REUSE OF EFFLUENTS:
METHODS OF
WASTEWATER TREATMENT AND
HEALTH SAFEGUARDS

Report of a WHO Meeting of Experts
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WHO MEETING OF EXPERTS ON THE REUSE OF EFFLUENTS:
METHODS OF WASTEWATER TREATMENT AND HEALTH SAFEGUARDS

Geneva, 30 November – 6 December 1971

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REUSE OF EFFLUENTS:  
METHODS OF WASTEWATER TREATMENT 
AND HEALTH SAFEGUARDS 

Report of a WHO Meeting of Experts

A WHO Meeting of Experts on the Reuse of Effluents: Methods of Wastewater Treatment and Health Safeguards was held in Geneva from 30 November to 6 December 1971. Dr B. H. Dieterich, Director, Division of Environmental Health, opened the meeting on behalf of the Director-General.

1. INTRODUCTION

Man cannot long prosper without access to adequate supplies of clean water. In the past, if one water supply failed another could be found. Clean surface and underground waters were in abundant supply. Rural communities in developing countries use only small amounts of water daily for domestic purposes—perhaps only a few litres per person—but need larger quantities for livestock watering and other purposes. Urban use, including industrial use, may amount to 300–600 litres per head, and with the increase of urbanization throughout the world the trend is towards an even greater total demand. In addition, the world’s population is increasing at an accelerating rate. The total amount of water available for use, however, is a fixed quantity, and water shortages are becoming common. The situation is further exacerbated by pollution, which may render water sources unusable for domestic consumption and other specific purposes.

Water has always been used and reused by man. The natural water cycle, evaporation and precipitation, is one of reuse. Cities and industries draw water from surface streams and discharge wastes into the same streams, which in turn become the water supplies for downstream users. In the past, dilution and natural purification were usually sufficient to allow such a system to be satisfactory, but in recent years, population and industrial growth have made it evident that wastewater must be treated before discharge in order to maintain the quality of the stream. More often than not, treatment has been inadequate or nonexistent.

Conservation measures would save much water that is now wasted. Manufacturing processes can often be altered to cause less pollution, and water in an industrial plant can be recycled. Nevertheless, cities and industries will still require large amounts of water. Pollution control
measures require the treatment of wastewater, which is thus restored to good quality and may find new uses. Wastewater so treated can be considered an additional water resource, and its planned reuse for lower-grade purposes than drinking can result in large savings of clean water supplies. From the health point of view, the direct reuse of wastewater may be different only in degree—or perhaps not at all—from the indirect or unintentional reuse resulting from the withdrawal of polluted water from rivers. The good management of all of our water resources is the key to optimum use.

In recent years WHO has convened several expert committees and scientific groups for the purpose of reviewing the latest knowledge in connexion with environmental health programmes, and in 1971 it published the third edition of the International standards for drinking-water.

All these expert committees and scientific groups have emphasized the need for research on the reuse of wastewater, the need to develop advanced methods of waste treatment, and the need to utilize effluents, as a means both of supplementing scarce water resources and of preventing pollution.

The present Meeting of Experts was convened for the purpose of reviewing and evaluating: the extent of the reuse of wastewater, whether intentional or unintentional; the specific health hazards associated with the reuse of wastewater for agricultural, industrial, recreational, and domestic purposes; and the latest technological developments in treatment. The Meeting was also asked to make recommendations on the research needed on wastewater treatment and on the health safeguards to be observed in the reuse of effluents for various purposes.

2. GENERAL CONSIDERATIONS

If wastewater is not treated and disposed of in a sanitary manner it may become the agent of diseases such as cholera, typhoid fever, and other enteric infections. Furthermore, the discharge of untreated wastewater may cause a physical, chemical, and biological deterioration of water sources. It may also lead to a depreciation of land values, the breeding of insect vectors of disease, offensive smell, the destruction of aquatic life, the eutrophication of ponds and lakes, and the eventual curtailment of other beneficial uses of water courses, e.g., recreation, boating, agriculture, fishing and the cultivation of shellfish.

Clearly, the pollution of water sources and land by the discharge of wastewater is aggravated by the accelerating growth of population and

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particularly of urban centres. In 1950, less than 30% of the world’s total population lived in cities. If present trends continue, it is estimated that the proportion will reach 44% by the year 1985 and 60% by the year 2000, and it should be borne in mind that the world’s population is expected by that time to reach some 7000 million. The concentration of population in urban centres results in the concentrated discharge of large quantities of wastes into rivers, lakes, and estuaries. The self-purifying capacity of the receiving waters is overtaxed, and the result is gross pollution, severe nuisance, and far-reaching economic and health consequences.

Another aggravating factor is the continuous development of industry which causes significant changes in the composition and characteristics of industrial wastewater. Each year industries are producing hundreds of new organic chemicals; some of them are persistent, nondegradable substances. They include new plastics and plasticizers, synthetic detergents and solvents, food additives, drugs, and pesticides. Many, if not all, may reach surface and underground water supplies. Furthermore, many of these toxic and nuisance-causing chemicals are not removed by conventional wastewater treatment processes, such as settling and biological treatment. Some of the new substances may be toxic, carcinogenic, or mutagenic.

The concern for the effects of pollution caused by wastewater on the environment and on man himself has gradually risen from an attitude of indifference to the point of serious anxiety. During the past few years the pollution of the environment, and in particular of water sources, has become a major topic of discussion in all the industrialized countries. The concern is shown not only by the experts and agencies dealing with problems of pollution but also by the public at large.

As pointed out in the report of the WHO Scientific Group on the Treatment and Disposal of Wastes, wastewater has been reused for many years, principally in agriculture. However, the subject is assuming increasing importance, both for controlling pollution and for increasing the quantity of water available for agriculture, industry, recreation, and domestic use.

The problem of controlling pollution may be considered from two points of view—the generation of wastewater and the procedures used for dealing with it.

The quality and quantity of wastewater produced by the community depends on such factors as urbanization, population density, standard of technology and the attitudes of individual members of the community. Clearly the quality of the environment can be improved, or its deterioration prevented, by reducing at source the quantity of organic and inorganic pollutants discharged into municipal and industrial wastewater systems, by improving the quality of wastewater discharged, and by recycling or

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reusing wastewater. However, for any of these measures to be successfully adopted, there must first be public support and some change in social behaviour.

The procedures for handling wastewater, treating it, and rendering it fit for other uses economically and effectively, without impairing water resources or adversely affecting the health of the user or the handler, make demands on diverse branches of technology. The design and management of the handling system from domiciliary sewer connexions, through the system of sewers and treatment plant, to the final disposal of the effluent are closely related to the generation of the wastes themselves. The establishment of standards and the imposition of controls will influence the quantity, characteristics, and composition of wastewater and will have a material bearing on the technology of its collection and treatment.

When reuse is considered as a means of increasing the quantity of water available, a clear distinction should be made between conservation and reclamation (Key, 1967). "Conservation" consists in making the best use of existing water resources and preserving them from deterioration; "reclamation" is the act of restoring used water as nearly as possible to its previous quality. If, by reclaiming wastewater, its further use becomes possible (whether for the same purpose or for one demanding less strict quality criteria), an equivalent amount of unused water is thereby saved, so that reclamation contributes to conservation. By judicious reclamation it is possible to reserve first-class water sources for first-class uses, the demand for second-class water being met from reclaimed water. First-class water would be used, for example, for drinking, cooking, and washing, while second-class water would be used for toilet flushing, gardening, and car washing. As much as 15 years ago, the United Nations Economic and Social Council (1958) stated: "No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade."

The WHO Scientific Group on the Treatment and Disposal of Wastes called attention to the possible health problems inherent in the use of waste water effluents for drinking. However efficiently designed and operated the treatment plant may be, there is always a risk of breakdown or human error; in addition, the long-term effects of trace chemicals that may remain in wastewater are as yet undetermined, and much has yet to be learned about the removal of microbiological pollutants, particularly viruses.

In practice, no economic method of treatment can remove all the impurities added during use, and reclaimed water is therefore never as good as a clean source. On the other hand, ample supplies of clean unused water can no longer be taken for granted. Water sources must be conserved by communities to the greatest possible extent and supplemented by reclamation for appropriate purposes. Meanwhile the search must continue for more efficient, effective, and economical methods of treatment, recovery,
and recycling, with the proviso that all systems, for whatever purpose, must be safe from a public health point of view at all times.

2.1 Specific considerations governing reuse

The reuse of treated effluents is most applicable where large volumes of water are used and the wastes are not too contaminated. Most municipal wastewater contains only 0.1–0.2% of contaminants, but industrial wastes may be heavily contaminated and may not offer much opportunity for the recovery of clean water. The location of the treatment plant and the possible transport of the renovated water are important considerations. A wastewater renovation plant need not always be located at the same place as the municipal wastewater disposal plant, nor should the renovation process be dependent on treating the total flow. Treatment processes work most efficiently and economically when dealing with a steady flow of wastewater rather than with irregular flow normally experienced from urban sources. This condition can be obtained by withdrawing only a part of the urban wastewater, as depicted in Fig. 1, which shows how water renovation and reuse can be planned to best advantage in the community.

FIG. 1. SIMPLIFIED WASTEWATER REUSE SCHEME

Discharge of household sewage

TRUNK SEWER

Even flow to plant

Wastewater renovation plant

Stages returned to sewer

Clean water for reuse

Discharges of industrial wastes unsuitable for reclamation

To municipal disposal plant

A The diversion of wastewater from the trunk sewer to the wastewater renovation plant should be chosen at a point where it is known that the trunk sewer contains only household sewage.

One very important question is whether the wastewater will be reused only once or whether it will be recycled many times, because multiple recycling results in a build-up of certain dissolved materials, especially inorganic ions, that may make demineralization necessary. Most reuses do not lead to a high degree of recycling. Irrigation, which is an increasingly common reuse, generally does not offer an opportunity for recycling. Industrial reuse is highly variable but may also not lead to a high degree of recycling. A recreational lake would not normally offer an opportunity for multiple recycling unless it was serving as a step in a treatment system for producing water for domestic use.

Domestic reuse offers the best opportunity, but even then the amount of water recycled falls short of the total amount of water used. The waste-
water arriving at the treatment plant is generally found to be less than the amount originally supplied to the municipal water system. Losses occur, and they may be quite large in warm dry areas, where domestic reuse is most likely to be practised. In the USA it is estimated that these losses range from less than 20% in humid areas to about 60% in arid areas. Parkhurst et al. (1968) estimate from their experience in the Los Angeles area that less than 50% of a water supply is available for reuse. Losses of this magnitude call for a substantial amount of make-up water, which in turn keeps the mineral concentration from building up excessively. The degree of demineralization needed is thus substantially less than it would be in the absence of losses and of make-up water. It can be achieved by demineralizing either the renovated wastewater or the supplementary water source. In certain circumstances the latter may be more effective.

Another consideration is the character of the wastewater entering the renovation plant, especially if this waste includes some industrial pollutants. Care should be taken to exclude materials that would be detrimental to the application for which the reclaimed water is to be used. This is especially true for domestic reuse. Such materials may not be only those usually considered toxic. Ordinary salt brines, for example, are undesirable if the renovated wastewater is to be demineralized. A survey of the sewer system will determine how much of the available wastewater could be reused. Water highly contaminated with metals or containing a high total concentration of dissolved solids may be unacceptable.

