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WORLD HEALTH ORGANIZATION
TECHNICAL REPORT SERIES

No. 404

WATER POLLUTION CONTROL IN DEVELOPING COUNTRIES

Report of a WHO Expert Committee

WORLD HEALTH ORGANIZATION

GENEVA

1968

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PRINTED IN SWITZERLAND

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IN DEVELOPING COUNTRIES

Geneva, 12-18 December 1967

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WATER POLLUTION CONTROL IN DEVELOPING COUNTRIES

Report of a WHO Expert Committee

A WHO Expert Committee on Water Pollution Control in Developing Countries met in Geneva from 12 to 18 December 1967. Dr. P. M. Dorolle, Deputy Director-General, opened the meeting on behalf of the Director-General and welcomed the participants and the representatives of UNESCO and the Economic Commission for Europe. Professor G. M. Fair was elected Chairman, Mr R. S. Mehta Vice-Chairman, and Dr B. A. Southgate Rapporteur.

Widespread and serious water pollution has occurred in developing countries and, unless effective measures are taken, is likely to increase rapidly. Most developing countries are situated in tropical and semi-arid regions, and it is necessary to consider the effect that such climatic conditions may have on water quality and on types and effects of pollution. At the same time, the developing countries are those that have the greatest rate of population growth and a very high rate of urbanization and industrialization. Since water pollution is caused by the activities of man, it occurs to the greatest extent where urban populations are growing rapidly and where water resources are limited.

The committee was convened to review the most important problems of water pollution control in developing countries. Specifically, its tasks were as follows: (1) to examine the inter-relationship of water pollution and water resources; (2) to evaluate the health aspects of the problem; (3) to make recommendations for the planning of water use and pollution control in urban areas, agriculture, and industry; (4) to formulate general principles for the prevention of water pollution in relation to the management of water quality; (5) to make recommendations for the training of personnel engaged in the management of water resources and the control of water pollution; and (6) to point out areas in which further research is necessary.

1. REVIEW OF THE SITUATION IN DEVELOPING COUNTRIES

The Committee had before it the report of, and documents prepared for, an Inter-Regional Seminar organized by WHO in New Delhi in November 1967, at which 14 countries from the 6 WHO Regions were represented.

These countries were at different stages of development as judged by their degree of urbanization and industrialization, and had widely varying physical, demographic, and social conditions.

The basic documents referred to the situation in some 16 countries, in which the proportion of population living in urban areas ranges from 68% (Japan) to 8% (Ethiopia); in 4 countries the proportion is less than 30%, in 6 it is between 30% and 50%, and in 2 it is higher than 50%; in 4 countries it is not known. The total populations range from 1.5 million (Liberia) to 500 million (India). The degree of industrialization of the countries varies widely; however, all are predominantly agricultural.

All 16 countries show certain characteristics in common; e.g., marked population growth, a rapid growth of towns and industries, and a great increase in irrigation, with corresponding rise in demand for water. The most striking example is that of Romania, where the annual consumption of water increased from less than 500 million cubic metres in 1944 to about 6000 million cubic metres in 1966. A number of countries reported that waste water is being increasingly re-used for agricultural and industrial purposes; such re-use serves both as a method of disposal and as a source of additional water.

In some countries (e.g., Bulgaria and Guatemala), there is satisfactory geographical distribution of constant and reliable sources of water; in others, the sources are one or more large and permanent rivers (e.g., the United Arab Republic, where the average rate of flow of the Nile, the only river, is 2600 m³ per second) or perennial lakes (e.g., Ethiopia, where the area of lakes is about 7000 km²). Some countries (e.g., India, Brazil, and Israel) have both arid or semi-arid regions and regions with permanent and sufficient supplies of water. The principal source may be either surface water, as in the United Arab Republic, or ground water, as in Romania and the Lebanon; some countries use both.

In some of the 16 countries covered in the reports before the Committee (e.g., Bulgaria and Japan) a large proportion of the population, both urban and rural, is provided with piped water; more often, however, piped supplies are provided only in towns, although provision for rural populations is increasing.

Large waterworks in almost all the countries treat water by conventional processes, and most piped supplies are disinfected. However, in rural districts where there are no piped distribution systems, measures are not usually taken to ensure the safety of the water.

Sewerage systems are not always provided in towns with piped water supplies. For example, of about 120 towns in the Philippines that have piped water supplies, only 5 have sewerage systems; in Guatemala, sewage is disposed of principally by means of cesspools or septic tanks; Thailand has no municipal sewerage systems; Liberia has only one municipal sewerage system and some industrial systems, sewage usually being disposed of

in pit latrines and septic tanks and by the dumping of night soil into a river or the sea.

In rural areas, faecal matter is usually disposed of in cesspools and pit latrines ; in some areas, however, even these methods seem to be unknown.

Industrial wastes, which may or may not be given preliminary treatment, are usually discharged into surface waters. In some areas of Japan, the treatment of such waste water is compulsory ; however, in some of the other 16 countries, there are few or no requirements, and even in large cities such as Rio de Janeiro and São Paulo, there is practically no treatment of municipal sewage or industrial wastes.

In general, the pollution of surface and underground waters is increasing and spreading everywhere ; in only a few areas (e.g., Guatemala) it is not yet considered to be severe. Ground water is reported to be polluted in Iraq and (by oil) in Romania ; pollution has caused the death of fish in the Philippines and Bulgaria. Several of the 16 countries reported that pollution has rendered water unsuitable for irrigation ; for this reason, the irrigation of some 1700 hectares in Bulgaria has been abandoned, and plans for the irrigation of a further 20 000 hectares are threatened.

Finally, 8 of the 16 countries reported the occurrence of intestinal diseases caused by water-borne bacteria and viruses, some of them affecting large numbers of people ; for example, an epidemic of infectious hepatitis in Delhi in 1955-56, caused by faecal pollution of the water supply, is estimated to have involved several tens of thousands of cases.

It seems clear that the importance of controlling pollution has generally not been realized until damage has already been done, though most of the 16 reporting countries are now beginning to take legal, administrative, and technical measures to deal with the situation. It is probably reasonable to assume that the experience of these countries is likely to be repeated in other countries at similar stages of development. The important lesson learned from the Seminar is the great importance of planning the water economy of a country, and pollution control measures, at as early a stage as possible in the process of urbanization and industrialization to which the country is committed.

2. WATER POLLUTION AND WATER RESOURCES

Some developing countries, particularly those that include arid and semi-arid regions, have scanty natural water resources ; rain falls during a comparatively short season and much of the water is lost by evaporation. Furthermore, precipitation may be heavy during the rainy season and, since much of the water cannot be economically stored, it passes to the ocean, causing erosion. In most countries that have a limited and seasonal

rainfall, there is an increasing demand for water for irrigation, needed to grow food for the expanding population.

Urbanization and industrialization have created new pollution problems.¹ Untreated or partly treated sewage from urban communities, and sewage overflows from overloaded treatment plants, are discharged into rivers. The provision of sewage treatment plants lags far behind the provision of sewerage systems, which in turn lags behind the provision of water supplies. Industrial waste waters are discharged into streams and rivers without treatment, creating serious water pollution. In contrast to domestic wastes, industrial wastes vary widely in composition. They may contain plant and animal wastes; acids, alkalis, oils, and other organic and inorganic chemicals, some of which may be toxic; synthetic detergents; and radioactive substances. In addition to such industrial wastes, streams receive drainage containing fertilizers from agricultural land, which may cause serious difficulties by stimulating the growth of algae in waterways and lakes. However the most serious result of water pollution is the threat to health that it causes, which alone makes it essential that human and industrial wastes be effectively treated.

Since water that is unusable because of pollution represents a partial loss from the water resources of a country, the management of water pollution is closely related to that of water resources, whether these be surface or ground waters. In some areas, ground water has been contaminated by domestic sewage and industrial effluents to such an extent that it has had to be abandoned as a source of supply. If it is not too greatly polluted, water undergoes self-purification, but when pollution is excessive this process is slow and uncertain.

