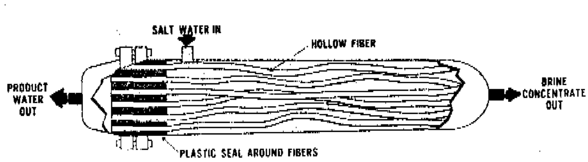

Fig. 3— Illustration of Hollow Fiber Reverse Osmosis Process.

At the present time, plants of all the above described designs have been built and tested on a number of natural brackish waters. Typical results obtained in these tests are shown in Table 1.

For developing nations, the reverse osmosis process offers a unique potential as a village water supply system. As stated previously, the process equipment is simple to construct and only a limited number of components are needed to construct an operational unit. These components can be readily manufactured locally with existing manufacturing facilities. The major components required for reverse osmosis equipment construction are:

1. Membrane,
2. Membrane support,
3. High pressure pump,
4. Standard filters and plumbing materials.

For membrane preparation, only three chemicals are required: cellulose diacetate, acetone, and formamide. The last two chemicals are available in most Asian countries and cellulose diacetate can either be imported or manufactured locally with very little capital investment. Any material that can withstand hydraulic pressures of 600 to 800 psi can be employed as membrane supports. As an example, 0.5 inch diameter, 1/8″ thick plastic tubes of sufficient mechanical strength, or 0.5 inch diameter porous fiber glass tubes, or copper tubing can be used as membrane supports. Since the plastic industry is very well developed in many Asian nations, the manufacture of plastic tubes suitable for reverse osmosis operation is not considered difficult. Low to medium pressure pumps are presently being manufactured in India, Pakistan, Korea, Singapore and other developing nations and, with the import of some machinery from abroad, the present manufacturing facilities can be tooled to produce higher pressure pumps. The filters and the plumbing materials required for reverse osmosis equipment construction are similar to those presently used in water treatment plants.

VILLAGE WATER SUPPLY REQUIREMENTS

There is a wide variation in the fresh water needs of villages. They are dependent upon climatic

Table 1 — Brackish Water Conversion to Potable Water by Reverse Osmosis Process (Chemical Analyses in Parts per Million)

Constituent	Brackish Water Feed	Potable Water	Waste
pH	6.7	5.3	6.8
Total Dissolved Solids	5,170	320	20,600
Total Hardness as $CaCO_3$	1,880	20	7,350
Ca^{+2}	360	7.6	1,400
Mg^{+2}	240	0.5	940
Na^{+}	900	110	3,400
K^{+}	26	3.8	91
HCO_3^{-}	340	12	1,150
SO_4^{-2}	630	0	2,580
Cl^{-}	2,020	170	7,850
NO_3^{-}	0.5	0.26	3.3
BO_3^{-}	0.3	0.22	0.53
SiO_2	34	76	120
Total Iron	6.5	0.12	24
Total Manganese	3.8	0	16
Total Phosphate	10.0	0.18	40
Total Alkalinity	280	10	940

Operating Pressure - 600 psig
Product Recovery - 75 %

conditions, location of the village, availability of other supplementary water sources for livestock, washing clothes, etc., number and type of small scale industries located near the villages, and local customs. Broadly, they range from 7 gallons per capita per day to 25 gallons per capita per day.

REVERSE OSMOSIS PROCESS ECONOMICS

The capital, operating and product water costs in U.S. currency for 0.1, 0.5, 1.0, and 10 mgd are given in Table 2. Product water costs for 10 gallons in local currencies are also listed in Table 2. Assuming an average per capita requirement of 15-20 gallons per day, a 100,000 gpd reverse osmosis plant is sufficient to provide all the water supply needs of a village with a population of 5,000 and some small industrial installations such as a sawmill or a leather factory. The 1 million gallon per day plant will supply the water needs of 40,000 to 50,000 people and will also support a number of small to medium sized industries.

CONCLUSIONS

The problem of providing reliable and adequate village water supplies throughout the year in Asian and Middle Eastern countries is a difficult one and requires a long-range program for a complete solution. The rainfall is seasonal and many countries do not have adequate capital resources and trained manpower to construct surface and underground storage reservoirs, dams, and other flood control measures to store rain water for use in the

Table 2 — Cost of Brackish Water Conversion by Reverse Osmosis Process (Basis: 3,000 ppm Brackish Water Reduced to 500 ppm Water; Amortization Rate 5.25% per Year; 0.07 mil/kwh Power; 25 cents/ft^2 Membrane)