Another point to be considered is the distribution of the renovated water. A multiplicity of piping systems, each one containing renovated water of a different quality, would be scarcely practical and would multiply any potential hazards. However, if there are, in the vicinity of the treatment plant, a few large users of reclaimed water for nondomestic purposes, distribution is simple and inexpensive. If the users are widely dispersed, however, one piping system in addition to the existing municipal water supply system is almost certain to be the most that is economically realistic. Dual piping systems have been discussed by Okun (1969) and Haney & Hamann (1965). The Meeting of Experts believes that further studies on the use of dual systems should be made. The goal to be aimed at is renovated wastewater of a quality sufficient to satisfy most agricultural or industrial customers without additional treatment. Treatments such as those necessary for boiler-water feed would be excluded, since they are more appropriately carried out by the user.
3. DEFINITIONS

For the purposes of this report the Meeting of Experts formulated the following definitions.

*Municipal wastewater*. The spent water of a community, consisting of water-carried wastes from residences, commercial buildings, and industrial plants and surface or ground waters that enter the sewerage system.

*Indirect reuse*. Indirect reuse of wastewater occurs when water already used one or more times for domestic or industrial purposes is discharged into fresh surface or underground waters and used again in its diluted form.

*Direct reuse*. The planned and deliberate use of treated wastewater for some beneficial purpose, such as irrigation, recreation, industry, the recharging of underground aquifers, and drinking.

*In-plant water recycling*. The reuse of water within industrial plants for conservation and pollution control purposes.

*Industrial wastewater*. The spent water from industrial operations, which may be treated and reused at the plant, discharged to the municipal sewer, or discharged partially treated or untreated directly to surface waters.

*Advanced waste treatment (tertiary treatment)*. Treatment systems that go beyond the conventional primary and secondary processes. Advanced waste treatment processes usually involve biological nitrification and the use of chemicals, activated carbon, filtration, or separation by membranes.

4. UNINTENTIONAL REUSE OF WASTEWATER

4.1 Current extent of reuse

Rivers and lakes often serve both as sources for potable water for public supply and as a medium for the disposal of wastewater, whether treated or untreated. It is not surprising that the raw water abstracted by many water supply authorities contains a proportion of wastewater discharged by previous users. This situation is common and is referred to as indirect reuse. (When it is due to the planned discharge of effluent upstream or to the planned recharge of ground water reserves, it is designated as “intentional” indirect reuse.)

The unintentional reuse of wastewater also occurs widely as a result of the use of river-water in agriculture, for recreation, and for industrial water sources. Drainage from septic tanks, ponds, and treatment lagoons into underground waters leads to unintentional indirect reuse when this water is subsequently abstracted.
4.2 Examples of indirect reuse in certain rivers

A study of a number of rivers in the USA, carried out in 1961 (Koenig, 1966), showed that at periods of low flow 3.5–18.5% of the water had passed through domestic waste systems—a proportion very much lower than that suggested by certain sensational newspaper reports (Cleary et al., 1963). If the volume of industrial effluents is also taken into account, it would be expected that 20–40% of the river-water at low flow in some areas may be reused water. The lower reaches of the Rhine, serving as a water source for 6 million people, may often contain 40% of sewage effluent, and this figure may rise to nearly 100% in periods of extremely low flow. In the United Kingdom, the River Thames, which provides two-thirds of the water supply for the Greater London area, contains about 14% of sewage effluent, when flowing at an average rate. In times of drought, the water supply source for Agra, India, consists almost entirely of partially treated sewage from New Delhi, 190 km away.

The Mardyke is a small river rising to the east of London and discharging into the Thames estuary. It has a dry-weather flow of about 18 000 m³ per day. The Essex River Authority has devised a scheme whereby about 36 000 m³ per day of sand-filtered secondary effluent from the Riverside wastewater treatment plant will be pumped into the headwaters of the Mardyke to supplement the flow, instead of being discharged direct to the estuary as at present. The mixture of river-water and effluent will be available for abstraction under licence by agricultural users in the middle reaches and by industry at the lower reaches—an area now suffering from a shortage of water owing to saline intrusion into the wells that provide much of the supply. A further supply of sand-filtered effluent will be made available for direct industrial use.

In the treatment of polluted rivers, the methods at present employed are based on those developed over the years for the treatment of relatively unpolluted river-water, and it appears that sufficient note may not have been taken of the increasing proportion of wastes in many rivers.

The inadequacy of these traditional methods may perhaps be indicated by the outbreaks of infectious hepatitis in New Delhi in 1955–56 (Dennis, 1959; Viswanathan, 1957), when there were 30 000 cases, and in 1958. The waterworks in question was of modern design, and, though there may have been some faults in operation, they were of the sort that may occur at any waterworks. However, at the time of the outbreak drought conditions prevailed, and the water abstracted from the river was estimated to contain about 50% of sullage water.

It appears, therefore, that the public health aspects of the production of potable water from polluted rivers should be reviewed. When rivers contain a high proportion of effluent, the production of water from them should be regarded as analogous to the direct recovery of water from a
sewage or industrial effluent, and safeguards appropriate to this situation should be imposed.

There is also an increasing need to consider the optimum distribution of purification between the wastewater treatment plant, the river itself (self-purification), and the treatment plant that produces potable water. There are two extreme cases:

(a) Wastewater is discharged with little or no treatment, all the purification occurring in the river or at the water treatment plant. This practice has been common in the past but is rapidly disappearing. In fact, raw sewage disposal into rivers is prohibited in some countries. Local authorities are requiring secondary treatment and in some cases the removal of the nutrients phosphorus and nitrogen, because incidental pollution that is as yet uncontrolled may well use up the natural purifying capacity of the river.

(b) The wastewater is purified to a standard as high as that of the river-water into which it is discharged, so that the type and degree of purification required at the water treatment plant is no different from that which would be required in the absence of the wastewater discharge.

Almost certainly the optimum solution lies somewhere between these two extremes, and optimization studies are required to determine it, taking into account all the costs and benefits involved. This may be difficult in practice because some of the social costs and benefits cannot readily be expressed in economic terms. Such optimization studies are likely to be most successful in the context of a single river basin authority having control over the treatment and discharge of wastewaters and also over the abstraction and treatment of potable waters.

Public water supplies derived from rivers are vulnerable to the effects of abnormal pollution resulting from the discharge of industrial effluents, mishaps at the wastewater treatment plant, spills from barges or land installations, or abnormal climatic conditions such as flood, drought, or ice formation. The fullest use should therefore be made of the developing techniques of water quality monitoring. While it is not practicable to carry out continuous monitoring of many of the pollutants of greatest significance, such as toxic substances, the instruments that are available will in many cases permit an early warning to be given of the development of abnormal conditions in the river so that appropriate action may be taken. Such monitoring does not, of course, obviate the need for close control of the treatment process itself and for rigorous examination of the treated water.

The unintentional reuse of wastewater also occurs widely as a result of the use of river-water for agriculture, recreation, and industrial supply, and for these purposes, too, there is a need for appropriate safeguards.
5. INTENTIONAL REUSE OF WASTEWATER

Treated wastewater may be deliberately used in a planned way for a variety of purposes, some of which are shown in Fig. 2. Intentional reuse is not new, but there is growing recognition of the need for it. No comprehensive survey of wastewater reuse exists, but there is an excellent compendium on the subject, edited by Cecil (1967). Some examples will illustrate the importance of intentional reuse.

FIG. 2. INTENTIONAL REUSE OF WASTEWATER

5.1 Agriculture

The reuse of wastewater for agricultural purposes is an old and common practice. Law (1968) cites 99 references on the use of sewage effluent as an agricultural water resource. The quality of the reused water is important both for the health of the workers in contact with it and for the particular application for which it is used. Trace elements toxic to crops may be a problem. Boron, for example, a component of many commercial laundry powders and one that is not removed by conventional treatment processes, is well known as a toxicant to citrus crops. Standards for various wastewater reuses and the treatment required are discussed in later sections of this report. In some places untreated sewage is still used for irrigation, but this practice should be abandoned.

5.2 Industry

Industries more and more frequently tend to conserve water by recycling and reusing water within the plant. Municipal wastewater treatment plant effluents have been used as cooling-water in industrial plants, and recent
trends indicate that their use for various other processes is becoming common. The publication by Cecil (1967) gives detailed examples of industrial water reuse. Funke (1969) has summarized the applications of reused effluents in South Africa.

In India the first tertiary treatment plant for purifying municipal effluent was recently put into operation to supply cooling and process water to an industrial plant (Chhabria, 1971). The effluent flow of 4500 m$^3$ per day is treated biologically and chemically, filtered through sand, softened, chlorinated, and used in the plant.

5.3 Recreation

The use of treated wastewaters for filling lakes to be used for boating, fishing, and sometimes swimming is relatively new. Lakes fed by treated wastewater at Santee, Calif., USA, (Merrell et al., 1967) have been in existence for 10 years. At this location the municipal wastewater is treated by the activated-sludge process, fed into a lagoon, chlorinated, and spread onto a natural bed of sand and gravel, where it passes through several hundred feet of horizontal filtering. The water then flows into man-made lakes, which are used for boating and fishing. The water has been found to be bacteriologically safe and free of enteric viruses. No deleterious effects on the health of the users have been detected. The community of Lancaster, Calif., is installing similar lakes (Dryden & Stern, 1968). At Lancaster the wastewater undergoes primary treatment and is held for a time in large oxidation ponds; it is then subjected to chemical treatment with alum to reduce the concentration of phosphorus and finally filtered and chlorinated.

The capability of advanced modern processes to produce a very high quality effluent that can be used in a man-made lake for boating, swimming, fishing, and irrigation has been demonstrated by the large treatment plant (28 000 m$^3$ per day) at Lake Tahoe, California (Culp, 1968). At Lake Tahoe the wastewater is treated by the activated-sludge process followed by the addition of lime and by recarbonation to recover the carbonate (which is reburned to lime). The water is then filtered, subjected to activated carbon adsorption, and chlorinated. The lake containing the renovated water, known as Indian Creek reservoir, is 30 km from the treatment plant.

5.4 Municipal reuse

Municipalities can use well treated effluents for many nonpotable purposes. Examples are:

(a) Street flushing

(b) Watering golf courses, roadside verges, public parks, and the grounds of the treatment plant itself
(c) Underground injection to repel salt water intrusion
(d) Fish farming.

In 1956–57 reclaimed water was used for public water supply in Chanute, Kans., USA, as an emergency measure for a limited period (Metzler et al., 1958). Despite an accumulation of dissolved minerals to objectionable levels due to continuous recycling, no adverse health effects were detected.

The supplementing of potable supplies with renovated wastewater has been successfully practised at Windhoek, Namibia (Stander & van Vuuren, 1969). At one period, up to a third of the town's supply was made up of highly treated wastewater. The treatment processes used were secondary treatment by trickling filters, retention in maturation ponds for 8 days, pH correction with carbon dioxide, air flotation to remove algae, foaming tank treatment to remove detergents, chemical coagulation, sand filtration, activated carbon adsorption, and chlorination. The Windhoek experience—the planned reuse of treated effluent for a municipal supply over an extended period—is the first of its kind. A shortage of water left no alternative and the system was apparently put into operation successfully and without serious objections from the public.