In many countries where urban and industrial growth have been more rapid than the development of public health engineering, it is now urgently necessary to consider how to meet present and future needs for water. In many areas, the use of new sources would involve the transport of water over long distances, at great expense. One obvious solution is to make the maximum use of the available water, by treating sewage and industrial wastes so that the water they contain can be re-used (e.g., for irrigation or industrial use). Fortunately, a great deal of experience has been accumulated in the treatment of organic wastes by relatively inexpensive methods (e.g., the use of stabilization ponds, which are particularly suitable for use in developing countries, where the comparatively large areas of land that are necessary are usually available. The replenishment of ground water with treated effluents, which in suitable strata undergo a natural process of purification, may be particularly valuable in hot climates, since it avoids the severe loss of water by evaporation that occurs from surface waters.

¹ See *Wld Hlth Org. techn. Rep. Ser.*, 1964, 292.

3. HEALTH ASPECTS OF WATER POLLUTION CONTROL

As noted in the report of the 1965 WHO Expert Committee on Water Pollution Control, "the claims of public health should always be regarded as of prime importance".¹ The protection of water resources from pollution, and the treatment and utilization of sewage and industrial effluents, involve very important public health considerations which must always be a major concern of any government. This is true of both developing and developed countries, and is particularly important in arid and semi-arid zones. Attention should be given to (1) the pollution of both surface and subsurface water into which waste water and industrial wastes are discharged; (2) the risk of contaminating land and food crops, and of infecting animals, as a result of the discharge or re-use of waste water; and (3) the pollution of lakes and marine areas from which fish or shellfish are taken for food, or which are used for recreation. The grave effect of water pollution on the health and well-being of the public should be recognized by health agencies at all levels, international, national, and local, so that water pollution control may be given the high priority it deserves.

3.1 Transmission of disease

The extent of the hazard to health resulting from the contamination of water sources with human wastes depends on the incidence of enteric disease in a given area. In many developing countries the incidence of typhoid fever, bacillary dysentery, infectious hepatitis, and other enteric infections that may be transmitted by water is often 10 to more than 100 times that in the more advanced of the developed countries. Furthermore, cholera is still widespread in some developing countries. Consequently, water pollution control should have a high priority in such areas. The problem is often complicated in arid and semi-arid zones by the scarcity and seasonal distribution of water, since under these conditions polluted wastes are not diluted and natural purification is often limited or does not take place.

In addition to water-borne enteric disease, improper water pollution control in some tropical urban areas has led to a serious increase in the spread of filariasis (the mosquito vectors of which breed in ditches and puddles that are heavily contaminated with waste water) and schistosomiasis. Mosquitos and midges may breed in stabilization ponds, unless these are carefully designed and closely supervised by health authorities.

The special problems involved in the transmission of virus diseases, particularly infectious hepatitis, by the water route were pointed out in

¹ *Wld Hlth Org. techn. Rep. Ser.*, 1966, 318, p. 23.

the previous report.¹ Concern with this problem has increased in recent years owing to a number of extensive outbreaks, and much research has been undertaken to elucidate the problems associated with virus contamination of the water environment. Thus far, the findings give no reason for the lessening of concern; on the contrary, it has been found that some pathogenic enteroviruses are more resistant to waste-water and drinking-water treatment processes than are the most resistant pathogenic bacteria that have been taken into account in designing such processes.

Epidemiological studies in temperate countries having relatively low rates of endemic enteric disease have not demonstrated any risk to health from bathing in polluted water; however, the risk may be significantly greater in warmer countries where the incidence of such disease is higher and where bathing customs are different. Health agencies should promote the prevention and reduction of pollution in recreational waters, both to reduce health hazards and to provide a pleasing and attractive environment.

The health hazards involved in the consumption of fish and shellfish caught in polluted lakes, rivers, and seas cannot be overlooked. It has been shown that shellfish are particularly efficient concentrators and carriers of pathogenic bacteria and viruses; for this reason, some countries prohibit the sale for food of shellfish grown in grossly polluted water although they may be sold after having been transferred to, and allowed to remain for some time in, clean water. Some countries require that, before they are sold for food, shellfish from contaminated water be "purified" by being kept for 3 days in clean sea-water that is repeatedly or continuously disinfected under the supervision of public health officials.

Fish and shellfish can also accumulate chemical poisons in concentrations high enough to be harmful to man—for example, "Minimata disease" has resulted from the consumption of shellfish that have ingested organic mercury compounds.²

3.2 Other risks to health

Chemical pollutants of water, including pesticides and herbicides, are becoming a major hazard to health in industrialized areas. Many such chemicals are highly persistent in the water environment and often do not follow the same pattern of natural purification as some "conventional" contaminants.

The problem can become particularly acute in arid and semi-arid zones, where there is less possibility of reducing the risk by dilution in

¹ *Wld Hlth Org. techn. Rep. Ser.*, 1966, 318.

² Katsure, I. (1967) *The pollution of Minimata Bay and Minimata disease*. In: *Proceedings of the Third International Conference on Water Pollution Research*, Washington, D.C.

bodies of surface or ground water. The accumulation of nitrates in ground water, for example, can be particularly troublesome in such areas. Developing countries in the early stages of industrialization must be made aware that their surface and ground water may be in danger of chemical pollution from industry and agriculture.

3.3 Re-use of waste water for agriculture

Careful consideration must be given to the hazards to health that may arise from the re-use of waste water ; in some circumstances they may preclude such re-use. The hazards to health can be reduced by the treatment of waste water before use in agriculture, but such treatment is often impossible for economic reasons. The health of the public can often best be protected by restricting irrigation with waste water to certain crops, so that municipal waste water will not come into contact with any part of a plant used as food for man, particularly if it is eaten uncooked. Broad irrigation of land bearing fruit trees is usually safe, whereas spray irrigation is not. It is clearly desirable to restrict the irrigation with waste water of crops used for fodder and industrial purposes ; if fodder crops or pasture are so irrigated, there is a risk that cattle will be infected with larvae of the beef tapeworm, *Taenia saginata*. In addition, waste water is acceptable for irrigation only if it does not contain substances that are toxic to plants and livestock. Similar considerations apply to the use of sewage sludge as a soil conditioner. Unless dried by heat, sludge is a potential carrier of pathogenic organisms, and in using it the same precautions should be taken as with liquid sewage. Wherever waste water is re-used, health agencies should establish strict regulations and provide for their rigorous enforcement, and should supervise the undertaking from the point of view of the hazards to health that it may create.

3.4 Re-use of waste water for household purposes

The reclamation of waste water for municipal and household purposes is under consideration in some water-scarce areas of developed countries, and pilot plants for the study of the problem are in operation. In addition to being satisfactory in taste, odour, and appearance, the reclaimed water must, of course, be microbiologically and chemically pure. Meeting the latter requirement involves considerable technical difficulties, and, although the necessary processing plants are being developed, they are likely to suffer from occasional breakdowns. Many cities are now using, as sources of drinking water, surface water that contains varying proportions of sewage effluent, but waste water should be re-used for domestic purposes only with the utmost caution. If water contains a considerable proportion of effluent, it is a valuable precaution to store it for a time, either under-

ground or in a reservoir ; and some of the planned experiments in the municipal re-use of water reclaimed from sewage effluent provide for a long period of storage underground.

Water used for domestic purposes should always meet certain minimum standards of quality.¹ The Committee recommends that water of only one quality be supplied to dwellings.

Water of two qualities, one for drinking and one for other household purposes, has been supplied to homes in a number of towns in different parts of the world. However, in every case this practice was proved to be a serious risk to health, and for this reason it has since been abandoned in almost all areas. An exception is the practice, in some arid coastal areas and islands, of supplying fresh water for drinking, cooking, and similar purposes and sea water for other household uses ; in this case, the two types of water are so unmistakably different in taste that they cannot well be confused. Several references to the separation of water for different purposes are made in this report, and it must be understood that these refer to *entirely* different purposes (e.g., domestic, industrial, and agricultural).

4. PLANNING OF WATER RESOURCES

4.1 Inventory of resources and determination of future needs

The first step in the rational planning of a country's water economy is to make an inventory of existing resources of both surface and underground water. Meteorological, hydrological, and hydrometric data are required, together with information on water quality, hydrogeology, and the extent to which water resources are naturally protected. The volume of the total water resources and of individual bodies of water can then be determined, and information can be obtained on their geographical and seasonal distribution.

The next step is to predict future needs for water for all purposes—first for urban, industrial, and agricultural uses, and second for recreation, power generation, shipping, transport of wastes, and other purposes. All these needs must be met, as far as possible, from within the country concerned. If the seasonal distribution of water is unfavourable, planning should provide for the storage of surplus water in periods of abundance to cover the needs in periods of deficiency. If the known resources are insufficient, new sources (e.g., artesian water) must be found, or water must be obtained from other regions that have a surplus.

