

# Health Aspects of Treated Sewage Re-Use

Report on a WHO Seminar

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# WHO SEMINAR ON HEALTH ASPECTS OF TREATED SEWAGE RE-USE

*Algiers, 1-5 June 1980*

## 1. SUMMARY

The principal forms of water re-use are, in decreasing order of magnitude, agriculture, aquifer recharge, industrial re-use and potable re-use. The last item may be greater than is generally realized if indirect discharges to water supplies are included. In arid regions of the world little water is wasted. Except in coastal cities, sewage is re-used directly or after a short sojourn in a receiving stream, primarily for agriculture. Both water and chemical fertilizers are conserved. Some aquifer recharge may take place from receiving waters and some intentional aquifer recharge systems have been developed. Municipal sewage is a valuable source of industrial water in desert regions and is increasingly used in moister climates as well.

The hazards of re-used water are, primarily, the risks of infection. Bacteria, viruses, protozoa and worms are all carried by water and may damage the health of those who come in contact with wastewater unless it has been adequately treated. Chemical hazards are of less importance for man, but salinity may limit the potential for re-use of sewage in agriculture and industry.

Treatment may be as simple as spreading sewage on the land or as complex as some advanced waste treatment systems used for industrial re-use or potable re-use. Treatments must be adjusted to the specific situation, and attempts to establish universal requirements for treatment or water quality tend to be counterproductive. High levels of treatment required to meet strict quality standards are very expensive and should only be employed where they are needed.

## 2. INTRODUCTION

The interregional Seminar, held on the premises of the Palais des Nations, Algiers, was attended by about 100 scientists, engineers, government officials and other workers from 20 Member States, including the dry countries of southern Europe, western Asia and northern Africa. It was opened by

Dr B. Hadj-Lakehal, Director of Prevention, National Institute of Public Health, who presented a brief review of his country's water problems. Algeria, which was situated not only geographically but also in the economic sense between the highly developed countries of Europe and the developing countries of central Africa, was already beginning to experience some of the evils of industrial pollution in its major cities and manufacturing complexes, while in many areas it still suffered from infectious and parasitic diseases typical of the tropics. Waterborne diseases had not yet been eradicated, as exemplified by the fact that there were 3000-4000 cases of typhoid a year and even cases of cholera.

On the other hand, Algeria, whose population was largely concentrated on the coast, had less industrial pollution of its rivers than Europe or North America. Sewage from the major coastal cities was collected and discharged to the sea. Inland communities discharged sewage to rivers, but a large amount was used directly in agriculture.

The national development plan provided for sewage treatment plants in cities of more than 50 000 inhabitants, with re-use of the water in agriculture and industry. Currently, agricultural re-use predominated; however, the mining complex of El-Hadjar in the south of the country recovered 600 m<sup>3</sup> of treated water per day. Other uses for treated water in cities and tourist centres included street flushing and the irrigation of parks and gardens.

The speaker emphasized that the programmes for improving health and the environment were not merely social objectives but were also significant factors in economic and cultural development, and concluded by outlining the responsibilities of the various ministries concerned with water supply and sanitation.

Mr C. Jaeger, UNDP Resident Representative in Algiers, noted that UNDP's financial support, though considerable, was unfortunately still not enough to deal with the massive problems that existed in the field under review. One third of the world's population did not yet have access to adequate water supplies and was therefore exposed to waterborne diseases. Water re-use was necessary for industrial and agricultural development. The Seminar was one of many activities being conducted during the International Drinking-Water Supply and Sanitation Decade.

Mr J.I. Waddington, Director, Promotion of Environmental Health, WHO Regional Office for Europe, addressed the participants on behalf of the Regional Director for Europe, Dr Leo A. Kaprio. He pointed out that the Seminar, originally planned as a national effort, had been expanded to cover the entire Mediterranean subregion. Subsequently it had been decided to include representatives from four of the six WHO regions. He then outlined some of the closely related programmes of the Regional Office for Europe, including those relating to the health and environmental aspects of air, water and solid waste, food safety and personal hygiene, both at home and at work and in recreational areas. He believed that the Seminar could make a valuable

contribution by formulating clear recommendations which might eventually lead to a code of practice and some assessment of the environmental impact of water re-use. Above all, he expected the output to be practical and to take into account national needs.

Dr A. Aroua was elected Chairman, Dr A. Vassallo Vice-Chairman, and Dr R.B. Dean Rapporteur. A list of participants is given in Annex II. Over 80 observers, most of them representing Algerian ministries and State organizations directly concerned with the topic under discussion, also attended the Seminar.

The technical sessions included 12 working papers presented by 7 experts (see Annex I). In addition, several case studies relating to various aspects of water pollution control and water re-use were submitted.

"Community responsibilities for sanitation and sewage", prepared by the Ministry for Local Government, described the water cycle in the El-Hadjar Steel Works, where net water consumption had been reduced to 20-25 m<sup>3</sup> per tonne of steel, and there were plans to reduce it still further to 10-15 m<sup>3</sup> per tonne.

Three classes of water were used: (a) drinking-water, (b) raw river water and (c) high quality industrial water. All wastewaters were stored, treated and recycled. Technical details were given about purification processes for acids, chromate and alkali wastes.