In general, however, drinking-water should preferably come from a clean supply, and communities should make every effort to conserve water so that there is always sufficient for potable purposes. Wastewater reuse for all other purposes should come first. If potable water is to be prepared from wastewater, a long-range plan setting out clearly defined stages is a great advantage. The water-supply authority in the city of Denver, Colo., USA, foreseeing the need to renovate wastewater for potable purposes at some time in the future, has produced a long-range plan (Linstedt et al., 1971) describing the successive stages envisaged in the reuse of water in the metropolitan area. The principal considerations listed are:

(a) the identification and implementation of suitable advanced water treatment processes,
(b) the development of data on potential beneficial uses and the determination of the quality requirements associated with each use,
(c) the establishment of distribution systems for the reused water,
(d) the provision of information to the public on the successive-use concept, in an attempt to secure its acceptance, and
(e) the formulation of plans to ensure the continuing and reliable availability of water for advanced treatment and reuse.

5.5 Economics of reuse

The economics of water reuse is governed by several factors such as the size of the treatment plant, the composition of the wastewater, the required quality of the finished water, the location of the plant, and the costs of
alternatives. The major costs of both water supply and waste treatment are in the distribution system, plant structure, and interest on the borrowed money. Only a quarter of the cost of water supply and waste disposal can be attributed to treatment.

Pollution control requirements are becoming more stringent all over the world. Contaminants must be kept out of systems whenever possible, and the remaining contaminants must be properly treated and disposed of in a way that does not pollute the environment. The treated effluent thus becomes clean enough for some further direct use or, after additional treatment, for any use. Thus part of the cost of water renovation can be charged to pollution control. The benefits derived from the increased quantity of water available may well exceed the cost of obtaining it. At the very least the reclaimed water will help pay for the cost of treatment.

When the production of usable water and the control of pollution are joint results of a single process, it may be inappropriate to try to separate the costs of obtaining fresh water from those of managing wastewater. Water is used as a means of transporting pollutants, but in areas short of water it is uneconomic to throw away 999 tonnes of water to dispose of 1 tonne of pollutants. Clearly, the provision of clean water in a clean environment costs a certain total sum of money. The task of managers and technologists is to ensure that this clean water is provided and at the lowest cost consistent with community needs. In most places, clean water can be assured for costs that are no higher than those of a telephone service, an electricity supply, or any other amenity.

5.6 Political and social constraints

In the past, water supply and waste disposal have often been managed by separate divisions of local government. The total management of water resources now goes far beyond such a system. At any plant, the water quality at the intake is affected by the pollution from upstream, while the wastewater effluent may affect downstream communities. The trend towards authorities for the management of water on an area basis is in the right direction. The United Kingdom announced in December 1971 a plan to divide the country into 10 multipurpose regional water authorities that would include in their functions the control of pollution and water use (United Kingdom, Department of the Environment, 1971).

Present-day wastewater management systems will need to be revised if wastewater reuse becomes common. The control of materials allowed into sewers is now exercised in some places to protect the system and the treatment process. More such control would be needed to protect systems concerned with water reuse.

Pollution control of a high order and wastewater reuse require the enforcement of regulations and the provision of extremely reliable treatment
plants and operators. The shortage of trained operators is a major problem in nearly all countries. More often than not, a plant is capable of producing a better effluent than it actually does. Errors in plant design occur, but many of these can be detected and corrected. When a wastewater treatment plant is producing a product for reuse instead of something to throw away, its operation will have to be improved because bad operation will be noticed and will have an economic impact when the water is sold.

Wastewater treatment must be given the same attention as other city services. It is a task that needs well qualified and well paid personnel, working with good equipment.

The public should be fully informed on matters concerning water supply. Today people are interested in and concerned about environmental pollution. Questions about the public acceptance of reused water have arisen from time to time, and the reuse of wastewater for potable supply would certainly be a controversial issue. The authorities at Windhoek won public acceptance of their plan by carefully explaining the need for the reuse of wastewater and by demonstrating the harmlessness of the product.

6. POTENTIAL HEALTH EFFECTS ASSOCIATED WITH THE REUSE OF WASTEWATER

One of the primary public health considerations for the proper sanitary treatment and disposal of municipal wastewater has always been the prevention of communicable diseases caused by enteric pathogenic microorganisms or diseases caused by toxic substances. Those planning the reuse of wastewater must be fully aware of potential health hazards, and precautions must be observed.

6.1 Microbiological health risks

It has been shown in many studies that domestic sewage usually contains the complete range of pathogenic organisms found in the community producing the sewage (Greenberg & Dean, 1953; Rudolf's et al., 1950). In one such study various species of pathogenic organisms, such as the agents causing typhoid fever, bacillary dysentery, amoebic dysentery, ascariasis, and other protozoan and helminthic diseases, were isolated from raw sewage as well as from the effluent of a high-rate trickling filter plant (Rigbi et al., 1965). Other studies have shown that all the major enteric viruses can be detected both in raw sewage and in the effluent from conventional treatment plants. Enteric viruses have been found in raw sewage in concentrations of 1–10 per millilitre in various countries (Berg, 1970; India, Central Public Health Engineering Research Institute, 1971b).

A recent example of the public health risks that can be associated with unregulated sewage irrigation of vegetable crops is the outbreak of cholera
in Jerusalem in the late summer of 1970. Some 250 cases of cholera were detected throughout the city during the 6-week period of the outbreak. The municipal water supply was from a safe, protected, properly chlorinated source. Investigations revealed that vegetable crops, irrigated with raw sewage contrary to Ministry of Health regulations, were the most probable pathway for the secondary dissemination of the disease after the introduction of cases and carriers into the city by visitors from abroad. Cholera organisms were detected in raw sewage samples from all sections of the city during the outbreak. They were also detected in soil that had been irrigated with raw sewage and on vegetables grown in it, some of which were found in the markets.

Another problem is to protect the health of agricultural workers when sewage irrigation is used. It has been reported from India (India, Central Public Health Engineering Research Institute, 1971a) that hookworm and other enteric infections are much commoner among workers on sewage farms than among the farming population in general; the local custom of walking barefoot is a major contributory factor to the spread of some of these diseases. On the other hand, a follow-up study of the health of workers at sewage treatment plants in the USA (Dixon & McCabe, 1964) did not reveal any excessive risk of disease or disability in this group. Reasonable standards of personal hygiene appear to be effective in protecting the health of workers involved in sewage utilization projects.

The possibility of transmitting certain parasites or diseases through cattle that graze on pastures irrigated with sewage must be more fully investigated. Reports from Denmark indicate that *Cysticercus bovis* infestations in cattle can result from the irrigation of pasture lands with sewage (Jepsen & Roth, 1952).

Studies have pointed out the possible development of anaerobic toxin-producing microorganisms dangerous to cattle under certain alkaline-anaerobic water conditions. The Meeting felt that there is a need to elucidate the possible significance of such findings for human health.

The use of wastewater in fish breeding ponds may also present certain health hazards. From the microbiological point of view there are two potential problems. One is the possibility that pathogenic microorganisms may be transferred from the external surface and the viscera of the fish to the kitchen. The other problem is that, in areas where schistosomiasis is endemic, the snails serving as the intermediate host of the schistosome may become infected from the sewage and communicate the infection to workers. The problem can be overcome by controlling snails in fish ponds—a precaution that should be taken whether or not the ponds contain wastewater effluent.

The use of municipal wastewater in industry has been successfully practised in many areas, but all such projects are attended by a number of potential public health problems. The main one is the danger of cross-
connecting pipelines carrying treated sewage and those carrying safe water for drinking or food processing. The careful colour coding of pipes would be helpful in reducing such risks, and such coding should be applied to buried as well as to exposed piping.

Generally speaking, if effluent is to be used in industrial processes it is sound policy to bring it into the factory only after it has been treated and disinfected and has achieved a bacteriological quality approaching that of drinking-water. Such a level of treatment would reduce the risk of a major outbreak of disease occurring as the result of an accidental cross-connection. If treated wastewater is to be considered for use in industrial food-processing plants, it must meet the standards applicable to drinking-water. The microbiological hazards involved in recycling industrial effluents are usually far less severe than those resulting from the use of municipal sewage; nevertheless, care must be taken to prevent possible cross-connections and the consequent contamination of potable water used in the same plants.

The health risks involved in the reuse of wastewater effluents in recreation are harder to evaluate. Epidemiologists have found it difficult to gather firm evidence on the extent to which communicable diseases are transmitted by bathing in water contaminated with sewage. Some evidence does however point to the possibility that bathers can become infected with enteric diseases by the involuntary ingestion of recreational water heavily contaminated with sewage. The Santee recreation project in California utilizes highly treated wastewater for recreational activities. A swimming programme was conducted on an experimental basis, and no adverse health effects were detected (Culp, 1963; Merrell & Katko, 1966). As a precaution, only wastewater treated to a high degree and nearly meeting the microbiological standards of drinking-water should be used for body-contact sports.

The reuse of wastewater effluents and polluted river-water for domestic purposes, including drinking, presents certain clear-cut potential health risks from the microbiological point of view, since there is ample epidemiological evidence that the ingestion of even a small number of certain pathogens can cause disease in nonimmune subjects. Limited studies have shown that ingestion of one tissue culture infective dose of poliovirus can cause infection in man, but it is not known what percentage of persons would become infected with such a low dose or what size of infective dose would be needed for other enteric viruses. It appears that, even if only low levels of enteric viruses pass through a water treatment plant, persons can become infected. It must be pointed out, however, that the potential microbiological risks involved in direct effluent reuse may not be appreciably different from those faced by many cities currently using surface sources heavily contaminated with municipal wastewater from upstream locations. Some rivers carry such a high proportion of treated and untreated wastewater that
their use as a water source can be considered as essentially wastewater reuse (Cleary et al., 1963).

Water treatment technology is today capable of removing or inactivating substantially all pathogenic bacteria, although waterborne viruses may be more difficult to control. There is evidence that enteric viruses have on occasion passed through conventional water treatment plants that draw water from heavily contaminated rivers (Grabow, 1968), although such conditions could normally be detected by adequate bacteriological monitoring. Only if water has been treated to such a degree that essentially all ammonia and nearly all residual organic matter have been removed is it possible to achieve the free chlorine concentration of 0.5 mg/l for one hour recommended by WHO for effective inactivation of enteric viruses.

Such a standard is unlikely to be achieved by poorly operated conventional water treatment plants treating river-water heavily contaminated with sewage. Activated carbon treatment, by removing organic materials, enhances the efficiency of the disinfection process. In direct wastewater reuse schemes, advanced procedures involving highly alkaline chemical treatment, filtration, and activated carbon treatment prior to disinfection appear to give very high levels of virus removal that may well provide adequate protection to consumers. The development of sensitive monitoring methods to detect low levels of enteric viruses in large volumes of water would be valuable in evaluating the safety of the treatment procedures.

6.2 Removal of pathogenic microorganisms in treatment processes

It has generally been accepted that the relative reduction of coliform organisms serves as an indication of the microbiological efficiency of wastewater treatment processes. In primary sedimentation, a reduction of 30–40% in the number of coliform organisms is obtained, while in most full biological treatment processes the reduction is between 90% and 95%. Stabilization ponds with a 30-day retention period have, in general, been shown to effect a higher reduction of coliform organisms—up to 99% (Gloyna, 1971). One study has shown that reductions of 90–99% in the number of coliform organisms can be achieved in ponds after about 6 days and 99.9% after 28 days (Meron et al., 1965).

A number of studies have been carried out to determine the efficiency of sewage treatment processes in removing specific pathogens (Rowan, 1964; Rudolf et al., 1950; Wang et al., 1956). Most vegetative bacterial pathogens appear to be removed in the same proportion as coliform organisms. Certain helminth eggs having rapid sedimentation rates may be effectively removed by conventional primary sedimentation treatment and even more effectively removed by stabilization pond treatment of 5–7 days retention. Viruses are less effectively removed by conventional wastewater treatment processes and may remain in a chlorinated effluent even when coliforms have been
reduced appreciably. Ozone disinfection is particularly effective against viruses but is rarely practised in wastewater treatment.