Plant Size, Capacity in Mgd	0.1	0.5	1.0	10.0
Plant Capital Cost	US $ 108,400	US $ 335,400	US $ 462,000	US $ 3,250,000
Annual Operating Cost (Includes Capital Cost Amortization Over 30 Years)	US $ 28,380	US $ 99,330	US $141,900	US $1,056,000
Product Water Cost				
UNITED STATES, Cents/10 Gallons*	0.86	0.60	0.43	0.32
THAILAND, Satangs	18	13	9	7
S. VIET NAM, Cents	101	71	51	38
S. KOREA, Won	2.5	1.8	1.3	0.93
INDIA, Nayapaisa	6.5	4.5	3.2	2.4
INDONESIA, Rupiah	2.8	2.0	1.4	1.0
JORDAN, Pils	3.1	2.2	1.5	1.1
ISRAEL, Agorot	0.25	0.17	0.12	0.09

*Water Distribution Costs are not Included.

dry season. The water in existing reservoirs is generally of poor quality and is often contaminated with bacteria and viruses. Utilization of such waters for drinking has been the major cause of epidemic diseases.

In most of these water-short areas, there are ample supplies of brackish ground water. By the use of the reverse osmosis desalination process, these brackish waters can be readily converted to fresh water supplies of potable quality. The process is very economical and produces water free of bacteria and viruses. Process equipment can be built and operated with local materials and manpower. The per capita water requirement in villages ranges from 10 to 20 U.S. gallons per day. Based on this demand, reverse osmosis plants of less than 100,000 gpd capacity will be adequate to meet the water needs of most villages. The capital and operating costs of these small size plants are small and the cost of fresh water from these plants is believed to be within the economic reach of the villagers.

Large size reverse osmosis plants from 1 to 10 mgd capacity may be considered for augmenting the existing water supplies of large cities. The economics of constructing large reverse osmosis plants should be compared with other available alternative methods such as construction of new reservoirs and long distance transportation by pipeline.

RESEARCH AND DEVELOPMENT OF NEW TECHNOLOGY

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This paper examines in some detail the research programs of the Federal Water Pollution Control Administration (FWPCA), the Office of Saline Water (OSW), and the Office of Water Resources Research (OWRR), agencies that carry out about 80 percent of the research on new techniques to provide large additional sources of pure water.

THE FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

The Federal Water Pollution Control Administration (now the Federal Water Quality Administration) conducts the single largest water research program in the United States to develop new and improved methods for controlling water pollution in the following three areas:

1. A storm and combined sewer program provides grants to states, municipalities, or intermunicipal or interstate agencies for developing new or improved methods for controlling wastes for sewers carrying storm and/or sewage wastes. The Federal share may be up to 75 percent of the project cost.
2. Grants may be made to any State, municipality, or intermunicipal or interstate agency to assist in development of projects to demonstrate advanced waste treatment and water purification methods or new or improved methods of joint treatment systems for municipal and industrial wastes.
3. Grants are available to persons for research and demonstration projects for prevention of pollution by industry, including, but not limited to, treatment of industrial wastes; methods are to have industry-wide application. Grants may not be in excess of $1 million, or 70 percent of cost.

Twenty million dollars have been authorized for each of the above three areas for each fiscal year beginning with 1967, or $60 million total research money each year since then.

In addition, FWPCA conducts its own in-house research program to develop improved technology for water pollution control. The need for such technology becomes strikingly evident when one examines the amount and complexity of wastes produced by modern industrial establishments, the difficult problems posed by agricultural runoff or acid mine drainage wastes, or those problems concerned with removing troublesome nutrients found in the effluent of even efficiently operated waste treatment plants. The FWPCA is developing technology to foster water reuse. This program, now at the pilot plant stage, appears to have a good possibility of developing techniques that will permit the direct, deliberate reuse of waste water at a quality often better than that which comes from the taps in a large number of American cities. Most of the FWPCA in-house research is being carried out at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio. In addition, the creation of a nationwide system of field laboratories and research facilities is under way as outlined in the appended Table.

FWPCA's total research, development, and demonstration program including both grants and in-house research, may be sub-divided into eight major programs. Five of these programs are focused on particular sources of pollution, e.g., municipal, industrial, agricultural, etc., with the objective being to develop, experimentally apply, optimize, and then demonstrate practical methods for control of pollution from these sources. The remaining three programs relate to assessment, evaluation, control, and prevention of pollution from multiple sources.