In "Relationship between environmental conservation and wastewater treatment: pollution and nuisance control policy", by the Secretary of State for Forests and Afforestation, the fundamental principles of Algerian environmental conservation and water resources conservation policies were presented. The environmental health impact of water pollution was described and the cost of wastewater treatment justified by reference to health problems, the shortage of water resources and the protection of environmental quality, despite the budgetary constraints resulting from the country's rapid economic development. The paper also included data on the water resources balance in Algeria, the coverage of the urban population by the sewerage service, and the degree of treatment applied to collected sewage. The cost of wastewater treatment to control marine pollution was considered to be justified even when urban or industrial effluents were discharged to the sea.

A paper by the National Steel Works Corporation, entitled "Water recycling at the El-Hadjar Plant", described Algerian legal and budgetary provisions regarding sanitation and sewerage construction and maintenance works. Responsibility for the works lay with the People's Communal Council, which received technical and financial support from the Ministry of the Interior. Details of planned investments for sewerage construction and sewage disposal during the next development planning period were given.

A paper by Mr J.C. Bazin, entitled "Sewage disinfection by ultraviolet rays: results from the Luc Mer Plant" described the use of ultraviolet light to disinfect domestic and tourist sewage before discharge to the sea off the northern coast of France.

Mr P.A. Banks described and illustrated several water re-use projects in the Persian Gulf. Projects ranged from providing green areas and shade trees in Abu Dhabi to forestry and dairy farming in Kuwait. In these and other areas the primary water supply was very expensive and every effort was made to obtain the maximum benefit from the supply.

Public health requirements were especially high in areas where people congregated in large numbers. In Abu Dhabi, where a large part of the water supply was produced by desalination, wastewater was given biological filtration treatment, then ozone treatment to disinfect it and finally chlorination to maintain a residual disinfectant within the distribution system. Some of the problems encountered in controlling unauthorized access to re-used water were considered.

The presentations illustrated that, from both a theoretical and a practical point of view, sewage is a reliable source of water for many purposes. They also showed that technology exists at many levels by which water which might otherwise be wasted can be purified so that it may be used without hazard to health. Treatment can be as simple as using sewage directly to irrigate non-food crops such as forests or fibres, or crops that are processed by heat before consumption, such as grain. The major part of the treatment in this case is supplied by the soil, where filtration, biological degradation and ionic adsorption occur as natural processes. The soil can also be used to treat water before infiltration into an aquifer or collection in underdrains. The major problem is to design the system in such a way as to protect the health of agricultural workers. Biological treatment in lagoons can also be very effective in many areas, providing both disinfection and storage that will help to balance supply and demand.

More elaborate techniques are also available to provide higher degrees of treatment which enable water of any required quality to be produced. A high quality of water is essential for certain industrial applications, including the feed water for high-pressure boilers. Although technology does exist for producing water of potable quality directly from sewage, there will be very few places where this is the best way to proceed. The paramount requirement of freedom from infectious organisms in potable water poses a number of problems, including that of storage. A high level of technology is essential to ensure the reliable operation of a potable re-use system.

The case studies presented showed that many relatively unsophisticated soil treatment and irrigation systems have been operated for periods of almost 100 years and are still operating without significant adverse effects on the environment. They also made it clear that improper operation, usually the application of too much water to the soil, can seriously damage the system. It was stressed in the discussions that water treatment systems that include agricultural applications must be well coordinated at a high level to avoid unsuitable applications such as irrigation of leaf vegetables with untreated sewage.

After the last paper had been presented, a small working group was set up to draft a set of conclusions and recommendations.

The Seminar met in general session on the last day to discuss and comment on the work of the group and to make corrections. The revised conclusions and recommendations are given below (chapters 6 and 7).

A number of speakers representing all the participants expressed thanks for the hospitality extended to them by the Algerian Government.

Some of the most significant points raised by the various speakers are summarized, with minor editorial changes, in the following sections.

### 3. REVIEW OF THE PROBLEM

Since the waterborne epidemics of the last century, the general public has associated wastewater essentially with the presence of disease-producing or infective agents. It seems quite likely that in many areas toxicological and related problems should be given the highest priority today. Industrial development has created new problems with the production of probably thousands of new chemical compounds which will eventually reach wastewater.

Problems connected with the removal of infectious agents have not disappeared. The distinction between domestic wastewater and industrial wastewater is more convenient than correct: the former contains numerous chemicals and the latter includes household-type wastewater from employees and also, for instance, waste from slaughterhouses, food industries and dairies. Industrial waste may thus contain quite high levels of infectious agents, including some pathogenic to man or animals. The distinction between sewage and stormwater is also more a matter of flow than of pollutant content. Bacteria, viruses and other parasites in stormwater can rival the concentrations found in domestic sewage, and the content of heavy metals is not greatly different from that found in municipal sewage that contains discharges from light industry.

The need for direct and deliberate re-use of reclaimed sewage effluent is increasing in many areas of the world. Re-use provides the key to the efficient and effective utilization of limited freshwater resources by making available a valuable new source of water to augment existing supplies. It has rightly been stressed that no higher-quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade. The benefits to be gained from advanced wastewater treatment and water re-use include not only the supplementing of freshwater supplies, but also an alleviation of the pollution problem at the same time.