According to Berg et al. (1968), coagulation with 400 mg/l of lime at a pH value of 11.3 is effective in removing 96.5% of poliovirus 1 from wastewater, and, with a coagulation treatment of 90 minutes followed by filtration through 20 cm of sand at a rate of 132 m³/m²/day, a total virus removal rate exceeding 99.997% can be achieved. Using aluminium sulfate as a coagulant, at a dose of 25 mg/l, Chang et al. (1958) achieved a removal of Coxsackie virus A9 of 98.6% and a removal of bacteria of 99.8%. Using ferric chloride as a coagulant at the same dose, they achieved somewhat lower figures of 93.8% and 94.8% respectively.

In India and Israel, the authorities recommend that wastewater should be pretreated in stabilization ponds before being used for any form of irrigation. This measure achieves a fairly effective reduction of pathogens, thus protecting the health of workers and minimizing the contamination of crops. Although such treatment is of undoubted value, it cannot be assumed to provide the pathogen-free effluent required for the unrestricted irrigation of vegetable and salad crops that may be eaten uncooked.

Studies have also been made on the viability of various indicator and pathogenic organisms in the soil or on crops irrigated with wastewater. The viability of these organisms varies from several days to a few months, depending on the type of organism and its resistance to environmental factors such as climatic conditions, soil moisture, and the amount of protection provided by crops (Dunlop, 1952; Falk, 1949; Rudolfs et al., 1950, 1951). Research has shown that salmonellae may persist for up to 70 days in soil irrigated with sewage under moist winter conditions and for about half that period under drier summer conditions (Bergner-Rabinovitz, 1956). Enteric viruses appear to be particularly persistent under natural conditions. A review of the literature led the Meeting to the conclusion that, despite the considerable reduction in the number of indicator or pathogenic organisms resulting from detrimental environmental conditions and biological competition, sufficient numbers of pathogens can survive under the conditions normally expected in agricultural practice to create a potential health hazard if crops, recently irrigated with fresh or partially treated sewage, are consumed uncooked.

6.3 Treatment of wastewater for unrestricted irrigation

Certain agricultural and economic conditions may warrant the treatment of sewage to such an extent that it can be used for the unrestricted irrigation of all agricultural crops. Farmers have some difficulty in carrying out normal crop rotation schemes if restrictions on the types of crops that may be grown are too onerous; this may become a major problem in the administration of programmes involving the restricted utilization of sewage. On the other hand, if the use of sewage is not restricted to particular crops,
a very high degree of treatment and disinfection is required. Studies have indicated that it is technically feasible under field conditions to produce a sewage effluent containing not more than 100 coliform organisms per 100 ml in 80% of the samples tested. This high standard can often be obtained after complete biological stabilization, followed by heavy and carefully controlled chlorination (15-20 mg/l of chlorine with contact periods of 1-2 hours).

A series of studies has been carried out to determine the feasibility of inactivating coliform and pathogenic bacteria and enteric viruses in sewage by means of heavy chlorination, in order to provide a safer effluent for unlimited agricultural irrigation (Rudolfs et al., 1951). They have shown that 20 mg/l of chlorine must be applied to primary effluent for 6 hours to achieve a count of not more than 100 coliform organisms per 100 ml, while 8 mg/l of chlorine will achieve the same result in 2 hours when applied to the effluent from a high-rate trickling filter plant. Most other species of bacteria pathogenic to man (including cholera organisms) are considered to be more sensitive to chlorine than are coliform organisms. The treatment was also effective in inactivating amoebic cysts.

Other studies, however, indicate that enteroviruses may not be destroyed to the same extent as coliform organisms, and in one case, despite a reduction in numbers of coliform organisms after heavy chlorination by a factor of 10^5 or 10^6, a considerably lower proportional reduction of polioviruses was obtained (Shuval et al., 1967). The epidemiological significance of these findings is difficult to evaluate, since little work has been done on the transmission of enteric virus diseases by foods contaminated by irrigation with sewage. However, the heavy disinfection of treated wastewater can reduce the number of enteric viruses significantly and can provide a degree of protection that will make its use comparable to that of river-water.

Despite the sparse information, it can be assumed that only a limited health risk would result from the unrestricted irrigation of agricultural crops with sewage effluents having a bacteriological quality of 100 coliform organisms per 100 ml. As it is, in many parts of the world where irrigation is practised, water may be drawn from rivers and streams that are often heavily polluted with treated or untreated sewage effluent (Dunlop, 1952), and in most cases the quality of the water is low. However, further studies will be required on the danger of disease transmission caused by irrigating crops with reclaimed water.

6.4 Treatment of wastewater for drinking

Work in Israel, South Africa, and the USA indicates that from an engineering point of view it is feasible to treat wastewater by a series of biological, chemical, and physical processes so as to produce an effluent meeting the most rigorous microbiological quality standards demanded of drinking-water (Amramy, 1965; Caspi et al., 1966; Cillie et al., 1967; Culp, 1963;
Stephan, 1965). Virus-free effluents can be expected from such processes. How safe such plants would be under continuous operating conditions is difficult to determine. However, owing to the high potential risk of infection that would result from an undetected mechanical breakdown or human error in the process, it was the conviction of the Meeting that rigorous control procedures and "fail safe" devices should be incorporated into any treatment plant aimed at the reuse of wastewater for drinking. The bacteriological and chemical testing of water before distribution would be most desirable, and processed water could be held in tanks until tests showed that its release was safe. This would be expensive and inconvenient in practice, except when reclaimed water is used to supplement a stored water resource such as a reservoir, when the delay would be automatic. As pointed out earlier, an effluent that is low in organic content and that can be chlorinated to obtain 0.5 mg/l of free residual chlorine after one hour's contact can be expected to be free of both coliform organisms and enteric viruses. Thus, for practical operating purposes, the continuous monitoring of free residual chlorine in the effluent before use may prove to be sufficient. This point should, however, be fully verified in laboratory and field studies before being put into practical application.

If wastewater is to be used as a source for drinking-water, the strictest microbiological standards for drinking-water should be applied. The absence of any coliform organisms in a 1-litre sample is a feasible standard, which can be met and maintained under proper operational conditions. A similar standard for viruses is recommended by WHO. In the future it may be possible to monitor water for viruses in samples of at least 100 litres. Tests should be completed before the water is actually released to the distribution system.

This monitoring requirement is stricter than any currently applied to water supplies drawn from even the most heavily polluted river—indeed, the Meeting felt that such a requirement might well apply in many cases of unintentional reuse of wastewater. But it is certainly justified for any future scheme for the intentional reuse of wastewater for drinking, in order to provide the public with the high degree of health protection it would rightly expect. In addition, the scheme should be supervised from beginning to end by the public health authorities. Rigorous monitoring of the kind described is perfectly feasible using existing techniques; it will be even more practical if rapid methods of detecting bacterial and viral contamination are developed. Such methods should be sought.

6.5 Health effects of toxic chemicals in potable waters

WHO's *International standards for drinking-water* gives maximum limits for 6 toxic substances and specifications for 18 substances or charac-

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teristics affecting the acceptability of water for domestic use. It may be thought that these drinking-water standards apply only to relatively pure and protected water sources and that more rigorous chemical criteria would be necessary to evaluate renovated wastewater prepared for eventual domestic consumption. However, the Meeting pointed out that a high proportion of existing surface water supplies throughout the world are so heavily contaminated with municipal and industrial wastes as to make the health risks associated with the drinking of water derived from such sources only slightly different from those involved in the direct reuse of wastewater.

Various chemicals can affect the wholesomeness of water because of either their toxic effects or their organoleptic properties. The question that must be raised is that of the extent to which it will be possible to establish criteria for the hundreds of organic and inorganic chemicals that can appear in polluted water today and are not now covered by drinking-water standards.

The approach that has been developed by toxicologists in setting tolerance limits for pesticide residues, food additives, and other chemical contaminants in food has been to establish acceptable daily intake levels for man. These levels are based on all relevant toxicological data available at the time of evaluation, including data from cases of human exposure. After determining the "no-effect level" and introducing a safety factor, toxicologists can establish an acceptable daily intake for each substance. It must, however, be under constant review and be revised periodically as additional information becomes available. These figures then provide a toxicological basis for establishing tolerance levels or practical residue limits in food, water, and air, taking into account known consumption patterns and realistic levels of contamination. Thus, toxicological methods for establishing tolerance levels for such chemicals in drinking-water are at least theoretically available, but to date little or no effort has been made to use them for that purpose. In establishing criteria for water, due consideration must be given to the total body burden from all environmental sources, the pollution levels actually found, and the ability of practical water-treatment methods to reduce the concentration of microcontaminants.

The Meeting recommended that efforts should be made to develop such standards, primarily because of the growing unintentional reuse of wastewater contaminated by industrial and agricultural chemicals. It considered that conventional water standards are entirely inadequate in these frequently occurring circumstances. However, when adequate standards are established they should be equally applicable to the intentional reuse of effluents for drinking-water in those special situations in which such reuse is necessary.

The toxicological evaluation of chemicals found in the environment must not be simplified to cover only acute or subacute effects. Today
such evaluation includes the effects of long-term exposure, carcinogenic, mutagenic, and teratogenic effects, and various biochemical and physiological effects.

Even if the specific toxicity of certain industrial or agricultural chemicals is established, the possible toxic effects of their breakdown products may be more difficult to determine. Natural biodegradation or specific wastewater treatment processes may lead to the development of new compounds having toxic properties quite different from those of the parent compound. Research must be undertaken to identify these breakdown products and to study their toxic effects. Another complicating factor is the combined and possibly synergistic effects of a mixture of toxic and nontoxic chemicals. Some combinations are known to produce an increased toxic impact in certain conditions, and account should be taken of this possibility when considering the treatment of heavily contaminated river-water or undiluted wastewater. The Meeting therefore recommended that a complete and proper toxicological evaluation should be made of the actual treated water intended for human consumption, with its real mixture of residual chemicals. Long-term feeding experiments with more than one species of experimental animals may be required as well as other toxicological tests.

The Meeting pointed out the value of epidemiological studies among population groups that have actually been consuming what is essentially reclaimed wastewater for many years. Such populations exist along certain major rivers, where, during periods of low flow, a large percentage of the raw river-water may consist of wastewater. A cooperative study of the long-term health effects of exposure to such contaminated water may prove particularly valuable in evaluating the health aspects of the problem.

It was the opinion of the Meeting that currently available advanced wastewater treatment processes can remove nearly all the dissolved and suspended chemical contaminants in wastewater and can provide a high degree of protection against possible toxic contaminants. A polished effluent with only a very few milligrams per litre of total organic carbon and less than 0.2 mg/l of carbon chloroform extract can be produced from raw wastewater. Many rivers currently used as sources of water supply for millions of people do not even approach this quality.

7. WASTEWATER TREATMENT TECHNOLOGY

Before selecting the treatment processes needed to provide water for reuse, the standards to be met or the quality to be achieved should be clearly defined. Local conditions, the available site, the size of the plant, and economic factors are among the considerations that will influence the selection of the process, which is best made by an engineer skilled in treatment process design.
The methods of primary and secondary treatment of sewage are well known and are described in detail in many standard textbooks of sanitary engineering. The removal of suspended matter from secondary effluent to produce effluents of higher quality for discharge to rivers providing little dilution is widely practised in England, and a review of available methods and their costs has been published by Truesdale (1970). Further treatment of secondary effluents is regarded as "advanced waste treatment" or "water reclamation", and good accounts of the current status of the technology are given in the book by Culp & Culp (1971) and in the summary reports of the US Advanced Waste Treatment Research Laboratory.\footnote{See: United States Public Health Service, Division of Water Supply and Pollution Control, Basic and Applied Sciences Branch, 1965; United States Department of the Interior, Federal Water Pollution Control Administration, Advanced Waste Treatment Branch, 1968.}

For those readers who are not familiar with the technology, brief descriptions are given below of the techniques available, the results they achieve, and, where appropriate, the approximate cost.