¹ See, e.g., World Health Organization (1963) *International standards for drinking Water*, 2nd ed., Geneva.

4.2 Planning

The planning of water resources should always form part of the general national or regional plan for social and economic development. When urban, industrial, or agricultural schemes are drawn up, the water resources they will require should always be planned at the same time. Recommendations to this effect were made in 1964 by the WHO Expert Committee on Environmental Health Aspects of Metropolitan Planning and Development.¹ This Committee noted that in urban planning, the provision of water, sewerage, and drainage is often considered only after completion of the over-all plan. Such a procedure is uneconomic, and at later stages is likely to cause serious difficulties, both with the general economy of water and with urban and industrial supplies. For this reason, it was recommended that the planning of water supply and sewage disposal be an integral part of physical and economic planning, and that "a single agency be responsible for water, sewerage, waste disposal and drainage on a regional basis".²

Planning in developing countries is often the responsibility of town planners and economists, and insufficient attention is given to environmental health. The Committee believes that urban, industrial, agricultural, or other planning, whether it be at national, regional, or local level, always requires the collaboration of specialists in environmental health, including those dealing with water supply and the treatment and disposal of sewage.

From the viewpoints of geography, hydrology, and economy it seems rational to plan water resources—and urban, industrial, and agricultural developments—on a regional basis, particularly since river basins and subbasins are usually distinct geographic and economic regions. It is often advantageous to plan regional systems for the distribution and treatment of water, and regional sewerage systems and sewage treatment plants are sometimes appropriate. Regional systems have fewer intakes and outfalls, thus reducing the chances of their becoming polluted; furthermore, they require less maintenance than a multiplicity of smaller systems and provide more efficient treatment of water.

It is important to plan urban and industrial development in such a way as to cause as little pollution of water resources as possible. Industries are often located on sites where it is difficult to ensure an adequate supply of water for their expansion, or where effluent from manufacturing processes must be discharged into a stream that should have been reserved as a source of high-quality water for domestic supply. In some circumstances it may be an advantage, from the point of view of minimizing damage to water resources, to locate industrial townships on the sea coast or on the lower

¹ See *Wld Hlth Org. techn. Rep. Ser.*, 1965, 297.

² *Ibid.*, p. 38.

reaches of rivers; this may sometimes reduce the cost of treating both water and sewage and cause least harm to agriculture.

Industrial wastes account for much of the difficulty of treating sewage and making use of the effluent resulting from such treatment; furthermore, the problems such wastes cause are not always proportional to the size of the industry that creates them. If a given industrial waste is known to be physiologically harmful, it may be particularly important to avoid its direct or indirect discharge into a stream that is used as a source of drinking water. Long experience has shown that both costs and total water pollution are reduced if many common industrial effluents are treated, not separately, but in admixture with sewage at a well-designed and well-operated sewage works. Such factors should be taken into account at an early stage in the planning of the industrial development and of the total water economy of a given country or region.

4.3 Lakes and impoundages

The eutrophication (i.e., the growth, often massive, of algae in water that were formerly clear) of lakes and reservoirs is being reported from many parts of the world. Eutrophication occurs when a body of water receives wastes containing plant nutrients, of which phosphates are usually considered to be particularly important; the rate of growth of algae in such water is likely to increase in direct ratio to the amount of solar radiation to which the water is exposed. Sewage contains considerable amounts of phosphates, of which a large proportion remains in the effluent resulting from biological treatment unless a process specifically designed to remove them is used. Phosphates are also present in drainage from agricultural land—particularly, of course, land to which phosphate fertilizers are applied.

Eutrophication may cause great damage to lakes and impounded waters by rendering them unsightly and by seriously interfering with the use of the water for domestic and industrial purposes. Some of the algae that flourish under eutrophic conditions are poisonous, and it has been reported from different parts of the world that they have caused the death of fish and aquatic birds. Many species impart to water an unpleasant taste that is difficult to remove by conventional treatment processes. Moreover, the heavy growths of algae in eutrophic bodies of water finally die and decay, sometimes resulting in anaerobic conditions, particularly at the bottom of a deep, thermally stratified lake or reservoir. Water in this condition is often foul-smelling and may contain high concentrations of iron and manganese, leached from the bottom in the absence of dissolved oxygen; it is then extremely difficult to prepare an acceptable potable water from it.

A particular danger of eutrophication is the likelihood that it will persist for a long period, since the inorganic nutrients that bring it about pass

through a cycle of assimilation by algae, release to the water, incorporation in the bottom muds, and release to the water, the cycle then being repeated.

At present, it is probable that the only reliable way to avoid eutrophication is to prevent the discharge of sewage and other nutrient-containing effluents into impounded water, as has been done in the past. Research is in progress on methods of removing phosphates from sewage effluents, but such techniques add to the cost and complexity of sewage treatment and there is little experience of their efficiency in large-scale operation. Furthermore, it is not certain that phosphate is always the essential nutrient in the eutrophication of lake water.

4.4 Water conservation

Many years of experience in industrial countries have shown that the volume of effluent produced can often be greatly reduced in a variety of ways, such as counter-current washing, the dry disposal of waste materials, and particularly the treatment and re-use of water within a given factory. In some industries (e.g., the manufacture of sugar from sugar beet) that use large quantities of water, the only economic solution of the waste-water problem is the segregation, treatment, and re-use of the water of different qualities used in each factory. In countries that have a serious water shortage, such measures are particularly important, and their adoption should certainly be considered when the over-all water economy of such countries is planned. Industry would probably need technical advice and assistance in putting these measures into effect, and it would be essential to provide trained staff and the necessary laboratory facilities.

4.5 Rural areas

In rural areas, clean and hygienically safe water can usually be obtained only from underground sources, which must be protected from pollution if the water is to remain safe in the future. In many countries, this presents great problems. Sewage and faecal matter must be disposed of in such a way as not to pollute supplies of potable water, provide breeding places for mosquitos, or contaminate soil or water with parasites or their ova. In planning such measures and putting them into effect, and in instructing rural populations in their use, the assistance and advice of trained staff and the provision of adequate facilities are essential.

5. SURVEYING OF WATER RESOURCES

As noted in the Introduction, the countries in which water is scarce vary widely in industrial development: some have little or no industry, whereas in others industry is already an important part of the national economy. The countries also vary in other respects; for example, some are reasonably well provided with water-carriage systems for waste disposal, whereas others have very few sewage treatment plants, although they may have piped water supplies.

On the other hand, all the countries discussed at the New Delhi meeting have two factors in common: in all of them agriculture is important, usually necessitating irrigation, and the pollution of natural resources is increasing. It was recognized that in most of these countries measures to stem the increase of pollution are urgently needed.

Since their conditions are so diverse, it is clearly impossible to make recommendations that would be applicable to all these countries. However, it can be assumed that in such countries agriculture will remain an important part of the national economy in the foreseeable future, that increasing volumes of water will be required for irrigation, and that urbanization and industrialization will grow rapidly. Consequently, water supplies and the disposal of human and industrial wastes must be planned in such a way as to make the best use of the water that is available.

5.1 Surveys

In a situation such as that outlined above, the first step is to make a survey of the existing water resources of the country, including rivers, lakes and underground resources. If the country borders on the sea, the latter should be considered as a possible diluent for waste water that could not otherwise be disposed of without detracting from the value of fresh water required for other purposes.

It is clearly impossible to make detailed recommendations for surveys, since much depends on the communications and means of transport that are available. However, a visual inspection of the territory should be the first step, together with the collection of as much information as possible from local sources on factors such as seasonal changes in water flow and fish mortality. A quantitative survey should then be made of the volume of water passing down rivers, and particularly in arid countries, of its seasonal and annual variations. The chemical analyses that should be undertaken will depend upon the purposes for which the water is to be used. For example, the requirements for water for irrigation or fisheries are not always the same as those for drinking water. Similarly, in planning bacteriological or other biological examinations it is important to have a knowledge of the potentially water-borne diseases that occur in the country.

Thus, before analysis is begun, the analyst should consult technical organizations having a knowledge of local conditions and of the ways in which public health, agriculture, and fisheries might be affected by contaminants in water.