If water sources were not polluted by wastewater there would be no reason to worry about health hazards of water or about methods for its

examination. Wastewater has, however, always been discharged into fresh surface and even underground water. When rivers and lakes are used both as a source of potable water and for the disposal of wastewater, and when drainage from septic tanks, ponds and treatment lagoons reaches underground water, the re-use is unintentional but at times certainly occurs. There is a consensus in the world today that water re-use is necessary to provide sufficient supplies. It would therefore seem more appropriate to plan for the intentional direct re-use of wastewater after it has been subjected to adequate treatment for the intended use. By proper planning, water could be upgraded for a number of uses, and sources meeting the requisite criteria could be protected by allowing only well treated wastewater to have access to them. Through such differentiation, conservation of the best water could be achieved.

## 4. PARASITIC ORGANISMS

### 4.1 Bacteria

Bacteria, including the agents that produce typhoid, cholera and a host of enteric disorders, are well recognized water pollutants of great public health significance.

A well run primary treatment plant can be expected to remove about 50% of pathogens from water, but it must be remembered that sludge will contain much higher concentrations than untreated wastewater. For activated sludge and trickling filters, the figures reported vary considerably, but 85%-99% of bacteria may be removed, except for clostridia, which are poorly removed. The important point is that even highly treated wastewater retains some of the original organisms. In biological processes there is not only removal but also actual destruction of bacteria. In oxidation ponds and lagoons equally high efficiency can be expected if they are properly designed and employed in series (1).

A number of factors are important for the fate of pathogenic bacteria on soil. Instead of the dilution that would be expected when wastes are discharged in surface water, the majority of micro-organisms are concentrated from wastewater and sludge and remain in the upper portion of the soil. If this system is efficient; it provides, of course, excellent treatment of the waste and may ensure good protection of groundwater, but if the land is used to grow food crops the risk of contaminating them is considerable. Larkin et al. (2) and others report the survival of salmonellae and other enteric bacteria in soil and on vegetables for weeks and even months. Tuberculosis bacteria may persist in drying-beds for up to 15 months. *Mycobacterium bovis* (BCG) has been demonstrated after a month in soil and on lettuce.

The migration of bacteria in soil depends on geochemical conditions and on the size of the soil particles. In sandy soil coliforms may travel more than 800 m; in other cases, a maximum of 450 m has been reported. In heavy soil, migration is considerably reduced. In groundwater recharge the risk of contaminating wells and underground water must be considered. Surface infiltration of wastewater, after suitable treatment, may sometimes be undertaken in a dry river-bed to supplement an aquifer.

Sewage irrigation and sludge application should not be undertaken on land employed for growing food crops which will be eaten raw. An extended period should be allowed after such irrigation has ceased before the land is used again. Wastewater should not be used to irrigate crops that enter the kitchen in the raw state, unless it is shown to be free from pathogens, even if the food is to be cooked, because of the risk of cross-contamination.

## 4.2. Viruses

More than 100 different virus types are known to be excreted in human faeces. More than 1 000 000 infectious virus particles may be excreted per gram of faeces by infected persons, regardless of whether or not they manifest illness. Concentrations as high as 100 000 infectious virus particles per litre have been detected in raw sewage. These viruses may survive for several months in wastewater, tapwater, soil and shellfish. Furthermore, they may resist conventional water and wastewater treatment procedures, including chlorination, and be found far from the original source of contamination (3).

Viruses will nearly always be present in raw wastewater from large cities, but in varying concentrations. In temperate zones there is a peak concentration in the late summer-autumn period, whereas the concentration found in tropical areas is more of an all-year-round occurrence. Enteric viruses have been found in the course of studies carried out all over the world, but the amounts are such that concentration procedures may be required for them to be detectable. In general, the methods employed are not quantitative, so what is detected may be only a part of what is really present. Many types of virus probably remain undetected in the wastewater or sludge samples studied from various areas. Viruses may be present in highly treated wastewater and may persist for several months in natural water and in soil.

The technique for sample concentration, the host cell system and the type of culture technique used will all be selective, to some degree, with respect to the viruses enumerated. No universal procedure or system is at present recognized for the cultivation of all viruses. It is likely, therefore, that many of the investigations of virus density in wastewater have not included all viruses present, due to the selectivity of the techniques employed.

Documented waterborne outbreaks of viral diseases have been due almost solely to the hepatitis A virus. Perhaps the infectious dose for man is smaller for this virus than for many other enteric viruses, and maybe the explosive

nature of the outbreaks and the characteristic symptoms also play a role in their recognition. As has been pointed out (3), current epidemiological techniques are not sufficiently sensitive to detect low-level transmission of viral diseases through water, for two main reasons.

(a) Most enteric viruses cause such a broad spectrum of disease syndromes that scattered cases of acute illness would probably be too varied in symptomatology to be attributed to a single etiological agent.

(b) Many viruses cause inapparent infections that are difficult to recognize as being waterborne. A person may contract a viral infection by coming into contact with contaminated water, and the virus may actively multiply in the intestines or in the upper respiratory tract without his developing overt symptoms of the disease. He may suffer only mild respiratory or gastrointestinal distress for a few days, or have no symptoms at all, yet he can act as an effective carrier and transmit the virus by droplet infection or by contaminated fingers to other individuals, who may then develop acute symptoms of the disease.