7.1 Conventional processes

Sewage farming

The disposal of sewage or treated effluent by spreading it on land on which crops are grown represents one of the earliest methods of sewage disposal. It is still used in many countries, particularly those having low rainfall and high temperatures. In wetter, cooler climates, the area of land required may become prohibitive for all but the smallest communities. The hazards to health of those working on the land or consuming the crops may be considerable, and for this reason it is no longer recommended as a method of disposal. The procedure may, however, be regarded as a means of reusing water for agricultural purposes and as a method of recovering nutrients contained in the sewage.

Primary treatment

This is the first major stage of conventional sewage treatment, following the screening of coarse solids and grit removal. The sewage is passed through specially designed tanks, providing a retention period of 2–4 hours, in which perhaps 30–50% of the suspended solids are removed and the associated biological oxygen demand (BOD) reduced. Means of disposal of the resulting sludge must be provided.

Secondary treatment

Broadly speaking, there are three basic methods of secondary treatment. The first two, which depend on biological flocculation and oxidation, are
the activated-sludge process and biological filtration (trickling filtration). Both are extensively used for the treatment of sewage and industrial wastes. When treating a sewage of normal characteristics, the overall reduction of BOD and suspended solids to be expected from a conventional combination of primary and secondary treatment will be 85–95%. In many cases, therefore, the resulting effluent will have a suspended solids content of about 20mg/l and a correspondingly low BOD, and it will be suitable for discharge to many rivers without causing obvious pollution.

The third method of secondary treatment is the waste stabilization pond, the design and use of which has been extensively reviewed by Glynna (1971). Wastewater, which may or may not have received some preliminary treatment, is retained in a pond or lagoon for periods of up to several weeks. In a properly designed and operated pond, well over 90% of the polluting matter (in terms of its BOD) can be removed and the number of microorganisms much reduced. Ponds have the advantage of providing a fairly high degree of treatment at relatively low cost, with little call for equipment or skilled operators.

7.2 Advanced processes

Removal of suspended solids

By relatively simple processes the content of suspended solids in a secondary effluent can be reduced to 5-10 mg/l. A "polished" effluent of this kind is suitable for discharge into most rivers and can be used for many industrial purposes (e.g., cooling, quenching, and washing) for which a low-grade water is adequate. The treatment processes used to obtain water of this quality include: (1) tube settlers consisting of tubes of various cross-sectional configurations inclined at 45°–60° to the horizontal, in which the suspended solids settle; (2) sand filtration; (3) microstraining, or microscreening and; (4) irrigation over grassland followed by retention in maturation ponds. The last two processes also remove microorganisms.

Clarification processes

By the application of techniques normally used for potable waters, the content of suspended solids may be reduced virtually to zero, yielding a water that from this point of view approximates to potable standards. Normally, the water would be treated with an aluminium or ferric salt or with lime, subjected to gentle turbulence to flocculate the precipitate, and passed through a sedimentation tank and then through a rapid sand or multimedia filter. If the dosage of coagulant is adequate, phosphate is also removed. Water produced in this way, after disinfection, would be suitable for a wide range of industrial and other uses.
The wider use of waters reclaimed by one or other of the methods outlined above may be precluded by the presence in the water of certain substances or groups of substances. These may be classified according to the proposed use as follows:

(a) Industrial—dissolved salts (unspecified), dissolved organic matter (unspecified), chlorides, phosphates, ammonia.

(b) Recreational—phosphates, nitrates, ammonia.

(c) Agricultural—dissolved salts, boron, toxic chemicals that may lead to the problem of residues.

(d) Potable—dissolved salts (unspecified), dissolved organic matter (unspecified), ammonia, nitrates, nitrites, chlorides, sulfates, toxic metals, toxic organic materials, substances imparting taste, odour, and colour.

The removal of phosphates and nitrogen compounds presents special problems and will therefore be dealt with separately. A single process will often remove more than one type of contaminant.

Removal of ammonia, nitrites, and nitrates

Sewage contains urea and organic compounds of nitrogen. During conventional primary and secondary treatment all these substances are converted to ammonia and, under favourable conditions, to nitrite and then to nitrate. Some nitrogen is normally lost in the elementary gaseous form during treatment.

For some potential applications of reclaimed water, ammonia is objectionable; it reduces the efficiency of chlorination and may lead to corrosion. Nitrate is a nutrient that is useful in irrigation but may contribute to the eutrophication of streams and lakes. It is objectionable at high concentrations in drinking-water (above the maximum of 45 mg/l recommended by WHO) as it may cause methaemoglobinaemia in infants. There is also evidence that nitrate may be reduced in vivo to nitrite, which, under certain conditions, may lead to the formation of nitrosamines or produce a neurotoxic effect (Gruener & Shuval—in press).

If the process of nitrification (conversion of ammonia to nitrate) can be allowed to proceed to completion in the secondary treatment process, the resulting nitrate may be less objectionable in industrial applications than the original ammonia. However, if nitrate is objectionable it may be reduced to elementary nitrogen by biological denitrification in a modified activated-sludge process.

Ammonia itself may be removed after either primary or secondary treatment by the addition of lime to raise the pH value to 10.5 or more, followed by aeration in a specially designed tower. Very large volumes of air are required—several thousand times the volume of liquid—and at
low temperatures the process is ineffective, partly because of the greater solubility of ammonia and partly because of freezing. It appears also that, under circumstances not fully understood, a hard scale may form on the elements of the tower. The liquid discharged from the tower has a high pH value and usually requires neutralization before being passed on to secondary treatment or sand filtration. When the process is applicable, it is likely to be the least costly of the nitrogen removal methods.

Removal of phosphate

Phosphate may be undesirable in water discharged to recreational lakes, where it may stimulate the growth of algae, or in water used in industry, where it may interfere with softening processes and cause scaling on heat-exchange surfaces. It is readily removed, however, during treatment with aluminium of ferric salt or with lime.

When lime treatment is specifically required, the removal of phosphate is most efficiently carried out in two stages. Details are given by Culp & Culp (1971). Where ammonia removal is not required, the dosage of lime will be smaller and neutralization may not be necessary. Phosphate may be removed by the use of lime before, during, or after secondary treatment. In the first case the organic material removed will reduce the pollution load on the secondary treatment plant, with a consequent improvement in capacity.

When phosphate is removed from secondary effluent using lime, the process of multimedia filtration may be used. In this process a layer of coarser granular material such as coal rests on a layer of finer but denser material, usually sand; three-media filters have materials of three densities. Thus the suspended matter passing downwards through the filter first encounters a coarse medium, where the larger particles are removed, and then a finer filter. The sequence of layers is not disturbed by backwashing, which is needed less often than is the case with single-layer filters, thus showing considerable savings in the cost of operation.

Activated carbon treatment

Activated carbon has the capability of removing from water a wide range of organic materials, particularly those of industrial origin. It is generally efficient in adsorbing aromatic hydrocarbons, chlorinated pesticides, and similar classes of compounds. Carbon is not universally effective, and tests need to be made on the particular substances to be removed. The removal of gross organic matter disposes of many organic toxicants and increases the efficiency of any final disinfection. Carbon treatment is an essential step in the production of the highest quality effluents and in the production of potable water from effluents. Many treatment plants producing drinking-water from polluted sources use carbon for taste and odour
control, and the Meeting recommended that this practice should be adopted as a standard precaution from a health point of view as well as for improving the acceptability of the water.

The simplest method of applying carbon is to add the powdered material at the clarification stage. This avoids the construction of a special treatment stage, but has the disadvantage that the carbon cannot be recovered and regenerated, as is the common practice at waterworks.

The more usual procedure is to pass the clarified water through columns filled with granular carbon, which, when saturated with contaminants, can be regenerated thermally on site or at a central installation. Losses of about 5% occur, and make-up carbon has to be added.

Removal of dissolved salts

Dissolved salts such as sodium chloride and calcium bicarbonate are always present to some degree in natural waters, and their concentration in the wastewater discharged from a city is about 200–350 mg/l higher. Recycling this wastewater in a completely closed system would cause salt concentrations to build up to an intolerable level. Salts may interfere with industrial processes and agriculture, and their removal may therefore be necessary. Several methods are available:

(a) Ion exchange. Almost complete salt removal can be obtained by ion exchange techniques. Only part of the flow need be treated, the remainder being diluted with the treated volume. Several other ways of using ion exchange methods have recently been developed.

(b) Electrodialysis. Electrodialysis utilizes membranes with selective properties, permitting ions to pass to a concentrating stream while retaining the less salty water. The process is in use for demineralizing brackish water and in industrial applications, but it is less frequently applied to wastewater.

(c) Distillation. Distillation is the most commonly used method for converting seawater to fresh water. Experimental work has shown that the distillation of wastewater effluents can be fairly effective, but some additional treatment before or after distillation is necessary to obtain good water. The high cost and the availability of suitable alternative methods have so far prevented the practical use of distillation in wastewater treatment.

(d) Reverse osmosis. Specially prepared membrane materials, including particularly cellulose acetate, permit the passage of water but retain most salts, organic substances, and bacteria. Further research is required to determine the extent to which viruses are also retained. A pressure of 20–50 kgf/cm² is required to counteract osmotic pressure and to produce an acceptable flow through the membrane.

Systems employing reverse osmosis are commercially available; they are used in several industrial separation processes and are being applied to
purify brackish waters. A considerable amount of research has been done on the application of this technique to wastewater purification. The method holds promise, and further developments are under way.

**Disinfection**

Disinfection is usually the last defence against any remaining microbial contaminants that may have survived the various treatment processes. The disinfection of drinking-water from surface sources is almost universally practised. Disinfection is also applied to wastewater treatment plant effluents and to water intended for reuse.

Chlorine is the most used disinfectant and has played a major role in the prevention of waterborne diseases, although it has some shortcomings. It is most effective as hypochlorous acid (HOCI)—or "free chlorine"—which is easily formed in clean water free of organic matter and ammonia. Hypochlorous acid kills coliform bacteria in a few minutes but takes an hour to kill some viruses. If organic materials are present, particularly nitrogenous materials, the chlorine will react with them and may not appear in the free form unless considerable excess is added.

In the presence of ammonia, mono- and dichloramines are formed. These are also disinfectants but are much slower acting. In the presence of an excess of chlorine the ammonia is destroyed, but each part of nitrogen present as ammonia requires for its destruction nearly 10 parts of chlorine (break-point chlorination). It has been suggested that organic chlorine compounds originating from chlorinated effluents discharged into streams may be toxic to fish life.

Ozone, a powerful oxidant, is also used as a disinfectant. WHO's *International standards for drinking-water* states that 0.4 mg/l of free ozone for 4 minutes is sufficient to inactivate viruses. In France ozone has been used extensively for disinfecting drinking-water. Ozone does not react with ammonia under most use conditions and decomposes to oxygen, thus leaving no objectionable residue.