The Committee does not believe it to be desirable to make detailed recommendations on the chemical analyses to be made in a preliminary survey, or to suggest any particular frequency of sampling. However, it should be pointed out that there may be large diurnal and seasonal variations in some of the chemical constituents of water; such variations are likely to be greater in arid or semi-arid countries—where, indeed, a river may not flow at all during the dry season. In such conditions, an adequate survey of surface waters involves a great deal of work. Recently, however, the introduction of automatic instruments has made it possible to reduce the work involved in recording at least some of the properties of water that are usually important (e.g., the concentration of total dissolved salts, which can quite easily be continuously recorded by means of an electrode system that measures electrical conductivity). Such techniques, although new, are undergoing rapid development.

Some of the instruments used, such as monitoring equipment, are complex and require constant expert supervision; furthermore, they often have to be housed in massive and expensive permanent structures. Their use in a preliminary survey of water resources is not to be recommended; they are more appropriate to a later stage of development, after determination of the key positions on rivers where it is most important to obtain information. In the early, and necessarily exploratory, stages of a survey greater advantage would be obtained from the use of readily portable and comparatively rugged recording or indicating instruments. Unfortunately, only a few such instruments (e.g., for the determination of dissolved oxygen) are available. One useful and trouble-free device is the automatic sampler, driven from a battery or by clockwork. If instruments of this type are to be used in a survey, it will probably be essential to train the staff at a centre where they are already in use.

In surveying resources of water for irrigation, the first survey should include analyses for common inorganic radicals (e.g., Na^+ , Ca^{++} , SO_4^{--} , and Cl^-) that have a general effect on the fertility of soil, and for elements (e.g., boron) that are known to have a toxic effect on plants.

In some countries (e.g., those in which a great development of tourism is expected), it may be particularly important to avoid the pollution of coastal waters. In some areas there is little tidal rise and fall, and materials discharged into the sea are carried away very slowly by currents. Such a situation might well have to be considered in planning the future water economy of a country; if crude wastes cannot be discharged into the sea, effective treatment or some other method of disposal will have to be adopted.

5.2 Indicators of pollution

If rivers or lakes are known to be polluted by human or other wastes, chemical examination should include the determination of factors that are normally accepted as being indicative of pollution (e.g., dissolved oxygen, biochemical oxygen demand, nitrogen compounds, and oils). If circumstances permit, bacteriological examinations may also be carried out. In addition, certain specific chemical or biological tests may be advised by medical authorities. In the examination of sea-water, the determination of chemical indicators of pollution is unnecessary, with the exception of dissolved oxygen and oils.

The Committee did not think it necessary to make detailed recommendations for drinking water. This subject has been dealt with in a previous report,¹ and detailed requirements for drinking water are available elsewhere.²

The constituents of water that affect fish differ from those that are important to public health and to agriculture; for example, zinc in very small concentrations is toxic to fish in soft water, although it is much less toxic in hard water. Other substances that are often present in water (e.g., ammonia and phenolic compounds) are also toxic to fish. Some species of fish require certain minimum concentrations of dissolved oxygen. Consequently, the chemist making the survey should be briefed on substances that may, if present in the water, represent a threat to fisheries.

Valuable information on the state of a river can be obtained by a survey of its flora and fauna. It is claimed that this method has an advantage over chemical analysis in that whereas the chemical composition of water may fluctuate widely and rapidly, the distribution of animals and plants living in the river gives an average picture of what the quality of the water has been over a long period. However, it has been pointed out in the past few years that the distribution of invertebrates is governed not only by the chemical composition of the water but also by its physical conditions, particularly its velocity and turbulence. Biological examinations have a further drawback in that if they show certain invertebrates to be absent (and presumably to have been killed), they can give no information on the identity of the poison that killed such organisms—information that is essential if the condition is to be rectified. Consequently, chemical analyses are in any case necessary, although their interpretation will depend on the results of toxicity tests carried out by a biologist.

¹ *Wld Hlth Org. techn. Rep. Ser.*, 1966, 318.

² World Health Organization (1963) *International standards for drinking water*, 2nd ed., Geneva.

5.3 Identification of sources of pollution

In making a survey of a given country, it is likely that a chemist will find some rivers already significantly polluted. If so, it is important to identify the source of pollution (e.g., a sewage works or a factory). The source having been identified, the following information is necessary: (a) the total flow of effluent, (b) the general composition of the effluent, and (c) any changes in either flow or composition that may occur in the future as a result of further urban or industrial development. It should be pointed out that even where a sewage works has been long established, the ultimate sources of polluting substances, particularly those derived from industry, are often not known. Industrial effluents and sewage effluents in industrial areas are often toxic to fish. In areas where fisheries are important, such effluents are commonly tested by immersing fish in mixtures of various proportions of effluent with aerated clean water. If a sewage effluent proves to be toxic, the poisonous substance almost certainly comes from industry and it is important to identify it and its source so that measures can be taken to prevent its discharge in the future. A survey of this kind can be made only with the active co-operation of the sewage works manager and of the industries that discharge effluents into the sewers.

5.4 Planning for the future

When the available water resources have been surveyed, the next step is to estimate (a) the quantities and qualities of water that will be required for different purposes in the future, and (b) the volume and type of sewage and industrial wastes that will be produced at a given stage of development. In making such an estimate, the planned development (e.g., agricultural, industrial, or recreational) of the country must be taken into account. It is important that each purpose for which water may be required be considered separately, particularly in a country where the total volume of water is limited, since the solution of the problem may well depend on using water of different qualities for different purposes. On the results of such an inquiry might also depend the measures to be taken in treating and disposing of effluents, both domestic and industrial.

6. WATER QUALITY MANAGEMENT

6.1 Organization

As previously noted, the health aspects of water pollution control are of prime importance in water quality management, particularly in many developing countries. Consequently, public health organizations and agencies at the international, national, and local level—whose responsibility

is to protect health—should play a leading role in the development and operation of water pollution control programmes and should, where necessary, be prepared to supply personnel and facilities for such programmes.

Under some circumstances, particularly in countries where water is scarce, it may be advantageous to create a single national authority for the management of water resources, including water pollution control. However, in some countries the powers and duties of water resource management are already vested in an existing government agency. Instead of a single national authority, several countries have a number of regional authorities, usually based on hydrologic considerations. In such cases, a co-ordinating body should be created to ensure the uniformity of water management policies, including water pollution control. In other countries, responsibility for the management of water resources is divided among different government departments (e.g., agriculture, public health, and power supply). In this situation, also, a central co-ordinating body is essential, particularly for planning, the setting up of priorities, the drafting of laws and regulations, and similar duties.

Whatever the organizational structure in a given country, the interests of public health must be strongly represented. A water inspectorate should also be established and given authority to enforce existing laws and regulations.

Whether water resources be managed by a central national authority or by a co-ordinating body, it is important that the available personnel, laboratories, and equipment be concentrated in a single water pollution control organization. This organization may be national or regional, but need not be centralized. In this way, the most economic use of personnel and technical resources, which are usually scarce in developing countries, would be ensured. At a later stage local regional water pollution laboratories and field stations might become necessary.

6.2 The stages of a control programme

The first stage of a water pollution control programme must involve an evaluation of the significance of the problem in the entire country. In some areas, pollution may be so obvious that there will be little difficulty in deciding where action is most needed; in others, only a cursory examination may be necessary. The next step is a pollution survey, which may be simple or, if the situation is complex, may involve a detailed study of water bodies and the sources of their pollution. Such a survey should be maintained and could well be integrated with existing meteorological and hydrological recording programmes.

When the conditions have been studied and the sources of pollution identified, it is necessary to establish standards of quality for receiving waters and polluting sources. Such standards must be set by taking future

uses of water into account. Regulatory action is required, and water and effluents must be continually inspected.

It is likely that a pollution control programme will eventually involve the construction and operation of plants for treating sewage and industrial effluents. The design, construction, and operation of such plants may be the responsibility of government agencies, local or regional authorities, or industry; the system that is adopted in a given country will depend on the pattern of government control and administration within the country, on the technical resources that are available, and on other factors.

6.3 Storage of water and its effects on quality

Integrated management of water supply and water pollution control may result in benefits that would not accrue from separate management. This is particularly true of water storage.

In arid and semi-arid regions it is often desirable to retain river flows so as to prevent the waste of water during wet or storm-flow conditions. Although the primary purpose of reservoirs is to store water for use in dry periods, they have secondary purposes that may, in certain situations, be equally important (e.g., flood regulation and improvement of the quality of downstream river waters by discharge of stored water).