These reasons may have accounted for the fact that in recent years about 60% of all documented cases of disease attributable to drinking-water in the USA were caused by unknown or unrecognized agents. In addition, at present no field-tested method exists for the detection in water of the agents of viral hepatitis A and non-bacterial gastroenteritis. These difficulties have led to an emphasis on the detection of the readily demonstrable enteroviruses in water as an indication of the possibility of contracting disease from other viruses present in water (3).

It has been recommended that wastewater intended to be re-used directly for drinking should be given advanced treatment which may remove viruses with a factor of at least  $10^6$ , rising to as much as  $10^{12}$ . Such directly reclaimed drinking-water should be tested and should not contain detectable viruses in samples of between 100 l and 1000 l. It would be desirable if other potable water were tested in a corresponding manner, but this would not be possible in most countries.

Difficult as it may be to obtain correct information about the actual occurrence of a number of the pathogens in wastewater, sludge and recipient water, it is still more difficult to evaluate the importance of their presence. The setting of standards for different kinds of water based on an "acceptable level of risk" concentration of waterborne pathogens is not an easy task. If it were economically and politically feasible, wastewater should be discharged only after treatment so that all potential dangers would be eliminated. This kind of "play-safe" attitude is, in fact, not put into practice anywhere in the world at present.

The setting of standards for various types of water is only tentatively attempted, and the levels suggested are somewhat arbitrary. WHO standards

for drinking-water (4) recommend less than one infectious virus unit per litre on the basis of an examination of 10-litre samples. A proposal has been made in the USA calling for less than one infectious virus unit per 10 gallons of recreational water and less than one unit per 1000 gallons of drinking-water. This is apparently somewhat more stringent than the WHO recommendation, but the methods employed in different examinations have not been inter-calibrated, so the interpretation is not necessarily correct. The important issue is still the quantity of a virus it takes to infect man at such a level that the infection may be transmitted and/or cause disease in the infected person. This information is needed to establish "acceptable level of risk" criteria for waterborne viruses.

It should be emphasized that conventional "disinfection" of treated effluents with chlorine for 30-120 minutes does not measurably change the content of viruses or parasites. Although faecal coliforms are excellent indicators of faecal pollution, they are less resistant than viruses, amoeboid cysts or worm eggs. Therefore, while the presence of the faecal coliform group is an excellent indicator of faecal pollution, the absence of such coliforms in treated wastewaters is no guarantee that viruses and other parasitic organisms are absent.

As enteric viruses are more difficult to remove than many bacteria, because chemical treatment under wastewater conditions does not inactivate viruses as fast as it kills bacteria, and as viruses survive longer in fresh and saline waters than bacteria such as *E. coli*, it is not possible to conclude that bacteriologically safe water is also safe from a virological point of view.

On the other hand, in all recorded cases of virus epidemics the evidence for faecal pollution could have been detected by bacteriological testing without the need for a virus assay. This is true even of the celebrated outbreak of viral hepatitis in New Delhi, which was caused by inadequate treatment of water grossly polluted with sewage (5). Therefore, routine bacteriological testing will give pragmatic assurance that serious contamination by viruses is probably not present.

The rational means of ensuring virus-free potable water and other water of sufficient quality seems to be the protection of raw-water sources from faecal pollution by banning insufficiently treated effluent discharge into surface water and similar precautions, rather than the setting of standards that cannot be properly enforced.

### 4.3 Amoebae and worms

A number of parasitic protozoa and helminths are so frequently found, especially in tropical and developing countries, that they are in fact the most serious threat to the wellbeing of man. The parasites of importance are spread as cysts or eggs through faecal pollution, but they cannot multiply outside the living host organism. In many cases intermediate hosts are required to

complete a life cycle. Usually only one or a few parasite eggs are required to establish infection, and the cysts and eggs are often extremely resistant to being killed in the environment. Extensive literature on the parasitic protozoa and helminths, their characteristics and the diseases they cause has been compiled with regard to the health aspects of excreta and wastewater management (6). Epidemiologically, there is a difference between the rural faeces-soil-human infection chain and the urban sewage-crop-human chain (7). The rural chain is linked to family exposure, whereas the urban chain is unlikely to respect the environmental and socioeconomic status of individuals, and infection follows marketing and distribution channels.

The shorter the path between the excreta and the susceptible individual, the greater the chance of being infected. Ascariasis, trichuriasis, hookworm diseases and taeniasis are infections caused by direct soil pollution by faeces and susceptible to environmental sanitation. They disappeared in cities following the introduction of modern water supply and sewage disposal. With continuing urbanization, they are now confined to rural areas where soil, climate and socioeconomic factors favour the establishment of the infection chain. However, they usually reappear whenever there is a breakdown in sanitation or infected persons are introduced into a community.

Trematode diseases of man have limited geographic distribution because of the parasite's complex life cycle that requires the presence of snail hosts and other favourable factors. In endemic areas, untreated sewage used for land irrigation or discharged into surface water is likely to aggravate infection in the community. The problem deserves even more attention when animal helminth diseases are included. The majority of helminth ova in municipal sewage are of animal origin. The economic factor in the occurrence of these animal diseases could be significant.