At doses applied for disinfection, ozone also lessens the colour of effluents. The destruction of organic residues, however, calls for much greater doses, and the use of this method then becomes costly. Although ozone is more expensive than chlorine, its use is expected to grow, especially for wastewater disinfection.

Iodine, ultraviolet radiation, and gamma radiation are good disinfectants but have not come into large-scale use in the treatment of wastewater.

Disinfection is most likely to be effective if the water is nearly free of organic matter and ammonia. Contact time is important; at least 0.5 mg/l of free chlorine or the equivalent of other disinfectants for one hour is recommended. Substantial kills of organisms occur when any disinfectant
<table>
<thead>
<tr>
<th>Health criteria (see below for explanation of symbols)</th>
<th>Irrigation</th>
<th>Recreation</th>
<th>Municipal reuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health criteria:</td>
<td>Crops not for direct human consumption</td>
<td>Crops eaten cooked, fish culture</td>
<td>Crops eaten raw</td>
</tr>
<tr>
<td>Primary treatment</td>
<td>A + F</td>
<td>B + F or D + F</td>
<td>D + F</td>
</tr>
<tr>
<td>Secondary treatment</td>
<td>B ● ● ● ●</td>
<td>B ● ● ● ●</td>
<td>B ● ● ● ●</td>
</tr>
<tr>
<td>Sand filtration or equivalent polishing methods</td>
<td>C ● ● ● ●</td>
<td>C ● ● ● ●</td>
<td>C ● ● ● ●</td>
</tr>
<tr>
<td>Nitrification</td>
<td>D ● ● ● ●</td>
<td>D ● ● ● ●</td>
<td>D ● ● ● ●</td>
</tr>
<tr>
<td>Denitrification</td>
<td>E ● ● ● ●</td>
<td>E ● ● ● ●</td>
<td>E ● ● ● ●</td>
</tr>
<tr>
<td>Chemical clarification</td>
<td>F ● ● ● ●</td>
<td>F ● ● ● ●</td>
<td>F ● ● ● ●</td>
</tr>
<tr>
<td>Carbon adsorption</td>
<td>G ● ● ● ●</td>
<td>G ● ● ● ●</td>
<td>G ● ● ● ●</td>
</tr>
<tr>
<td>Ion exchange or other means of removing ions</td>
<td>H ● ● ● ●</td>
<td>H ● ● ● ●</td>
<td>H ● ● ● ●</td>
</tr>
<tr>
<td>Disinfection</td>
<td>I ● ● ● ●</td>
<td>I ● ● ● ●</td>
<td>I ● ● ● ●</td>
</tr>
</tbody>
</table>

Health criteria:
A Freedom from gross solids; significant removal of parasite eggs.
B As A, plus significant removal of bacteria.
C As A, plus more effective removal of bacteria, plus some removal of viruses.

In order to meet the given health criteria, processes marked ●●● will be essential. In addition, one or more processes marked ●● will also be essential, and further processes marked ● may sometimes be required.

D Not more than 100 coliform organisms per 100 ml in 80% of samples.
E No faecal coliform organisms in 100 ml, plus no virus particles in 1000 ml, plus no toxic effects on man, and other drinking-water criteria.
F No chemicals that lead to undesirable residues in crops or fish.
G No chemicals that lead to irritation of mucous membranes and skin.

* Free chlorine after 1 hour.
is applied, and sensitive organisms such as the cholera vibrio are killed easily. Enteric viruses in general and hepatitis virus in particular require much more treatment than most bacteria, but the recommended contact period of one hour will provide a margin of safety.

7.3 Quality of treated effluents

The quality of effluent produced will depend largely on the concentrations and types of contaminants in the wastewater and on the treatment processes applied. Table 1 suggests some suitable treatment processes that may be used, taking account of health safeguards (see section 6). Table 2 shows the high average quality obtainable by applying advanced treatment processes to secondary effluent.

### TABLE 2. QUALITY OF WATER FROM RENOVATION SYSTEM FOR PRODUCING POTABLE WATER

<table>
<thead>
<tr>
<th></th>
<th>Concentration in effluent (mg/l)</th>
<th>United States Public Health Service drinking-water standard (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical oxygen demand</td>
<td>5</td>
<td>1/100 ml</td>
</tr>
<tr>
<td>Coliform organisms (mean density)</td>
<td>Effluent breakpoint chlorinated</td>
<td>5 units</td>
</tr>
<tr>
<td>Turbidity</td>
<td>&lt; 1 unit</td>
<td>15 units</td>
</tr>
<tr>
<td>Colour</td>
<td>&lt; 2 units</td>
<td>3 units</td>
</tr>
<tr>
<td>Threshold odour number</td>
<td>No odour</td>
<td>0.5</td>
</tr>
<tr>
<td>Methylene blue active substances</td>
<td>&lt; 0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Chloride</td>
<td>&lt; 250</td>
<td>250</td>
</tr>
<tr>
<td>Carbon chloroform extract</td>
<td>&lt; 0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>Cyanide</td>
<td>0</td>
<td>0.01</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt; 0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Manganese</td>
<td>&lt; 0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Nitrate (NO₃)</td>
<td>&lt; 45</td>
<td>45</td>
</tr>
<tr>
<td>Phenols</td>
<td>0</td>
<td>0.001</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>&lt; 0.5</td>
<td>—</td>
</tr>
<tr>
<td>Sulfate (SO₄)</td>
<td>&lt; 250</td>
<td>250</td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>&lt; 500</td>
<td>500</td>
</tr>
</tbody>
</table>

* The values given are a combination of results from a number of pilot studies (primarily the study at Pomona, California) and from the advanced waste-treatment plant at South Lake Tahoe, California.

7.4 Typical combinations of unit processes

Fig. 3 depicts a treatment system that should produce water satisfactory for a recreational lake. It includes nitrification and the removal of phosphorus compounds down to the level of about 0.1 mg of phosphorus per litre.
FIG. 3. TREATMENT SYSTEM FOR PRODUCING RECREATIONAL LAKE WATER

The removal of organic impurities should be excellent because of the two-stage biological treatment and filtration, and suspended solids in the treated water should be almost zero. Costs for a plant capable of processing about 38,000 m$^3$/day (10 million US gallons) are shown in Table 3. The costs given are for conditions in the USA and are not necessarily applicable to other countries. This plant size was chosen because it is roughly in the range that might be used for producing recreational water. For comparison, the total operating cost for a plant ten times smaller would be $0.185/m^3$ and for a plant ten times bigger, $0.04/m^3$.

For the production of potable water a system such as the one shown in Fig. 4 might be used. With the exception of the demineralization step, it is very much like the advanced waste treatment plant at South Lake Tahoe. The treated water from the system would meet the International standards for drinking-water.

The costs of the system, for a plant producing 38,000 m$^3$/day, are given in Table 4. The operating cost, including amortization, of $0.135/m^3$ is reasonable in comparison with the cost for water from other sources in water-short areas. The operating cost for a plant ten times the size would be about $0.085/m^3$.

TABLE 3. COSTS FOR A TREATMENT PLANT PRODUCING 38,000 m$^3$/day OF RECREATIONAL LAKE WATER (10 million US gallons)

<table>
<thead>
<tr>
<th>Process</th>
<th>Capital cost ($)</th>
<th>Operating cost ($/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary treatment and activated-sludge process</td>
<td>2,400,000</td>
<td>0.057</td>
</tr>
<tr>
<td>Biological nitrification</td>
<td>1,030,000</td>
<td>0.011</td>
</tr>
<tr>
<td>Two-stage lime treatment</td>
<td>1,500,000</td>
<td>0.025</td>
</tr>
<tr>
<td>Dual-media filtration</td>
<td>510,000</td>
<td>0.009</td>
</tr>
<tr>
<td>Chlorination (15 mg/l)</td>
<td>80,000</td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5,520,000</strong></td>
<td><strong>0.075</strong></td>
</tr>
</tbody>
</table>
FIG. 4. TREATMENT SYSTEM FOR PRODUCING POTABLE WATER

TABLE 4. COSTS FOR A TREATMENT PLANT WITH A CAPACITY OF 38,000 m³/day, FOR THE PRODUCTION OF POTABLE WATER

<table>
<thead>
<tr>
<th></th>
<th>Capital cost ($)</th>
<th>Operating cost ($/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary treatment and activated-sludge process</td>
<td>2,400,000</td>
<td>0.027</td>
</tr>
<tr>
<td>Biological nitrification</td>
<td>1,080,000</td>
<td>0.011</td>
</tr>
<tr>
<td>Two-stage lime treatment</td>
<td>1,500,000</td>
<td>0.025</td>
</tr>
<tr>
<td>Dual-media filtration</td>
<td>510,000</td>
<td>0.009</td>
</tr>
<tr>
<td>Granular carbon treatment</td>
<td>1,600,000</td>
<td>0.026</td>
</tr>
<tr>
<td>Ion exchange (~40% mineral removal)</td>
<td>1,200,000</td>
<td>0.034</td>
</tr>
<tr>
<td>Chlorination (15 mg/l)</td>
<td>80,000</td>
<td>0.003</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8,390,000</strong></td>
<td><strong>0.135</strong></td>
</tr>
</tbody>
</table>

* Capital cost is for a plant producing 19,000 m³/day, since it is assumed that only half the water will be treated for 80–90% mineral removal.

7.5 Sludges and residues from treatment processes

Within the scope of this report it is possible to discuss only briefly the question of sludges and other residues resulting from treatment. The Meeting recommends that WHO should undertake a separate study on this subject.

The treatment of municipal and industrial wastewater nearly always involves the removal of solids. Sludges, slurries, and brines resulting from treatment create problems of disposal, which may account for half the total cost of treating wastewater. The application of additional treatment processes beyond the conventional biological methods results in more sludge, and sludge with different properties. For instance, phosphorus is best removed by chemical precipitation using iron or aluminium salts or in some cases lime, the sludges from which are sometimes difficult to dewater. Brines resulting from reverse osmosis or other demineralization processes also give severe disposal problems.
Most sludges are disposed of either by spreading on the land or by burial in selected locations. Many cities incinerate municipal waste sludge after separation by drying or vacuum extraction. Coastal cities often convey the sludge out to the sea in pipes or barges, but this practice is now being seriously questioned.

Sludges tend to concentrate the most unwanted materials. This is an advantage in obtaining clean water, but makes disposal a more difficult and dangerous operation. Bacteria, viruses, and parasite eggs and cysts are all to be found in raw sludges and to a lesser extent in digested sludges. Heavy metals such as iron, zinc, mercury, and cadmium are found in much higher concentrations in city industrial sludges than in the wastewater from which they were produced. Most sludges contain small amounts of DDT and other chlorinated pesticides, and many of them contain polychlorinated biphenyls from industry.

Sludges are not without some nutrient value, since they contain nitrogen, phosphorus, and trace elements. Where land spreading can be carried out for agricultural purposes, the value of the water in the sludge may be of more value than the nutrients since most sludges contain over 90% water. Although sludges have been used in agriculture for a long time, good guidelines to the practice are scarce. In general, land disposal is the cheapest way of disposing of sludge, particularly if it enables crops to be grown on poor land. In some places sludges are subjected to heat treatment to kill any remaining pathogens before agricultural use is permitted. In Switzerland, for instance, pasteurized sludges may be used on the land in certain circumstances.

Another method of disposal is to compost sewage sludges with municipal solid waste. It is advantageous to have the composting plant and wastewater plant at the same location. Many soils are depleted in organic matter and hence unstable, and the run-off from such soils adds to water pollution. The return of organic matter from city wastes to the soil is warranted in such cases. The city of Chicago is sending sludge by rail to sites 50 km away to spread it on poor land and is considering transporting it up to 150 km. Early results are encouraging.