The retention of water in reservoirs often improves its quality as the result of many different processes (e.g., sedimentation, photosynthesis, and bacterial oxidation). The phenomenon is influenced by many factors, such as climate, vegetation, and the composition of the ground; it is also affected by the way in which the reservoir is operated (e.g., the duration of retention and the discharge programme) and by pollution prevention measures in the catchment area.

On the other hand, as previously noted, the retention of water polluted by sewage, industrial waste, agricultural drainage, or anything containing plant nutrients often leads to eutrophication, which has a highly detrimental effect on water quality. Similar results may follow if a reservoir site is not cleared of vegetation before it is filled. It is not always possible to divert polluting discharges or to remove nutrients from them, and some water authorities attempt to prevent the growth of algae by the use of organic algicides or copper salts. However, this technique necessitates thorough knowledge of the biological and chemical changes taking place in a reservoir, so that the algicide can be added immediately the rapid proliferation of algae begins. Furthermore, the results are by no means always predictable, and indeed may be harmful. Consequently, algicides should never be used without expert advice.

If the water in a reservoir is stratified, the consequences of eutrophication may sometimes be minimized by drawing off water at a selected level.

However, this procedure is of no value if the stratification breaks down and vertical mixing occurs.

Water may also be stored underground. Pumping from underground aquifers is a traditional way of obtaining water, but the controlled use of aquifers for both storage and improvement of quality is a relatively modern technique. Whether or not the quality of water can be improved in this way depends principally on the structure of the soil. Little change in quality occurs in fissured strata, since the water flows readily through the fissures; porous formations, however, have an important purifying effect, since they act as a filter through which the water flows very slowly. In addition, clays in the soil may adsorb detergents and other substances that cannot be broken down biologically. There is as yet no way of predicting the degree to which water will be purified by storage in a given soil formation for a given length of time. Substantial improvement may be expected, but definite figures will be obtained only after the method has been in use for several years.

6.4 Composition of wastes

Pollution of water may be described as a condition arising from any activity of man that renders water less suitable for any purpose for which it was suitable in its natural condition. It may result from the discharge of domestic sewage or of waste water from a wide range of industrial activities, including the processing of food and other agricultural products, manufacturing, and mining.

The composition of industrial waste water varies widely, and no satisfactory system of classification is possible. However, effluents may be roughly divided into those that contain only inorganic substances and those that contain mainly organic materials. In the former type, the pollutants may be chiefly in suspension (as in washings from coal preparation and similar processes) or in solution (as in effluents from metallurgical industries). Many effluents of this type contain toxic substances (e.g., almost all effluents from electroplating industries). If the principal pollutants are organic, the effluent usually contains a mixture of soluble and insoluble substances. Many organic compounds inhibit bacterial activity (this is also true of toxic inorganic substances), a fact that must be taken into account if effluents containing such compounds are treated in admixture with sewage. Furthermore, some organic substances (e.g., natural plant and animal substances from the food industries) can be decomposed by biological action and can, consequently, be treated in the same way as domestic sewage, whereas others (principally synthetic chemicals) cannot be decomposed, or can be decomposed only slowly and with difficulty, in this way.

Sewage, of course, contains large numbers of bacteria, some of which may be pathogenic to man. It may also contain viruses and the ova or

cysts of parasites, the incidence of which depends on the general level of health in a given district. The incidence of viruses also depends on the extent to which inoculation against viral diseases is carried out in the district.

6.5 Sewerage systems

The conveyance of sewage and industrial wastes from their place of origin to a place where they are treated and disposed of involves a system of sewers. Sewers may be combined, for the conveyance of sewage (and industrial effluents) and surface water, or separate (i.e., there may be two systems, one for sewage and industrial effluents and another for surface water). In practice, separate systems tend to become less separate with time, owing to the difficulty of excluding all surface water from them. A combined system cannot usually be designed to carry the total flow at times of heavy storms, nor could this volume of liquid be treated at a sewage works if it arrived there. Consequently, combined systems must have relief overflows, through which a mixture of sewage and surface water is discharged to a stream when the flow exceeds a certain rate. Such systems are a common cause of serious pollution in many countries. Separate systems do not cause pollution in this way, and the Committee recommends that, wherever possible, they be adopted when new sewerage systems are provided in developing countries.

In deciding whether a given industrial waste should be discharged into a sewer, the most important considerations are whether it will (*a*) be a danger to men working in the sewerage system; (*b*) damage the sewerage system or interfere with its maintenance; (*c*) interfere unduly with the treatment process; and (*d*) cause a serious deterioration in the quality of the sewage effluent. If an industrial waste is unacceptable in its original state, it should be pretreated to correct the condition before discharge into the sewerage system.

Perhaps the chief hazard to men working in sewers is poisonous and other gases, particularly hydrogen sulfide, hydrogen cyanide, ammonia, carbon dioxide, and inflammable gases.

Certain effluents that contain insoluble substances may cause difficulty by physically blocking the sewers, and the same effect may be produced by the precipitation of insoluble substances (e.g., the precipitation of calcium carbonate from hard water when an alkaline effluent is added). Concrete sewers may be damaged by hot effluents and by chemical reaction (e.g., by acidic substances and by high concentrations of sulfate). It is common practice to require that acidic effluents be neutralized before discharge.

A problem of particular importance in hot countries is that concrete can rapidly be damaged by hydrogen sulfide, which is usually formed when anaerobic conditions occur in a sewer. Although the risk can be reduced

by the careful design of sewers so as to prevent the development of anaerobic conditions, the discharge of highly concentrated organic matter is always liable to lead to trouble from this cause.

A wide variety of substances can interfere with biological processes of sewage treatment. When such substances are known to be present in an effluent, some form of pretreatment is usually necessary to remove them before discharge of the effluent.

The strictness with which the discharge of industrial wastes must be controlled depends on the quality of sewage effluent that is required. The strictest control is required when little dilution of the effluent occurs in a stream and when it is desired to maintain the quality of the stream at as high a level as possible.

6.6 Methods of treatment and disposal

In treating sewage and industrial wastes, the concentration of polluting substances and organisms (solids, dissolved organic or inorganic compounds, and pathogenic agents such as bacteria, viruses, and parasites) must be reduced. A wide variety of processes for achieving such reduction of pollution is available. However, the process that is used must be appropriate to the pollution situation and other conditions in a given country. Conditions in developing countries frequently impose limitations on the choice of treatment.

Selection of the means of ultimate disposal has a considerable bearing on the type and degree of treatment adopted. If the effluent is to be disposed of in a large flowing river or the sea, limited treatment may be sufficient, but if it is discharged into a dry stream bed to which livestock have access, or into underground aquifers, thorough treatment is necessary.

Suspended solids and most soluble organic compounds can be removed and destroyed by sedimentation and biological decomposition, either anaerobically (as in the sludge digestion process) or aerobically (as in trickling filters and activated sludge). These processes are well-established and information on them can be found in many text-books. Very low temperatures may cause difficulties with all treatment processes; not only may moving machinery be immobilized, but the speed of biological reaction is greatly reduced. Moreover, the effluent may have to be discharged into a river covered with a layer of ice which prevents aeration of the water by atmospheric oxygen.

6.6.1 Irrigation

The oldest method of sewage treatment and disposal, which is still in use, is irrigation, the sewage being distributed by the flooding of broad areas, by ridges and furrows, or by spraying. If the method is to be success-

ful, the soil must be permeable and well-drained. Part of the water is evaporated and part seeps into the ground and is purified, organic matter being destroyed, solids filtered out, and plant nutrients absorbed by vegetation. Economic returns can be achieved if the water is used to irrigate pastures, fruit or forest trees, or suitable crops. However, as noted elsewhere, strict control must be exercised if this method is to be used without endangering human health.

Care is necessary if sewage containing certain types of industrial wastes is used for irrigation. For example, the presence of excessive amounts of toxic materials, such as heavy metals and some organic compounds, may adversely affect crops, and excessive sodium content may detrimentally affect soil permeability. The use of irrigation for the disposal of industrial wastes unmixed with sewage is subject to the same considerations; furthermore, the success of the method depends on the intermittent application of water, and it cannot be used at times of heavy rainfall, when alternative methods of treatment, storage, and disposal are necessary.