Essentially, sewage treatment consists of a transfer of pollutants from wastewater to sludge. Such treatment is especially important in controlling parasites because of the resistant nature of the eggs. Thus it is very unsafe to use untreated municipal sewage as irrigation fluid on land. If cysts or eggs are not removed by sedimentation in a treatment plant, they will still be present in the treated water, because conventional treatment will not kill them. The enteric helminth ova have shells resistant to bacterial activity and are too large to be ingested by zoomicrobes normally present in sewage treatment. Hence, processes such as trickling filters and activated sludge are relatively ineffective in their removal or destruction. Schistosome ova may even hatch during these processes.

There is no 100%-effective yet practical method of treatment. However, if a method produces a high level of reduction of an infective agent, say 99%, it will eventually be effective in eradicating the disease, because impairment of the infection cycle works towards the elimination of the parasite.

Regarding the different sludge treatments only heat treatment, irradiation in the range of 2-5 kGy (200-500<sup>3</sup> kRad) and holding for extended

periods are effective against the more resistant parasite eggs and cysts. Chemical flocculation may remove them, but not even lime will destroy the parasite eggs in sludge. Rowan (8, 9) has collected information on the efficiency of sewage treatment.

## 5. IRRIGATION AND AQUIFER RECHARGE

Wastewater re-use for irrigation is one of the oldest forms of water reclamation and it has always been most important from a quantitative point of view. "Sewage farming" has been practised for many centuries and several projects based on the re-use of municipal wastewater for agricultural irrigation have been reported at the end of the last century (10, 11).

Re-use of sewage for irrigation has become increasingly popular in water-short areas all over the world as a means of avoiding pollution of sources and providing water as well as nutrients to agricultural areas in order to improve soil fertility and crop yields. Examples of this type of re-use have been reported in the USA (12), India (10) and Israel (13). Sewage is often untreated or insufficiently treated before land application, although it is known that this practice creates serious health risks for sewage farm workers (10), for those consuming contaminated vegetables and for cattle grazing on the irrigated grasslands. Only during the last few decades has application of treated sewage been intentionally practised to replenish freshwater aquifers. This type of re-use is promoted along coastal areas to prevent intrusion of salt-water from the sea and at all kinds of suitable locations to benefit from the purifying capacity of the ground, with subsequent use of the recharged water for different purposes. In Europe, artificial recharge of the water of the River Rhine, a kind of indirect re-use, is frequently undertaken as a final step in the production of drinking-water. Groundwater replenishment generally requires pretreatment to prevent rapid clogging of the infiltration surface and to reduce maintenance costs.

Filtration is the primary means whereby soil removes constituents of recharge water in particulate form. As the water moves into passages of the porous media, particulates of particle size greater than the soil pores are strained off at the water-soil interface. The accumulated solid particles in turn form a mat retaining additional suspended particles. The eventual consolidation and collapse of the accumulated layer under static hydraulic pressure results in a reduction in water infiltration. Since the suspended solids of wastewater are closely associated with biodegradable organic matter, the infiltration capacity and filtering function of soil may be restored by periodic resting to promote biological decomposition of organic solids. Particles of smaller size not retained at the soil surface may be trapped and adsorbed in

the stationary soil matrix as they travel with the percolating water by a combined mechanism of particle interception, inertia momentum, sedimentation, diffusion and hydrodynamic action (14). Colloidal suspended solids may also be removed by filtration after they have been chemically destabilized and coagulated. In the soil, the efficiency of removal of suspended solids increases with the distance the water travels. In almost all groundwater recharge investigations, water has been found free of turbidity after several metres of travel in the soil (15, 16).

### 5.1 Sanitary and chemical requirements

The bacteriological quality of municipal wastewater is usually controlled where food crops or landscape areas (parks, golf courses, etc.) are to be irrigated or where aerosol generation by sprinkling is anticipated. Generally, public health agencies place limitations on the quality of municipal wastewater that can be used for irrigation.

Pathogens in raw and treated wastewaters include various bacteria, spirochetes, helminths, protozoa and viruses. Sprinkler irrigation requires the best quality of water from a microbiological point of view, as the water and organisms are frequently applied directly to the plant surface. Surface flooding may pose the same microbiological problems if the plant surfaces come into contact with the reclaimed water and the crop is eaten without processing. Subirrigation and furrow irrigation present fewer problems as the water rarely reaches the upper portions of the plant, and root crops, as well as leafy crops and fruits, ordinarily do not permit penetration of the plant by animal and human pathogens (17). While pathogenic bacteria may survive for periods of several days to months or even years in the soil, pathogens are seldom detected on farm produce unless the plant samples are grossly contaminated with sewage or are observed to have faecal particles clinging to them (18). It is important to note, however, that because some pathogenic organisms can persist for periods longer than that required for distribution to the consumer a potential health hazard does exist.

Aerosol travel and pathogen survival increase with increased wind velocity and relative humidity, lower temperatures, and darkness (19). A direct means of human infection by biological aerosols is inhalation. A summary of virus infections by the respiratory route demonstrates that extremely low doses in the range of 1-800 plaque-forming units can cause infection in man (20). Recent studies have shown, however, that aerosols emitted from wastewater treatment plants do not create a significant health hazard for persons living in the vicinity (21). Current methods employed to reduce the potential problem of aerosol disease transmission include isolation distances, vegetative screening, and application techniques to reduce aerosolization, such as low-pressure large-droplet spray-irrigation equipment, spraying during low-wind periods, and disinfection prior to application (22).