The activities under these programs may be categorized as follows:

1. *Municipal Pollution Control* research involves the effective and economical control of pollution from sewered wastes, storm and combined sewers, non-sewered wastes, storm runoff, and joint (municipal-industrial) wastes. Strong emphasis is placed on developing and demonstrating new and improved methods for the treatment of sewered wastes since this is one of the country's major problems. For non-sewered wastes, the objective is the development of improved treatment devices for individual homes and isolated groups of homes or institutions, etc. Special efforts are also being made to demonstrate the technology necessary to permit joint processing of industrial and municipal wastes for greater economy and efficiency than independent handling of these wastes can achieve.

2. *Industrial Pollution Control* research is being carried out for such industries as those producing metals and metal products, chemicals, paper, petroleum and coal products, food, textiles, etc.

3. *Waste Treatment and Ultimate Disposal Technology* covers the renovation of wastewaters for reuse. It is now technically possible to achieve almost any degree of waste treatment desired and to return wastewater to a quality at least as high as it was before use. However, considerable work remains to be done to achieve this degree of treatment at any necessary location, under any conditions, and at minimum cost.

4. *Water Quality Control* research is directed toward the prevention and control of accelerated eutrophication, thermal pollution, the control of pollution by means other than waste treatment, the socio-economic, legal and institutional aspects of pollution, the assessment and control of pollution in extremely cold climates and the identification, source, and fate of pollutants in surface, ground and coastal waters.

The fertilization of waters has accelerated in recent years due to the nutrient loads imposed by increased quantities of municipal and industrial wastes and land runoff. The basic mechanisms involved in lake eutrophication are not well understood. Controlling it calls for study of the biology and chemistry of the aquatic environment, more complete analytical data on nitrogen and phosphorus compounds, and research on new and improved methods for nutrient removal in waste treatment.

Mathematical models need to be evolved to relate pollution levels to the broad range of effects expressed in social and economic values. Research applicable to multiple sources of pollution must be expanded. This includes identification and characterization of pollutants, methodology for detecting and quantifying pollution sources, and determining the fate of pollutants as they move through the water environment, all essential to effective pollution control.

5. *Water Quality Requirements* research is needed to provide an improved scientific basis for determining the water quality necessary for municipal, industrial, agricultural, and recreational uses, and for the propagation of fish and other aquatic life. This information is essential to the establishment and refinement of the Nation's water quality standards. Because of the tremendous number of new chemical compounds being synthesized and finding their way into our environment, intensive research investigations must be conducted to develop a predictive capability allowing us to project the potential pollutional impact of these compounds in advance.

Far too little is known about the effects of pollution. Drastic effects, such as massive fish kills, can easily be recognized, but quite often the true cause of such events cannot be defined. There is also the challenge of detecting, understanding, and preventing the more subtle, long-term effects of pollution. These effects, as yet unknown, may be just as dangerous as the sudden fish kill, the unpalatable water supply or the condemned bathing beach.

6. *Mining-Pollution Control Technology* concerns the areas of mine drainage, oil production, phosphate mining and other sources of mining pollution.

An estimated four million tons of acid from mines discharge into more than 4,000 miles of streams. Attempts to prevent or reduce such drainage have failed thus far due to high costs.

7. *Agricultural Pollution Control* problems include nutrients, pesticides, silt from runoff, salts and other pollutants in irrigation return flows, BOD runoff from animal feedlots, and silt and other solids from logging and forestry operations.

Many of these wastes are not "collectable" and, therefore, not capable of being given waste treatment in conventional fashion. New and imaginative solutions are needed for these problems. Of particular concern at present are the nutrients and pesticides being flushed into our streams and lakes as agricultural runoff and the tremendous load of animal wastes discharged from a rapidly growing number of animal feed lots.

8. *Other Sources of Pollution Control Technology* include recreational boats and commercial vessels, construction projects, impoundments, saltwater intrusion, natural pollution, dredging and landfill operations, and the whole area referred to as "oil pollution."

Increasing amounts of wastes are discharged from the evergrowing number of recreational and commercial vessels which ply our waters, both inland and coastal. Suitable on-board equipment for properly treating vessel wastes before discharge is not fully developed.

Construction activities that affect the quality of water are housing developments, roads, railroads, power transmission lines, etc. The polluting substances likely to enter streams during and after construction include silt, chemicals, oil, gasoline, and sanitary wastes from construction camps.

Saltwater intrusion is a growing groundwater pollution problem in coastal areas. One solution now being researched involves recharging the aquifers with renovated waste water.

Water impounded in reservoirs can be used to alleviate pollution through flow augmentation. Unfortunately, the storage of water in reservoirs can adversely affect its quality. Thermal stratification can occur, leading to chemical stratification as well. New techniques are being searched to accomplish artificial destratification of impoundments to alleviate these problems. Both short-term and long-term solutions for the important problems of pollution from dredging operations and oil pollution are urgently needed.