A modified form of irrigation usually known as "broad irrigation" or "grass filtration" is sometimes practised. In this process, sewage passes continuously over grassland and enters a collecting channel at the lower end of a slope; it is reported that with careful control a large measure of purification is achieved.

In many countries sewage is pretreated before being applied to land. In the early days of irrigation, sludge was removed by sedimentation; a more recently developed method is to pass the sewage through stabilization ponds before using it for irrigation, which reduces the risk to public health. However, much more information is required on the health aspects of irrigation, where the hazard is clearly greater than with treatment in conventional plants.

6.6.2 *Lagoons or stabilization ponds*

Studies conducted during the past 20-30 years have shown that the degree of purification normally achieved by conventional processes can be achieved by the passage of sewage and certain industrial wastes through properly constructed ponds. Although such ponds vary considerably in design, they are usually built to maintain a water depth of not less than 1 metre. In properly designed ponds arranged in series, solids are retained and organic matter is completely digested and stabilized; there is also a considerable reduction in the content of coliform bacteria. In areas where land is available and inexpensive, this process can be used to treat raw sewage to a high standard at very low cost; a further advantage is the fact that mechanical equipment is not required.

The oxygen required for oxidation in stabilization ponds is usually obtained from the air or the photosynthetic activity of algae. Recently,

however, mechanical aeration and aeration by diffused air have been introduced, making it possible to design stabilization ponds for certain conditions under which they might not otherwise be feasible.

Ponds have already been constructed in many developing countries, but there is an urgent need for information on their performance, and particularly on their efficiency and significance for public health when operated under arid and semi-arid conditions.

Pond treatment may be used for industrial organic wastes, but attention must be given to requirements for microbiological growth, such as the carbon/nitrogen ratio and the concentration of phosphates and of trace metals. Ponds are unsuitable for the treatment of toxic or purely inorganic wastes, although they may serve as balancing tanks or settling basins.

6.6.3 *Oxidation ditches*

Where land is not available for irrigation or stabilization ponds, the use of oxidation ditches may cost less than conventional activated sludge treatment. The ditch may be built of earth, and the only mechanical equipment that is required is a motor-driven rotor and possibly a return sludge pump.

6.6.4 *Sludge disposal*

If sewage is treated in oxidation ponds, no substantial problem of sludge disposal arises. However, if biological filtration or the activated sludge process is adopted, there will be a continuous output of liquid sludge, the disposal of which is often the most difficult part of the entire process of sewage treatment.

In countries with temperate climates and with long-established sewage works, the method of disposal usually adopted in the past has been open-air drying on bottom-drained beds, the dried solid material being used by farmers as a soil conditioner or otherwise disposed of. This system has usually been retained since it is relatively inexpensive, but serious difficulties are now being encountered in its use. If the liquid material is to be dried in the open air without causing unpleasant odours, it must first be digested anaerobically, usually at a temperature of about 35°C. However, an increasing number of constituents of industrial effluents inhibit the microbiological process of digestion. Furthermore, some wastes—particularly those containing nonferrous metals—render the dry sludge toxic to plants. A further disadvantage of this process is the fact that dried sludge usually has little economic value, at least in temperate countries where agriculture is well developed. It is possible that in a hot and arid country with a less well-developed agricultural system, sewage sludge might be of greater value as a source of organic matter for soil. The assessment would depend on local conditions. A decision on the matter must be made at an early stage,

since, if sludge is to be used on the land, the admission of industrial effluents to sewers must be controlled, particularly if they contain substances that interfere with plant growth or (if digestion systems are used) substances that inhibit anaerobic fermentation.

Certain intestinal parasites are not entirely eliminated by mesophilic digestion and air drying, and are likely to be a serious health hazard in developing countries; for this reason, it may not be possible to use digestion and air drying without a long period of storage. The same problem may be involved in the composting of mixtures of sewage sludge and household refuse, a method of disposal that is widely used in some semitropical countries. Much further information on these problems is needed.

If natural processes of drying, including prolonged storage, are ruled out, the only processes that can yield a product that can safely be used in agriculture are those employing some form of heat treatment. However, such processes are expensive to operate, as are such modern processes as wet combustion and incineration that entirely destroy the organic matter.

Sludge is also produced in the treatment of certain industrial wastes and it may be difficult to dispose of. Industries that produce large quantities of sludge will usually have developed some method, depending on local conditions, for dealing with it. However, many industries produce relatively small quantities (sometimes only a cubic metre or so per month), often in catch pits or in pretreatment plants on the factory site. In heavily industrialized districts, the disposal of these materials has become a difficult problem. Usually their composition is not known; nor is it known whether they would cause a major hazard if they should come into contact with water supplies. The only general solution so far proposed is to transfer such sludge, usually in tank wagons, to some place where it can be dumped in a pit—from which, it is hoped, it will not contaminate ground water. The possibility of using regional incinerators has been discussed but—in view of the varied and often unknown nature of the materials collected—this form of disposal presents great technical difficulties.

In developing a new industrial area, the problem of sludge disposal should be borne in mind and, if possible, some place in which such residues could be safely deposited should be provided.

6.6.5 Selection of treatment method

The selection of the appropriate treatment process in a given situation depends on several factors, of which public health is paramount and cost always important. If large areas of land are unavailable, conventional processes may be the proper choice. Often however, where suitable flat land is available, sewage and certain industrial effluents can be treated to an equally high standard by much less expensive methods.

If local labour is available and not unduly costly, it is desirable to select processes that require the minimum of equipment, materials, maintenance services, and skilled supervision. In this situation, low-cost methods such as the use of stabilization ponds or irrigation are the obvious choice, provided they are suitable from the point of view of other local conditions. Where agricultural requirements for fertilizers are important, irrigation may well be the most appropriate treatment. Climatic conditions must also be taken into account in selecting methods of treatment; for example, stabilization ponds are highly efficient if temperatures are high and if there are long hours of sunshine.

Numerous studies have conclusively demonstrated the economic advantages of irrigation or pond treatment where conditions are suitable and where the use of such methods will cause no hazard to health. A study should be made of the relative costs of (a) conventional treatment adjacent to a large urban centre and (b) transport of wastes to a remote location where land is available for low-cost methods of treatment.

6.7 Direct reclamation and re-use of waste water

In industrial countries it is becoming common to use sewage effluents directly for certain industrial purposes (e.g., as make-up water for recirculating cooling systems in electricity generating stations, and for the hydraulic transport of raw materials in cement works). Sewage effluents used in this way are often given some form of treatment (e.g., straining to reduce the concentration of suspended matter, and treatment with lime or a coagulant to remove phosphate and thus reduce the deposition of scale on heated surfaces). Effluents have been used in this way when they are produced conveniently near factories and, in heavily industrialized areas, when their composition is more constant than that of a nearby river. The quality of a sewage effluent can, at relatively low cost, be greatly improved so as to make it suitable for a wide range of industrial uses. It is then a saleable commodity, competitive with water from other sources; indeed, it has certain advantages in that it represents a sure source of supply. Furthermore, treatment can conveniently be carried out in a sewage works that has the necessary equipment and engineering and chemical staff.

A large proportion of the population and industry of a country may be situated on the coast or on estuaries, where sewage (or sewage effluent), unless re-used, is discharged into the sea and lost from the fresh-water resources of the country. There is increasing interest in the reclamation of water from sewage in order to avoid such loss.

The treatment applied to sewage effluents may range from the simple to the complex, although the use of complex processes has so far been studied mainly in pilot plants. Comparatively simple treatment (including sedi-

mentation after the addition of a coagulant, sand filtration, and chlorination) produces water that is substantially free from suspended matter, that has little or no biochemical oxygen demand, and whose phosphate content is greatly reduced; however, such water contains all the nitrogen that was present in the effluent as nitrate or ammonia. If chlorination is adequate, the water will contain few or no coliform bacteria. It is not known whether such treatment eliminates viruses, largely because of the difficulty of enumerating them, although present evidence suggests that their numbers are greatly reduced.

The purpose of such reclamation is not to produce potable water, but to produce water for industry; however, the water should be physiologically safe to the extent that it would cause no harm if small quantities of it were drunk accidentally. In most countries it is held to be undesirable to produce potable water in this way, since biological processes of sewage treatment, and processes commonly used in waterworks, leave in the reclaimed water a substantial concentration of organic substances whose identity is unknown but which might be physiologically harmful. The same is true, in varying degrees, of the preparation of water from a river into which sewage or industrial effluents have been discharged, although in some areas such water has been drunk for many years without any observable harmful effect on the population.