## 5.2 Treatment requirements

In recent years there has been a trend to re-use wastewater for purposes such as landscape and food crop irrigation and for recreational impoundments, while uses requiring lower-quality effluents have increased only moderately. These changes have brought about a significant increase in the probability of public exposure to reclaimed water. As noted earlier, a reasonably clear understanding of crop uptake and the acute health significance of heavy metals and toxic chemicals is available and these substances are, to a large extent, effectively removed by conventional wastewater treatment processes (23).

In terms of chemical quality, not all wastewater is suitable for re-use by land application. Aside from pathogenic organisms, salinity and sodium hazards are by far the most serious quality defects associated with the re-use of wastewater for irrigation. Compared to original water, wastewater effluent usually has a greater potential to cause soil salinity and permeability problems. There are also significant increases in the boron and zinc content of the water. Because of differences in the salt tolerance of crops, in soil composition and in water management, wastewater with a wide range of chemical properties may be made suitable for irrigation. Procedures to determine the chemical requirements of wastewater for irrigation should be identical to those applicable to water from other sources used for this purpose. Because of the soil's inability to effectively retain dissolved chemical constituents in water, the water-quality criteria for aquifer recharge are not as flexible as those for irrigation. Unless the chemical properties of recharge water already meet the quality criteria for the intended use, it should not be used in aquifer recharge.

Wastewater irrigation practices vary widely throughout the world. Some of the major differences are related to the quality of the wastewater applied, the rates and total volume applied, the degree of treatment before application, storage requirements, irrigation methods used, and the type of crops grown (24). Climate is very important as it influences such requirements as the amount of water applied, storage volumes, the type of crops and possibly the method of irrigation. Although in the past it was common practice to use raw untreated domestic wastewater to irrigate crops (a practice followed even today in some areas), the need for some preapplication treatment of the wastewater is now recognized in most quarters.

In California, USA, primary effluent is acceptable for surface irrigation of orchards and vineyards (except during seasons in which windfalls of fruit lie on the ground) and of fodder, fibre and seed crops. The equivalent of primary treatment is usually required as minimum pretreatment to remove suspended solids, some heavy metals and coliforms. Biological treatment plus disinfection to a level of 23 total coliform organisms per 100 ml is required for irrigation of golf courses, parks, freeway landscapes and pastures grazed

by milking animals. For direct irrigation of food crops, oxidized, coagulated, filtered wastewater disinfected to a level of 2.2 total coliform organisms per 100 ml is required. In order to obtain these low figures for coliform organisms the secondary effluent might first have to undergo sand filtration or equivalent polishing, since low turbidity is a guarantee of the effectiveness of disinfection with chlorine. The presence of pathogens, even in chlorinated secondary effluent, places a restriction on the type of crops which are suited to wastewater irrigation. There appears to be a danger of pathogen contamination of vegetables to be eaten raw if wastewater is applied to fields within 2-3 months of harvesting, thus limiting the usefulness of this form of irrigation for crops such as lettuce and radishes which have short growing seasons.

In other countries less rigid criteria are used. 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. In fact, 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 effluent.

In order to meet the strict standards set in California, heavy disinfection is needed. It has been shown that 20 mg/l of chlorine must be applied to primary effluent for six hours to achieve a count of not more than 100 coliform organisms per 100 ml, while 8 mg/l of chlorine achieves the same result in two hours when applied to effluent from a high-rate trickling-plant. Most other species of bacteria pathogenic to man are considered to be more sensitive to chlorine than coliform organisms. However, enteroviruses may not be eliminated in the same proportion.

Another problem is to protect the health of agricultural workers when sewage irrigation is used. It has been reported from India that hookworm and other enteric infections are much more common among workers on sewage farms than among the farming population in general (10); the local custom of walking barefoot is a major contributory factor in the spread of some of the diseases. On the other hand, a follow-up study of the health of workers at sewage treatment plants in the USA did not reveal any excessive risk of disease or disability in this group (25). Reasonable standards of personal hygiene appear to be effective in protecting the health of workers in sewage utilization projects. Personal hygiene should include the following: avoiding exposure to recycled water where possible; the use of protective garments and changing of clothes at the end of the work period; and care in hand-washing and bathing following exposure and prior to eating food or smoking.

Water-quality requirements for aquifer recharge should provide for acceptably high infiltration rates over extended periods of time, should limit soil contamination to acceptable proportions and should allow for use of the recharged water for agricultural, industrial and certain domestic purposes. As

pathogens are, in general, rapidly removed during soil passage, the sanitary requirements should give more emphasis to physical/chemical than to microbiological parameters. Moreover, advanced treatment is needed to prevent clogging at high infiltration rates (30–300 cm/day) in recharge by means of open canals or basins and very high rates (500–1000 l/min) in the case of recharge wells. In 1979 the Council of Ministers of the European Communities adopted a directive on protection of groundwater against contamination, in which Article 6 states that artificial aquifer recharge is only allowed after a special permit has been obtained and that this can be issued by national authorities only if the groundwater quality will not be endangered.