THE OFFICE OF SALINE WATER

A second major research and development program in the area of water resources is that which is being carried out by the Office of Saline Water, which may best be examined by looking at the research being carried out in its various administrative entities. The branch of the department entitled *Research* covers basic research, with applied research being carried out in the other branches.

Within the Research branch, the Chemical Physics Division is concerned with the development of more fundamental knowledge about the factors in desalination, especially problems associated with interfacial phenomena. Some of the more interesting programs of this division are as follows :

1. transport properties of aqueous electrolyte solutions,
2. water structure research,
3. thermodynamic properties of large ions in solution,
4. relaxation phenomena in electrolytic solutions,
5. ion hydration and ion interaction,
6. water-membrane interactions,
7. electro-chemical studies of electrode reactions.

The Chemistry Division sponsors studies of water and aqueous solutions, ion-ion and ion-solvent interactions, thermodynamic and transport properties of solutions, interactions at phase interfaces, nucleation and precipitation, selective removal of ions, and improved analytical procedures.

The objectives of the Polymer and Biophysics Division are two-fold: (i) development of new and improved membranes for current membrane processes; and (ii) development of new membrane processes for the purification of various chemically charged waters. The approaches used to attain these objectives include: screening of new and and solute permeabilities in the absence and presence of various driving forces for the separation of dissolved solutes from water; development of correlations between polymer structures and their transport properties for the design of new and improved polymers for membrane separations; development of concepts and techniques for the conversion of promising polymers into useful and efficient membrane-separation systems; laboratory testing and evaluation of the desalination performance of such membranes on various synthetic and natural saline waters; and studies of various membrane-separation phenomena, including those involving living membrane systems. The current program may be divided into five areas of research: (1) reverse osmosis, (2) pressure dialysis, (3) electrodialysis, (4) model biomembrane desalination systems, and (5) living membrane-separation phenomena.

The Applied Science Division evaluates the technical and economic feasibility of the various processes of desalting and product recovery. Division responsibility includes crystallization, membrane, ion adsorption, and colloidal phenomena. Particular emphasis is given processes based upon physical and chemical phenomena occurring at surfaces and interfaces.

The Materials Division is responsible for research relevant to the economical and efficient use of materials of construction. The program includes studies concerned with deterioration of materials in service, development of improved or less costly materials, and generation of design principles leading to use of less material.

The largest single branch within the Office of Saline Water is entitled *Engineering and Development*. This branch is responsible for the development of technology which will allow the design and construction of reliable desalting plants capable of producing fresh water at minimum cost. A diverse program is conducted which encompasses engineering-design studies, materials tests, component tests, and process investigations using pilot plants, test beds, and large plant modules. These investigations are directed at a number of desalting processes suited to particular feedwater conditions, plant locations and operating environments. The engineering and development program is carried out through four separate divisions.

The Distillation Division is responsible for the design, field development, operation, and continuous testing and development of distillation pilot plants, test-bed plants, large modules, and their equipment and auxiliaries. The Division is also responsible for engineering and development conducted to develop new or improved distillation processes, heat transfer, deaeration, and scale-control methods unique to distillation, and engineering and research development in the areas of solar-humidification, and diffusion-still projects.

The Special Projects Division has responsibility for the development of freezing, hydrate, and ion-exchange processes for the desalting of sea and brackish waters. In addition, the Division carries out studies and experimental programs in related areas, such as brine disposal at both coastal and inland locations and chemical sealing of soils for impounding wastes and residues from desalting plants.

The Membrane Division is conducting some of the most promising and exciting research work in water resources in the United States. Major program activities administered by the Division include development of low-capital-cost plant designs, high-flux, low-cost, long-life design, construction and evaluation of pilot plants and test beds to obtain engineering and operating data for process scaleup to large-size plants; economic-analysis studies to estimate costs of desalting different brackish waters and sea water in different plant sizes; and development of feed-water-pretreatment systems specifically suited for coupling with membrane desalination plants.

The Materials Technology Division is concerned with problems related to the behavior of materials in desalting applications. One of their more exciting programs deals with the development of concrete-polymer combinations. The addition of certain types of polymers to concrete appears to enhance its suitability for distillation markedly.

The *Project Management and Plant Engineering* branch of the Office of Saline Water deals with specific large-scale programs. They are managing the assistance that is being given by the United States to the government of Saudi Arabia in the design, construction and initial operation of a dual-purpose desalting plant in Saudi Arabia.

Finally, there is a small *Desalting Feasibility and Economic Studies* branch. This is the group that recently studied the feasibility of dual-purpose nuclear power and desalting plants to supply fresh water and electricity to the Southwest United States and Northwest Mexico.