Wastewater is often treated with lime to precipitate phosphorus, and these lime sludges may be returned to the soil. Another advantage of the lime process is that much of the calcium can be recovered and reused in the process. The recovery of aluminium and magnesium from sludges is less advanced, but there are good prospects of suitable methods being developed.

8. QUALITY CONTROL OF RENOVATED WATER

Quality control is essential for any water derived from polluted sources, and the more recent the derivation, the more important the quality control. In planning water reuse projects a positive laboratory testing and control
programme must be set out. The types of examinations needed are outlined below; standard textbooks should be consulted for details.

8.1 Biological examination

Irrespective of the proposed reuse of the renovated water, a direct microscopic examination should be made for protozoan cysts and eggs of parasites, and if any are detected their viability should be determined. Ten-litre samples of reclaimed water should be taken and the sediment examined after filtration.

8.2 Detection and monitoring of bacteria

The level of faecal coliform organisms permissible depends on the anticipated use of the water. As there may be a regrowth of bacteria in irrigation reservoirs after disinfection, the bacterial counts should be carried out directly after treatment to assess the performance of treatment and disinfection. Work on methods allowing a faster determination of bacterial content should be encouraged, to overcome the delays inherent in present methods between the taking of samples and the result of analysis. The full testing of batches of water before their release is usually the safest way of handling renovated wastewater intended for domestic consumption, but it necessitates the retention of large volumes of water while the tests are carried out, which may be impracticable. In situations where anaerobic conditions may exist, e.g., in sediments, the presence of Clostridium species should be checked.

The precaution outlined in WHO’s International standards for drinking-water (third edition, pp. 45–49) should be observed when samples are being collected, transported, and stored.

8.3 Virus detection

It is not practicable to examine water for viruses as frequently as for bacteria. Several days are required to carry out virus tests, and only a few countries have suitable laboratories and personnel.

When wastewater is reused for domestic purposes, examination for enteric viruses is very important, especially in view of the fact that viruses are much more hardy than bacteria. They may thus be present even in waters that are, from a bacteriological point of view, satisfactory.

As viruses are stable and do not multiply outside host cells, samples may be transported before examination without greatly affecting the virus content. Thus a few reference laboratories may serve a large area and may be set up on a regional basis. Unnecessary delays in transportation should be avoided.
Research on improved methods for the quantitative evaluation of virus content is in progress, and further work should be encouraged. As long as the observation of cytopathic effects in tissue culture cells remains the basis of testing, and as long as tests must be carried out on as much as 10 litres of water, rapid results cannot be expected.

8.4 Chemical testing

The chemical testing programme is determined by the quality requirements of the water reuse application. Important tests in almost any reuse application include measurements of pH, suspended solids, chemical oxygen demand, total dissolved solids, alkalinity, turbidity, ammonia, nitrates, phosphorus, and any toxic chemicals suspected, particularly the heavy metals. Further research is needed to establish simple methods of determining the concentrations of organic chlorine, nitrogen, and phosphorus.

For testing high-quality water, the total organic carbon offers a quick measurement of organic matter but does not measure specific materials. The instrument for carrying out the test costs several thousand dollars. The carbon adsorption method measures the carbon chloroform extract. This is a standard test for drinking-water in the USA, and it should also be carried out occasionally on renovated water used in food processing. If chlorinated pesticides are suspected, direct tests can be made for them. In general, suspected carcinogens should be identified and tests carried out for them.

The identification of trace amounts of organic substances remaining in effluents after extensive treatment is beyond the capability of all but the best equipped laboratories, and it is at present not practical or possible to identify all compounds. Thus the safety of renovated water can be judged only from the tests that can be made. When the source of water is known and appropriate treatment is applied, and where the efficacy of treatment is confirmed by careful and regular testing, the risk of harm is small. Modern analytical tools such as gas chromatography, mass spectrometry, and nuclear magnetic resonance can identify and measure trace substances rapidly, but they are expensive and their use requires considerable skill. Continuing research on more practical, quicker, and cheaper methods is warranted.

8.5 Bioassays

Bioassays are conducted to evaluate the toxicity of effluents discharged into other waters. Fish are the usual test animals but mice and organisms such as phyto- or zooplankton may also be used. Bioassays can be used to check the presence of toxic materials in water, calling attention to the necessity for other forms of testing.
8.6 Organization for water quality surveillance

Many countries are now monitoring rivers and lakes for various contaminants. Drinking-water and treated wastewater are likewise frequently monitored automatically and continuously. Reliable automatic measurements can be made of pH, conductivity (which is related to dissolved solids), turbidity, dissolved oxygen, and temperature, but no similar methods have yet been devised for measuring toxicity, pesticides, or specific industrial chemicals. Hence a well-equipped laboratory is necessary for quality control.

The effectiveness of water pollution control programmes and the control of water and waste treatment processes depend on accurate measurements. It is often necessary to compare the results of analyses over a period of years or to compare the results from one place with those from another, and such comparisons are not reliable without standard tests. It has been found that reliability is greatly improved if a selected laboratory in an area or a country serves as a reference centre for analytical methods. Samples sent from the reference centre to cooperating laboratories permit the regular testing of analytical techniques. Statistical evaluation of the test results will show the precision with which the tests are carried out. The Meeting recommended that WHO should consider establishing such a service for countries requiring it. The storage of accurate laboratory data in a computer permits the analysis of pollution trends and forms a permanent record of great value.

9. WATER QUALITY STANDARDS

To ensure the safety of water supplies, standards have to be applied. Standards for drinking-water have been available for many years.1

While national standards may be set for drinking-water, the qualities of river-water, industrial effluents, and reused wastewater are the responsibility of the local controlling authority. Even so, the standards set must take into account the possible transport of pollutants across borders or the effects of discharges on downstream water users. Standard setting is a most difficult and critical job, with important economic implications. Standards must be given the force of law, and an authority must be created to ensure that they are observed. A survey of existing water pollution legislation has been published by the World Health Organization (1967).

Standards governing the quality of water in rivers and lakes are becoming common. Some countries have, and others are formulating, standards

applicable directly to effluents, though few countries yet have standards for the planned reuse of treated wastewater. As wastewater reuse grows, it is important that standards be set for the reuse purpose.

As wastewater—treated or untreated—has been reused in agriculture for a fairly long time, some countries have developed standards for this purpose. A summary of some representative standards for the use of renovated water in agriculture is given in Table 5.

**TABLE 5. EXISTING STANDARDS GOVERNING THE USE OF RENOVATED WATER IN AGRICULTURE**

<table>
<thead>
<tr>
<th></th>
<th>California</th>
<th>Israel</th>
<th>South Africa</th>
<th>Federal Republic of Germany</th>
</tr>
</thead>
</table>
| Orchards and vineyards | Primary effluent;  
no spray irrigation;  
no use of dropped fruit | Secondary effluent. | Tertiary effluent,  
heavily chlorinated where possible.  
No spray irrigation. | No spray irrigation in the vicinity. |
| Fodder, fibre crops, and seed crops | Primary effluent;  
surface or spray irrigation. | Secondary effluent,  
but irrigation of seed crops for producing edible vegetables not permitted. | Tertiary effluent. | Pretreatment with screening and settling tanks.  
For spray irrigation, biological treatment and chlorination. |
| Crops for human consumption that will be processed to kill pathogens | For surface irrigation, primary effluent.  
For spray irrigation, disinfected secondary effluent (no more than 23 coliform organisms per 100 ml). | Vegetables for human consumption not to be irrigated with renovated wastewater unless it has been properly disinfected (<1000 coliform organisms per 100 ml in 90% of samples). | Tertiary effluent. | Irrigation up to 4 weeks before harvesting only. |
| Crops for human consumption in a raw state | For surface irrigation, no more than 2.2 coliform organisms per 100 ml.  
For spray irrigation, disinfected, filtered wastewater with turbidity of 10 units permitted, providing it has been treated by coagulation. | Not to be irrigated with renovated wastewater unless they consist of fruits that are peeled before eating. | | Potatoes and cane—irrigation through flowering stage only. |

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1 California State Department of Public Health (1968); Indian Standards Institution (1965b); Israel, Ministry of Agriculture, Water Commission (1969); Müller (1969); Peru, Ministry of Health, Department of Environmental Sanitation (1970); Shuval (1967).
The Indian Standards Institution (1965a) has laid down standards for industrial effluents discharged into public sewers, and South Africa (1956) has promulgated general standards for the return of municipal and industrial effluents to watercourses.

The standards laid down by the California State Department of Public Health (1968) cover recreational waters as well as irrigation. Very little information exists on standards for industrial reuse, and no standard for potable waters derived from effluents is known. The passages on health effects in this report (section 6) include some recommendations on quality criteria.

Not all health authorities will automatically accept renovated wastewater for drinking purposes, even though it may meet their quality standards for drinking-water, the reason being that the source of water is usually a part of the standards. In the past the source was usually considered to be a protected watershed or the “best source available”, meaning that dilution, storage, sedimentation, and natural purification had taken place. As pointed out in this report, many water sources now in use cannot be considered clean. Time is always a favourable element in reducing pollution, and if wastewater is reused very soon it is wise to take additional safety precautions. Pipe-to-pipe renovation and reuse pose many risks, and storage is always advisable before any reuse. Groundwater recharge involving extended periods of underground storage can provide a considerable safety factor in wastewater renovation.

10. RESPONSIBILITIES OF REGULATORY AND OPERATIONAL AUTHORITIES

If the maximum benefits are to be obtained, water reuse must be planned on a broad basis. The responsibilities of various levels of governmental and operational agencies are considered below.

10.1 Central government

Central government agencies for water pollution control, water supply, and health must formulate appropriate laws and policies on water reuse. Such laws and policies may be stated in general terms, specific rules being applied by the various political subdivisions. In the USA, Public Law 87–88 passed in 1961 amending the Federal Water Pollution Control Act, directed the Secretary (at that time of Health, Education, and Welfare), “to develop and demonstrate practicable means of treating municipal sewage and other waterborne wastes to remove the maximum possible amounts of physical, chemical and biological pollutants in order to restore and maintain the maximum amount of the Nation’s water at a quality suitable for repeated reuse.”
In Israel, maximum wastewater renovation is an official part of the national water resources policy.

In the United Kingdom, the Government has set up 10 authorities in England and Wales for "the provision of water and the reclamation or disposal of used water" (United Kingdom, Department of the Environment, 1971).

A further role of central government is to establish guidelines and criteria for water quality standards. Local governments then have the responsibility for setting detailed standards for general water quality or water reuse. This subject has been discussed in section 9 of this report.

10.2 Pollution control and water supply agencies

In many countries, water supply, pollution control, and water reuse are the responsibility not of one agency but of several. In such cases, close coordination among the various agencies is essential, particularly when it is necessary to promote the renovation and reuse of wastewater.

The responsible agency or agencies should determine the potential amount of water reuse over a wide area, and specific studies should then be made in smaller areas. Successive actions in the development of water reuse might be as follows:

1. to list water uses in the local area in order of acceptable water quality
2. to estimate the extent to which the available water supplies could be supplemented by wastewater reclamation
3. to estimate the extent to which wastewater reclamation could relieve downstream collection and treatment systems
4. to develop legislative, economic, and planning procedures to implement water reuse
5. to examine the available technology, to assess public acceptance, and to determine cost/benefit ratios.