No official standards have been proposed by the Commission of the European Communities for the quality of water to be infiltrated into underground aquifers. In the case of direct infiltration of riverwater, upper limits of about 5 mg/l for settleable solids, 10–20 mg/l for plankton and less than  $10^5$ /ml for bacteria have been recommended (26). Much experience of open recharge ponds has been obtained in the recharge projects in dunes in the Netherlands, which have been in operation for some 25 years (27). As in Israel (28), intermittent recharge of pretreated water is practised, allowing infiltration for long periods (e.g., about one year) and simple maintenance at low cost. This practice is possible as clogging at the surface takes place only in the first 1–2 cm of soil, which can be removed naturally by drying and weathering.

### **5.3 Benefits from re-use on the land**

The benefits of re-use and conservation are most apparent in arid and water-short areas. In such areas, water for agricultural use may not be available otherwise, the small amounts of fresh water, of necessity, being used for higher-priority needs. Even in more humid areas, the trend is to use wastewater for irrigation as a conservation measure. In rapidly growing regions that are becoming more industrialized, the demands for a good reliable water supply can severely tax the available sources, making the substitution of reclaimed wastewater attractive from a conservation standpoint.

One of the most tangible benefits of wastewater irrigation is the recycling of the plant nutrients of nitrogen, phosphorus and potassium, as well as other micronutrients which are essential for healthy plant growth. The monetary value of these nutrients can be calculated and, in some cases, these nutrients are sufficient for crop needs and no supplemental fertilizer is required.

Generally, a land application system, including wastewater irrigation, is more cost-effective than mechanical treatment plants. In some places where agricultural production is not of major concern, wastewater irrigation may, nevertheless, be used as an alternative to conventional treatment because of the lower total cost. This may not always be the case, as land application costs are highly dependent on storage requirements, the cost of land, and the distance wastewater must be conveyed to the treatment site.

The primary consideration in an agricultural operation is production. There are many documented cases of the benefits of wastewater irrigation, including increased production and crop quality (24). A survey of users of wastewater for irrigation concluded that crop yields were markedly increased, and that the quality of the product was not sacrificed.

The value of wastewater irrigation is dramatically illustrated in the results obtained at Lubbock, Texas (29). Table 1 provides a comparison of yields from (a) non-irrigated land, (b) irrigated land with well-water plus commercial fertilizer, and (c) wastewater without commercial fertilizer. It is interesting that the yields from land irrigated by wastewater were even greater than those from land irrigated by well-water with commercial fertilizer added, which is the common practice in the Lubbock area.

Table 1. Relative yields of crops grown in the Lubbock area per acre (29)

Crop	Dry land	Irrigation with well-water with commercial fertilizer	Irrigation with wastewater without commercial fertilizer
Grain sorghum (pounds)	800–1000	4000–5000	6500
Wheat (bushels)	10–12	30–40	80
Lint cotton (pounds)	150–225	600–800	1250

In most places in the USA new supplies of agricultural irrigation water may be available at a cost that is 10–40% less than the expected lowest-cost water from a recharge system. For municipal purposes at capacities above 450 l/s, the cost of developing and treating freshwater from new sources is in the same general range as water produced by groundwater recharge using the lowest-cost systems. For municipal purposes at capacities above 4500 l/s, water from even the most sophisticated groundwater recharge system may be competitive in cost with development of new freshwater supplies in locations such as the city of Denver, Colorado, where the costs for new supplies are high.

There are several advantages in storing water underground. The cost of recharge may be less than the cost of equivalent surface reservoirs. The aquifer serves as an eventual distribution system and eliminates the need for surface pipelines or canals. Water stored in surface reservoirs is subject to evaporation and pollution, which may be avoided by underground storage.

Furthermore, particularly in the USA, suitable sites for surface reservoirs may not be available or environmentally acceptable. Even more important, the inclusion of groundwater recharge in any water re-use scheme provides psychological and aesthetic benefits. Groundwater recharge seems to provide a "loss of identity" for reclaimed water due to time-in-storage and separation-in-space. The infiltration and percolation of reclaimed water through the soil and the groundwater zone adds additional treatment reliability to the overall wastewater treatment system. This aspect of recharge is an important public health consideration where potable water supply aquifers may be affected by reclaimed water.

For economic and physical reasons, groundwater recharge with reclaimed water requires intensive hydraulic application and infiltration over relatively small land areas. The advantage of groundwater recharge by surface spreading is that underground water supplies may be replenished in the vicinity of metropolitan and agricultural areas where groundwater overdraft is severe, with the added benefits of the filtering effect of soils and transporting facilities of aquifers. Groundwater recharge by injection is practised, in most cases, where the groundwater is deep or where topography or existing land use makes surface spreading impractical or too expensive. This method of groundwater recharge is particularly effective in creating freshwater barriers in coastal aquifers against the intrusion of saltwater from the sea.

It is recognized that criteria applicable to reclaimed water for groundwater recharge are urgently needed. These will dictate the degree of removal of contaminants and the type of treatment systems required. However, the lack of specific information makes it practically impossible to establish a comprehensive list of potentially toxic organic substances and their permissible concentrations. The position of the California Department of Health Services on wastewater re-use is therefore based on the "multiple barrier" approach, which specifies minimum acceptable treatment levels, limits for indicator organic substances, gross and specific water quality standards, time requirements and other safeguards. Because of the lack of specific information referred to above, the current California wastewater reclamation criteria (30) recommend that the following factors be considered in planning a groundwater recharge programme:

- (a) treatment provided,
- (b) effluent quality and quantity,
- (c) spreading area operations,
- (d) soil characteristics,
- (e) hydrogeology,
- (f) residence time,
- (g) distance to withdrawal.