THE OFFICE OF WATER RESOURCES RESEARCH

The Office of Water Resources Research, a relatively new organization established in 1964, is basically concerned with taking an overall view of the water resources problem. One of its major responsibilities is to fill in the gaps that exist between the various mission-oriented water research programs in our government and to supply basic information that can be of value to them. Further, it serves as the vehicle by which a large number of future scientists are trained in water resources research at each of our 50 state universities.

OWRR states that its program:

1. Involves research competencies from engineering and scientific disciplines, academic and non-academic, in both public and private entities, all directed towards the solution of water related problems,
2. Contributes to the training of water resources personnel,
3. Sponsors both short range research on current problems and more fundamental research needed for long range solutions,
4. Fosters research in new problem areas such as water resources planning methodology,
5. Promotes water resources scientific information exchange, research coordination and public education.

The major portion of the funding allotted to the Office of Water Resources Research is intended to provide $100,000 annually to each state institute. Every state university in our country has established a water resources research institute which is supported by this program. The program actually has resulted in over 400 research projects that are going on at the present time, and it is providing for the training of more than 1,000 students per year. In addition, a program of matching grants to the state institutes also exists.

The Office of Water Resources Research also administers a program that gives research contracts to universities, research institutes, and industrial concerns, which can show a demonstrated competence in water resources research. The purpose of this program is to sponsor research by experts in specific areas. This program is uniquely suited for accomplishment of multi-disciplinary research representing the physical, life, and social sciences, engineering and law. Particular emphasis during the coming year in this area will be placed on urban water problems. Projects of this type may deal with water systems management and with the economic and related aspects of municipal and industrial water.

CONCLUSION

We stand on the threshhold of new breakthroughs which should greatly enhance our supplies of fresh water as well as contribute significantly to cleaning up polluted water and preventing further contamination.

APPENDIX TABLE

RESEARCH ASSIGNMENTS FOR FWPCA LABORATORIES

Laboratory	Research Assignments
Ada, Oklahoma	*Treatment and Control Research* Treatment, control or prevention of pollution from: (1) petrochemical industry, (2) oil production, (3) petroleum refining, (4) irrigation return flows, (5) impoundments. *Water Quality Control Research* Control of pollution by means other than waste treatment (e.g. process change, dilution, dispersion, environmental treatment, etc.) *Ground Water Pollution Research* Research on fate of pollution in ground water, ultimate disposal of waste concentrates under the ground, soil treatment, soil chemistry and microbiology, and ground water recharge.
Athens, Georgia	*Treatment and Control Research* Treatment, control, or prevention of pollution from: (1) agricultural runoff, (2) pesticide manufacture, (3) fertilizer manufacture, (4) phosphate mining, (5) textile mills, (6) chicken processing. *Pollution Identification Research* Physical and chemical analytical methods for detecting, measuring, characterizing, and indicating pollution. *Pollution Source and Fate Research* Methods for identifying and measuring sources of pollution and fate of pollution in streams and lakes.
Cincinnati, Ohio	*Treatment and Control Research* Treatment, control or prevention of pollution from: (1) municipal sewers, (2) unsewered homes. *Physical-Chemical Treatment Research* Physical-chemical separation, modification or destruction of impurities in wastewaters. *Biological Treatment Research* Biological separation, modification, or destruction of impurities in wastewaters. *Ultimate Disposal Research* Non-pollutional disposal of waste concentrates except disposal under the ground.
College, Alaska	*Treatment and Control Research* Treatment, control, or prevention of pollution from: (1) fish processing, (2) copper mining. *Cold Climate Research* Pollution in the Arctic environment.

Appendix Table (cont'd)

Laboratory	Research Assignments
Corvallis, Oregon	*Treatment and Control Research* Treatment, control, or prevention of pollution from: (1) power production (thermal pollution), (2) potato processing, (3) pulp and paper manufacture, (4) lumber mills, (5) logging operations. *Eutrophication Research* Control and prevention of accelerated eutrophication. *Coastal Pollution Research* Fate of pollution in estuarial and coastal waters.

Appendix Table (cont'd)

Laboratory	Research Assignments
Duluth, Minnesota	*Fresh-Water Quality Requirements Research* Physical, chemical, and biological water quality requirements for all fresh-water uses—municipal, industrial, agricultural, recreational, and for propagation of fish, other aquatic life, and wildlife.
Narragansett, Rhode Island	*Marine Water Quality Requirements Research* Physical, chemical, and biological water quality requirements for all marine water uses—industrial, recreational, and for propagation of fish, other aquatic life, and wildlife.

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