In a few areas, more complex methods of treating sewage effluents are in use; they include passage of the effluent through beds of activated carbon, which further reduces the concentration of organic compounds but does not usually remove them completely; the removal of detergent residues by various processes; and the removal of sodium chloride and other inorganic salts added to water during domestic use.

The reclamation of water from sewage effluents for direct industrial use, or for agriculture, is likely to be increasingly adopted in countries where there is a water shortage. It is unlikely to be economically attractive in developing countries at present, but may well become increasingly important as urbanization and industrialization expand, particularly in arid countries where the maximum use must be made of the available water resources.

7. RESEARCH AND TRAINING

Although modern engineering techniques and laboratory services are playing an increasingly important role in various aspects of water pollution control, there is a conspicuous shortage, particularly in developing countries, of well-trained personnel at all levels. As a result, many authorities have been forced to employ insufficiently qualified personnel for responsible positions. The lack of qualified personnel is felt not only in the practice of water pollution control but also in research. The development of

many research institutions has been considerably delayed by the inability to recruit and retain scientific staff with adequate technical knowledge and—often more important—with an adequate understanding of the purpose and meaning of research in environmental health and sanitary engineering.

There is no doubt that both fundamental and applied research should be encouraged in developing countries, but it should be pointed out that the most fruitful research in environmental health and sanitary engineering has always originated from operational experience.

7.1 Research

Research in water pollution is particularly important in developing countries at the beginning of their industrialization and urbanization. Plans for the protection of surface and underground water resources must be made before waste water begins to pollute them. Economic and efficient treatment processes must be available for the effective implementation of pollution control measures. In some developing countries, stream surveys have been started, and field studies of the usefulness of treatment plants that incorporate stabilization ponds and oxidation ditches are being undertaken. Such measures are a good beginning, but if they are to be fully effective they need the support of local laboratories for the control of treatment operations and, to serve national requirements, properly organized and equipped central research laboratories staffed with scientific, engineering, and other technical personnel.

Several WHO expert committees and scientific groups have drawn attention to the areas in which research is necessary and to specific questions that must be answered if economic treatment plants are to be developed and if the pollution of surface and ground water is to be fully understood.¹

Since developing countries must save capital for their future development, they require efficient low-cost treatment processes. Such processes must be suitable for the prevailing climatic conditions and the land-use policy of a given country, and in selecting them the availability of the necessary personnel must be taken into account. Generally speaking, waste-water treatment processes developed in technologically advanced countries, and the highly mechanized and automated plants found useful in such countries, are neither appropriate nor financially justifiable in developing areas.

The Committee recommends the further study of simple, low-cost sewage treatment processes, such as the use of stabilization ponds, oxidation ditches, and irrigation, which are already in use in many developing countries. Further research is necessary on the use of such processes under arid,

¹ Further information will be found in *Wld Hlth Org. techn. Rep. Ser.*, 1968, 401.

tropical, and low-temperature conditions. In particular, attention should be given to (1) the effect of environmental factors on performance ; (2) methods of designing plants so as to achieve different degrees of treatment in tropical conditions ; (3) the possibility of reducing the size and improving the performance of stabilization ponds ; (4) the possibility of improving performance by combining oxidation ditches and stabilization ponds ; and (5) the use of such processes for treating different kinds of industrial wastes.

Since a number of low-cost installations are already operating under arid and tropical conditions, it is desirable to develop a co-ordinated plan for studying their performance and the factors that influence it. In this way, much duplication of effort would be avoided, and water pollution control facilitated.

There may be advantages in using waste water, and sludge derived from it, for growing crops. However, such a programme should be thoroughly studied before it is put into effect. If chemical industries are established in the area, the safe disposal of waste water is particularly important. Only a properly equipped and staffed research institute would be able to carry out the required studies. National or regional research laboratories would fulfil such requirements and would enable developing countries to solve their most urgent research problems in the light of local conditions and without undue delay.

The principal responsibility of the laboratories will be to assist the government and industries in the solution of emergency pollution problems and the establishment of water quality standards. In the absence of specialized consulting engineering bodies, they may also be in a position to study and give advice on certain problems of communities and industries.

In the past, WHO has assisted a number of countries in establishing such research laboratories (e.g., in Nagpur, India and Rio de Janeiro, Brazil), which have played a useful role in water pollution control. Further assistance is needed to encourage the establishment of similar institutions in other developing areas.

The results of laboratory research should be tested at field testing stations, where they should be applied to the development of economic treatment processes suitable for local needs. In some instances, WHO may be able to assist in establishing useful demonstration plants for study and for process improvement.

Research, no matter how essential, should never be regarded as an alternative to active control work ; nevertheless, it is unlikely that a vigorous and well-balanced field programme could be fully successful without the encouragement, support, and co-operation of a research centre. The establishment and support of water pollution research in developing countries will strengthen the field effort, by attracting high-level scientific and technical personnel to the field and by stimulating originality in approach,

rather than an over-dependence on the technology developed to meet the needs of highly developed countries.

7.1.1 *Availability of information*

In addition to well-equipped laboratories, research institutions will of necessity maintain good libraries, which can provide valuable information not only for governments but also for the national and regional engineering and scientific communities.

The New Delhi Seminar drew attention to the urgent need for easy access to information on water quality management and on the treatment of water, sewage, and industrial wastes. Similar statements were made in 1965 by the WHO Expert Committee on Water Pollution Control¹ and in 1966 by the WHO Scientific Group on the Treatment and Disposal of Wastes.² In spite of world-wide efforts to solve the problems of abstracting and retrieving scientific and technical information on environmental pollution, the improvement and extension of information services is urgently necessary. In particular, information must be made easily accessible to institutions and experts in the developing countries. The Committee recommends that WHO investigate ways in which Member Countries could be assisted in this matter and existing services improved.

7.2 **Training**

Thorough training of personnel is essential if water pollution control is to be effectively managed in developing countries. The training that is necessary for personnel of different grades is discussed in the following sections.³

7.2.1 *Managers and executives*

Senior experienced civil engineers, chemists, microbiologists, and sanitary inspectors should be given a year or two of intensive training in environmental health theory and practice to prepare them for senior managerial or executive posts in water management authorities. Such training, which can be given in well-established and properly staffed schools of engineering or public health, is important because those who undergo it will have to advise their governments in the making of far-reaching decisions. It should, therefore, bring them abreast of the most advanced thinking in the profession. The training should be supplemented by field studies both in and outside the trainees' own countries, exposing them to

¹ *Wld Hlth Org. techn. Rep. Ser.*, 1966, 318.

² *Wld Hlth Org. techn. Rep. Ser.*, 1967, 367.

³ For further information, see *Wld Hlth Org. techn. Rep. Ser.*, 1967, 376.

widely varying situations demonstrating the necessity of adaptability and independent thinking.

7.2.2 University teachers

Intensive programmes should be offered for the training of both senior and junior university teachers. If local institutions are not available, such training may have to be given overseas. If personnel with good practical experience could be encouraged to engage in teaching, some emphasis on applied research might be developed in the universities, although basic research should not be neglected.

7.2.3 Middle-grade professionals

Training is also necessary for young graduates who wish to make a career in environmental health work. Local institutions should provide both undergraduate and post-graduate training for sanitary engineers, microbiologists, chemists, sanitarians, and members of related professions.

The training of mechanical and electrical engineers should also be undertaken, since plant operators will need assistance in the maintenance of mechanical and electrical equipment that may be used in treatment plants.

7.2.4 Auxiliary personnel

At first, few engineering works and institutions concerned with water pollution control will be in existence in developing countries. Consequently, the demand for auxiliary personnel will be small, and few will be available. The establishment of schools for the training of such personnel will be delayed, and in-service training may be the only solution. It is probable that the highest grades of auxiliary personnel, such as laboratory technicians and skilled mechanics, will be the first to receive formal training when it becomes available, while the lower grades will continue to be trained in service. As a result of the shortage of personnel who can perform the more delicate operations in water and sewage treatment plants, difficulties may be expected in the initial period of plant operation.