10.3 Industrial role in water reuse

Industrial plants are at once large users of water and producers of pollution. Thus the industrial operator has responsibility for water conservation and pollution control. Close attention to plant practices can often minimize the industrial problem. Water should be recycled within the plant, and the use of municipal sewage plant effluents as a source of water should be instituted whenever practicable. There are many ways in which factory managers and engineers can help to minimize the use and pollution of water resources. For example, they might:
(1) examine all plant practices to obtain optimum water use and recycling, with a minimum of waste effluents, and so endeavour to become a minimum discharge industry

(2) consider the use of available waters of secondary quality (sewage plant effluents, brackish waters, seawater, etc.) for suitable purposes

(3) examine chemicals and processes contributing to pollution and determine whether changes can be made that will lessen pollution

(4) consider the recovery of materials from waste

(5) maintain a constant awareness of new developments in processes to control pollution

(6) encourage all plant personnel to become conscious of the problems of water and pollution.

11. SUMMARY AND RECOMMENDATIONS

For many purposes, such as irrigation, industrial cooling and processing, the watering of parks and golf courses, and the provision of recreational and ornamental lakes, wastewater can be, and has been, used safely after suitable treatment.

As a general principle, water uses should be graded according to the degree of purity required, and, in any area in which water is short or likely to become so, available water sources should be allocated in such a way that water of high quality is not used for a purpose that can tolerate a lesser degree of purity.

By grading and reusing effluents for low-grade purposes, it will usually be possible to effect such water savings that potable water may be obtained from existing natural sources. If this proves impossible, present-day technology is adequate if proper conditions prevail to treat most municipal wastewaters to a degree that will render them safe for drinking and other domestic uses, but careful management, the application of appropriate treatment processes, and a rigorous programme of sophisticated surveillance, monitoring, and testing are absolutely essential if the public health is to be protected.

Whenever the intentional direct or indirect reuse of wastewater is planned or becomes inevitable, the following conditions should be ensured:

(1) Water quality standards appropriate to the reuse should be formulated and rigidly enforced.

(2) As a guide to governments wishing to formulate national standards, international agencies such as WHO and FAO should develop reuse
standards for various purposes, including food preparation and the watering of agricultural crops.

(3) Full knowledge should be maintained of each water source whatever it may be, whether a natural body of water or wastewater, so that treatment may be adequately designed to allow for possible fluctuations in quality, account taken of potential health risks, and adequate safeguards taken to ensure the safety of workers and consumers.

(4) Laboratory facilities should be adequate to undertake the programme of monitoring and testing appropriate to the proposed water use. For certain complicated test procedures, involving special skills and equipment such as are needed to identify viruses or traces of certain organic materials, it may be sufficient to provide facilities on a regional or area basis.

(5) Reuse systems should be designed by well qualified engineers experienced in such new treatment processes as chemical coagulation, high-efficiency filtration, carbon adsorption, reverse osmosis, and ion exchange, appropriate combinations of which make it possible to reduce nearly all contaminants in wastewater to concentrations found in natural unpolluted sources. The operation and supervision of these systems should be entrusted to highly trained personnel.

(6) The safe disposal of sludges, slurries, and brines, which may be highly dangerous to handle, should be taken fully into account both at the design stage and in operation.

Existing natural sources of drinking-water in several parts of the world already contain industrial and municipal wastewater in proportions that may approach 100% in periods of low flow. The degree to which this unintentional and indirect reuse affects existing sources should be determined and appropriate measures should be taken, particularly in critical areas, to ensure the safety of drinking-water.

Further research is required in the following areas, in which the present state of knowledge is known to be insufficient:

(1) The potential long-term health effects of trace materials and residues remaining after conventional water treatment. Research on this topic should include both physiological investigations on individuals known to have been using drinking-water derived from polluted sources and toxicological studies on the waters themselves under laboratory conditions.

(2) The improvement of methods of identifying, measuring, and monitoring chemical and microbial pollutants. Rapid identification of bacteria and viruses is required, and there is a need for a means of monitoring chemical pollutants by simple field tests, without the use of expensive equipment and highly qualified analytical staff.
(3) The development and improvement of treatment and separation processes suitable for use in many parts of the world. The reliability of treatment processes should be increased, and a more accurate determination should be made of their capabilities, separately and in combination, to remove different types of contaminant in varying concentrations.

(4) The practicability and cost of dual water systems for first and second class waters. Dual systems may become a necessary feature of water management in the near future in some areas, and investigations should be put in hand, including studies on health hazards and their avoidance, so that guidance is available to governments faced with the necessity of installing such systems without prior experience of their advantages or dangers.

WHO should encourage the standardization of present analytical methods, possibly through its present network of international reference centres and collaborating institutions. It is considered important that the techniques used by government and waterworks laboratories in various parts of the world should lead to uniform results through the use of standard tested methods.

Water supply, waste disposal, and water reuse are inextricably interrelated activities, usually affecting more than one population group and several geographic areas. Where applicable, the establishment of regional multipurpose authorities having control of both water resources and water treatment may be the best solution to the management of these activities; where such authorities are unsuitable or undesirable, a coordination body should bring together all the various interests to ensure integrated action for the conservation of water and the protection of the consumer.

Water reclamation and reuse may be the most practicable solution to water shortages, and they are likely to be forced on governments in certain areas with increasing urgency. They present no insuperable technical problems, although more knowledge will lead to economies and greater reliability. Reclamation is a practical solution to water scarcity in most conditions, provided that adequate precautions are taken in the design and operation of systems to protect the health of the individual and of the community.

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Annex 1

A SURVEY OF WASTEWATER REUSE IN CERTAIN COUNTRIES

An informal questionnaire was sent to experts in various countries, among whom were members of the WHO Expert Advisory Panel on Environmental Health, directors of WHO collaborating institutions for wastes disposal, and participants in the Meeting of Experts on the Reuse of Effluents: Methods of Wastewater Treatment and Health Safeguards. Replies were received from experts in the following 30 countries:

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The questions asked and the replies received are given below.

To what extent are wastewater effluents currently being used for agricultural, industrial, recreational, or municipal purposes in your country?

Agricultural use. The reuse of wastewater for agricultural purposes is by far the largest reuse and is indicated in the replies from experts in 18 countries. Raw sewage is used in 3 of the countries to irrigate grazing lands, vegetables, and grasses or for other unspecified uses. Also used for irrigation are treated municipal effluents and discharges from breweries, starch factories, textile works, dairy farms, and slaughterhouses; the crops irrigated include rye, potatoes, grass, and sugar beet.

Industrial use. The industrial use of effluents is common and increasing; it was reported by experts from 12 countries. Recycling in factories is extensive. Secondary effluents, usually with some additional treatment such as sand filtration or chemical treatment, are used for cooling. Effluents treated by chemicals, filtration, or other advanced processes are used in a paper mill, for rinsing water in metal finishing, and for coke quenching. In one country, effluent, after tertiary treatment, is piped to an industrial estate for general use.

Recreational use. Municipal effluents treated by advanced methods such as chemical treatment, filtration, and chlorination are in use in the
USA for water supply to man-made lakes used for boating, fishing, and, in one case, swimming. In Mexico, effluents have been utilized for artificial lakes in parks. Golf links are watered with treated effluents in several countries.

Are there plans for expanding wastewater utilization in your country? To what extent have these plans reached the engineering design stage?

**Austria** At one plant, the effluent will be discharged to a pond system, which will be part of Vienna's International Garden Fair in 1974.

**Canada** Only in the industrial field; more for pollution control than for anything else.

**Czechoslovakia** Plans exist for wastewater utilization, either in agriculture, or for recirculation in almost all branches of industry, and the State authorities are enforcing them.

**Hungary** The reuse of wastewater will increase in the next 5–10 years owing to the rapid increase in demand and the limited resources of water available. The possibility is being considered in a long-term plan for the development of water resources.

**India** There are plans for an increased use of wastewater—for example, whenever new sewerage schemes are approved. From March 1969, i.e., from the beginning of the Fourth Plan, States are making provisions for use of wastewater effluent for agricultural purposes.

**Iran** A study of wastewater reuse is a component of the UNDP-assisted pre-investment survey of sewerage needs and facilities in Teheran, for which WHO is the executing agency.

**Israel** Major reuse projects designed to serve one million people in the Tel Aviv region are under construction. Wastewater utilization is part of national resources planning and will include domestic use. Wastewater is already being reused in 180 agricultural projects, which utilize about 25% total sewage flow during summer months.

**Malta** A UNDP-assisted project on wastes disposal and water supply, for which WHO is the executing agency, includes a feasibility study on the recharging of effluent (tertiary treatment including chlorination, activated carbon, and sand filtration), and on the agricultural use of effluent (secondary treatment).

**Mexico** There is a complete technical and economic feasibility study for expanding the reuse of industrial wastewater in Mexico City.

**Peru** In studies for the disposal of the effluent of the Lima sewerage systems, a possibility that is being considered is land use after lagoonning.

**Singapore** Expansion of the present industrial water-treatment plant, for the tertiary treatment of sewage effluent, from 9000 m³/day to 45 000 m³/day, is planned for the near future.

**South Africa** The industrial reuse of wastewater is expanding, and reuse for other purposes is being considered since it is regarded as a necessity throughout the country.
United Kingdom: An increasing indirect reuse of effluents is regarded as inevitable in the future if the increasing demands for water are to be met. Several direct reuse schemes are also planned or in operation.

United States of America: There is increasing interest in all types of reuse—for industry, reinjection into underground water bodies, recreational lakes, and irrigation of parks, green belts, and highway shrubbery.

Have any standards been established governing the required degree of treatment or the required quality of effluent for use in agriculture and industry or for recreational or municipal purposes? Are there any specific requirements for the irrigation of crops that are consumed raw?

Only 5 replies indicate that standards for wastewater reuse have been set. Standards for agricultural reuse are the most common. California has set standards for the reuse of wastewater for recreational purposes. Further information on standards is given in section 9 of this report.

At the present time is there in your country any wastewater treatment the effluent from which is being used for unrestricted domestic consumption? If so, have the authorities established standards governing the treatment required, the quality of the water, or the specific laboratory controls for the supply?

The only known example of current use of renovated wastewater for partially meeting potable water needs is at Windhoek, Namibia. In 1956-57 renovated wastewater was used for drinking at Chanute, Kans., USA, during an emergency. Details are given in section 5.4 of this report. No standards are reported from any country for renovated wastewater for domestic supplies.

Are there any plans or research studies in your country concerning the possible future utilization of wastewater for drinking?

Planning or research on the reuse of wastewater for drinking is mentioned in the replies from experts in India, Iran, Israel, Netherlands, Singapore, South Africa, Thailand, the United Kingdom, and the USA. In Israel, the Dan region project is expected eventually to reclaim most of the wastewater from Tel Aviv, store the reclaimed supply underground, and reuse it for all purposes. It has already been demonstrated at Windhoek, Namibia, that drinking-water can be made from wastewater, and experimentation on improved systems is continuing. In the USA, plans are being made to study the removal of toxicants and viruses from wastewater during treatment by advanced processes. Work will shortly begin on formulating standards for renovated water. The health effects of renovated water will be tested.
Do you feel that the public in your country would view the utilization of wastewater for drinking as a possible, acceptable solution to water-shortage problems that may arise in the future?

Nearly all replies indicate that public acceptance of renovated wastewater for drinking would be most doubtful and would have to be won by extensive public education programmes. Two replies specify opposition by the health authorities.

General comments

The replies show that some countries have favourable water supplies and do not see the need for reuse, whereas others still lack adequate water supply and sewerage systems.
Annex 2

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