When circumstances permit, periodic training may be given to employees (including entrants) in works that have a well-developed operational routine. In the long run, however, it will not be sufficient merely to train workers for the mechanical aspects of individual operations. Suitable courses will be necessary, including instruction on the purpose of each operation and on the possible consequences of faulty execution. Adequate training is as important for auxiliary and subprofessional personnel as for professional staff, and it is recommended that WHO investigate whether there are means by which it could assist in this area, possibly in conjunction with the existing community water supply training programme.

7.2.5 *Training facilities*

To provide suitable training programmes, local and regional institutions, which may be attached to schools of engineering or public health, are necessary. Such institutions should concentrate on the training of young environmental health workers, in whom they should strive to inculcate an attitude of originality and the ability to improvise. Such workers should be trained to seek simple, inexpensive, but well-engineered solutions to pollution problems. During the early stages of development, high-level managers and executives, university professors, and lecturers would probably still receive the greatest benefit from overseas training.

The research institutions discussed in section 7.1 could be used as meeting places for seminars and symposia to contribute to the further education of engineers and scientists. Research and auxiliary staff members could offer "refresher" courses for water pollution control personnel at all levels, including periodic courses for plant operators and technicians.

7.2.6 *Need for outside assistance*

Developing countries may need outside assistance to achieve their educational and staffing needs. Such assistance may have to take the form of development grants to institutions, travel or study grants to senior personnel, and the provision of experts to assist in the establishment of sanitary engineering institutions such as regional post-graduate colleges. Experts from different countries could also assist in the establishment of adequate organizations for the management of water resources and could take part in special short-term training programmes.

The assistance of the World Health Organization and other agencies in making it possible for trainees from developing countries to attend sanitary engineering courses abroad has been a great stimulus to the development of the profession. Such efforts should not be relaxed until the developing countries have proved their ability to meet their own needs. As time goes on, however, local schools should be best equipped to solve local problems.

8. PUBLIC SUPPORT

Success in developing a system of water pollution control depends to a great extent on creating a national sense of responsibility. Much support can be obtained from the general public, if their interest is aroused in the importance of preserving water resources. It is, therefore, essential to inform the public of the dangers involved in water pollution. Different types of information may have to be supplied to different groups of the public. For example, the information that would be appropriate for a large industrial concern would be of little interest to a young mother.

Persons who have influential positions in public life can assist water pollution control by promoting the necessary legislative measures, by supporting water pollution control organizations, and by securing necessary funds. The same group, unfortunately, can also do much harm by opposition or indifference.

Action should be initiated by those responsible for water pollution control. Information, which should be issued continually and systematically, should be prepared by specialists in both publicity and water pollution control, and should concentrate on essential facts concerning the main sources of pollution, the principal types of pollutants, and on the effects of such pollutants on receiving waters. Emphasis should be given to (1) the natural process of purification that occurs in surface and ground water, and its limitations, and (2) the principles, methods, and achievements of pollution control.

Such information should be disseminated by all possible means. Daily newspapers may establish regular columns on water pollution and its control, and publish news from the field, articles of special interest, and news on court proceedings connected with water pollution. The press should also be used for the correction of misinformation, and can publish appeals for public co-operation. Other means for disseminating information are radio, educational films, and particularly television. Lectures for the general public, school lectures illustrated with lantern slides or films, demonstrations of water pollution control measures in the field, and well prepared pamphlets containing more detailed information may also prove useful.

It is particularly important that the leadership of a country be correctly informed on the nature, importance, tasks, and achievements of water pollution control.

In short, water pollution control should be publicized by the methods used in good commercial salesmanship. For such activities, it is desirable to enlist the aid of persons from tourist associations and agencies, water sports associations, fisheries, industries that require clean water, boy-scout and girl-guide organizations, conservation associations, women's associations, schoolchildren, and riparian populations.

It is suggested that WHO might examine the possibility of making films on water pollution and its control, which could be supplied, with accompanying texts, to schools in developing countries. Audio-visual programmes suitable for transmission by television might also be useful.

9. CONCLUSIONS AND RECOMMENDATIONS

Developing countries are experiencing a rapid growth of both the total population and its density, primarily in areas of rapid urbanization and industrialization. Consequently, the demand for water is increasing, while

growing water pollution is reducing usable water resources, particularly in arid and semi-arid zones. The increase of water pollution also poses a serious threat to health (e.g., from diseases such as cholera, filariasis, and schistosomiasis and from the presence of toxic substances). It may introduce new diseases into a given area, and in general it hinders progress and economic and social development.

The only rational way to protect public health in such conditions, and to ensure unobstructed progress, is the organization of water pollution control as part of over-all planning of the water economy of each country. The Committee unanimously agreed on the necessity of the following measures.

(1) In order to provide maximum protection from pollution, the planning of water resources should not follow the planning of urban, industrial, or general regional development, but should be an integral part of it. In this way, vital water resources would be protected, and sites for urban and industrial development could be selected so as to minimize problems caused by waste-water discharges. This is particularly important in areas where a water shortage already exists.

(2) As a general rule, water supply and waste disposal should be planned so as to make the best possible use of available water resources without endangering health. Consideration should be given to the quality of water required for different uses and to the character of the effluents resulting from such uses.

(3) In order to estimate the total volume of water resources and to study their quality, adequate meteorological, hydrological, hydrometric, and hydrogeological data must be collected.

(4) If future needs threaten to exceed resources, provision should be made to make good the deficit by appropriate methods of water and waste-water treatment and by storage, conservation, recovery and re-use, and other procedures.

(5) Rational water management is normally based on river basins or sub-basins. Since such areas are also suitable for urban, industrial, agricultural, and general regional planning, they might well be adopted as the basis for the planning of water resources. Due consideration must be given to the health implications of all such schemes.

(6) As noted in the report¹ of a previous WHO expert committee, pollution control and the quantitative management of water resources in a river basin are part of the same problem and should be functions of the same authority.

¹ *Wld Hlth Org. techn. Rep. Ser.*, 1966, 318.

(7) Although water management may be organized in different ways, the water management authority should be responsible for the entire area of the planning and management of water resources, including water pollution control. Since such control is essential for the protection of health, there must be provision for the full participation of public health authorities in all such activities, particularly pollution control.

(8) In developing countries it is useful to pool the available personnel, equipment, and laboratories in central agencies rather than to disperse them among different services and institutes.

(9) The storage of water in reservoirs is the most obvious method for conserving water in arid and semi-arid regions having a surplus of water in rainy periods and a deficit in the drier months. It is also useful for improving the quality of the water and of the water course below the reservoir, but care must be taken to prevent deterioration, particularly if water carries pollutants into such reservoirs.

(10) Water pollution may be controlled either by prevention or by reducing the concentration of certain physical, chemical, and biological pollutants to levels commensurate with the use to which the water is to be put. It follows that the way in which polluted water is treated depends upon the way in which it is to be used or disposed of.

(11) It is recommended that sewage and storm water be removed by separate sewerage systems.

(12) Waste water that is likely to cause obstruction or damage, or to create hazards for maintenance teams, should be treated prior to discharge into the sewerage system.

(13) In selecting methods for treating sewage and industrial wastes, developing countries should give special consideration to low-cost systems that do not require complex machinery. Irrigation, stabilization ponds, and oxidation ditches are particularly suitable, if used so as to avoid the creation of health hazards and nuisances.

(14) In selecting methods for treating sewage and waste water, considerations of public health should come before those of cost.

(15) There are wide opportunities for research in developing countries, particularly on the possibilities of using waste water and sludge for growing crops. National or regional research centres should also be used for the dissemination of information, for the training of personnel, and for assisting governments.

(16) Efforts should be made to ensure the adequate training of executive, teaching, and auxiliary personnel at all levels. Centres for the study of water pollution control should be developed at suitable institutions of higher learning.

(17) All possible means of communication should be used to inform the general public, to arouse their interest, and to gain their co-operation in water pollution control.

(18) The Committee recommends that WHO consider the possibility of rendering further assistance to Member Countries in the establishment of training institutions and in using them to promote studies of the potential uses of wastes, particularly for crop production. The Committee further recommends that WHO investigate the possibility of assisting Member Countries to improve and extend existing services for information retrieval.

(19) In planning measures for water pollution control, plans should be made to secure the necessary funds for the construction, operation, and maintenance of installations.

(20) Charges for the use of water and sewerage systems, or for the discharge of wastes into receiving waters, are sometimes paid into the general treasury of a country. The Committee is of the opinion that such funds should be used for the operation and maintenance of water supply and sewerage systems, and for financing water pollution control.