There is, however, no mention in the criteria of the direct injection of reclaimed water into domestic water supply aquifers. The position of the Department of Health Services regarding the direct injection of reclaimed water is understood to be that: (a) the Department will, in general, recommend against direct injection of reclaimed water for groundwater replenishment, and (b) direct injection for saline water repulsion and reclamation of saline aquifers is acceptable when accompanied by proper controls.

The current minimum treatment requirements in California for reclaimed water which is spread for groundwater recharge is biological secondary treatment followed by carbon adsorption and soil infiltration-percolation. Carbon adsorption is intended to reduce the concentration of soluble organic substances in the reclaimed water. Percolation through the unsaturated zone of undisturbed soil will provide additional treatment, which has been demonstrated to be effective in the removal of soluble organics and pathogenic organisms.

## 6. INDUSTRIAL RE-USE

It is apparent that, as the demand for and cost of freshwater supplies increase, wastewater reclamation will be an economically attractive alternative for industry in a growing number of instances. Such reclamation can be accomplished by three methods. An industrial plant can re-utilize its own wastewater within the plant boundary. Alternatively, it can market its effluent for other uses such as irrigation. The third method, which is discussed below, is the use of municipal wastewater by industry. In many cases such wastewater is available near the areas where demand is greatest, thus eliminating the high economic, environmental and energy costs of diverting untapped surface water and transporting it over long distances. Reclaimed water may also provide a more dependable source, since the amount available does not vary greatly from year to year.

The required quality of water for industrial re-use varies widely, depending upon the specific use involved. The required quality of cooling-water differs greatly from that of boiler feedwater, for example. Standards exceeding those of drinking-water may, for instance, be applicable to water for beverage preparation, and to high-pressure boiler feedwater and water used in certain electronic manufacturing operations.

About 75% of all industrial water is used for cooling. The use of secondary effluent as cooling-water has proved satisfactory in some cases. Wastewater constituents which may prove troublesome in cooling-water supplies but are readily controlled by advanced wastewater treatment include suspended solids, hardness agents, dissolved organics, dissolved oxygen or gases,

algal nutrients and slime-producing organisms. Chemical additives to inhibit scale formation and slime growth may be used in conjunction with wastewater treatment.

Water employed in the manufacturing process usually leaves the production line in the form of more or less polluted waste, in some instances highly contaminated by toxic or radioactive matter. It follows that the reclamation process should be preceded by carefully managed treatment to restore the natural properties of the water. The quality of reclaimed water depends on its future use, and activities aimed at achieving clean water should be supported and controlled by water quality standards. Renovated water should first of all meet health requirements, irrespective of whether or not it will be used for agricultural irrigation, domestic consumption or cooling purposes. The hazards to the health and wellbeing of humans, animals and plants arising from the use of industrial wastewater are primarily due to the chemical substances it contains. Some representative hazardous substances present in the wastewater of selected industries are indicated in Table 2.

The greatest health hazard is from the inhalation of aerosols containing pathogenic organisms, as the gut is a much better device for dealing with foreign micro-organisms than the upper respiratory tract. The ingestion of water containing pathogens presents the second most severe hazard. Another type of hazard is from chemical or, to a lesser extent, microbiological substances causing irritation of the mucous membranes.

There are currently no established health standards relating to exposure of workers. However, treatment standards for health purposes might cover oxidation, coagulation, filtration and effective disinfection; such treatment is required where recycled water is available for nonrestricted recreational use by the public. Where there is any exposure at all, the lowest degree of treatment would probably be secondary treatment, followed by an intermediate degree of disinfection. Where the possibility of exposure to aerosols exists, as in the case of cooling towers, a high degree of treatment and disinfection may be necessary to ensure the protection of the neighbourhood as well as plant employees.

## **6.1 Treatment requirements**

By relatively simple processes such as filtration, the content of suspended solids in a secondary effluent can be reduced to 5–10 mg/l. "Polished" effluent of this kind can be used for many industrial purposes (e.g., cooling, quenching, washing) for which low-grade water is adequate. Of course, disinfection might have to be introduced to safeguard workers' health.

By the application of techniques normally used for potable water, the content of suspended solids may be reduced virtually to zero, yielding water that from this point of view is approximately of potable standard. Normally, the water is treated with an aluminium or ferric salt, subjected to gentle

Table 2. Presence of representative hazardous substances in waste streams of selected industries (37)

Industry	Hazardous substances										
	As	Cd	Chlorinated hydrocarbons <sup>a</sup>	Cr	Cu	Cyanides	Pb	Hg	Miscellaneous organics <sup>b</sup>	Se	Zn
Mining and metallurgy	x	x		x	x	x	x	x		x	x
Paint and dye		x		x	x	x	x	x	x	x	
Pesticide	x		x			x	x	x	x		x
Electrical and electronic			x		x	x	x	x		x	
Printing and duplicating	x			x	x		x		x	x	
Electroplating and metal-finishing		x		x	x	x					x
Chemical manufacturing			x	x	x			x	x		
Explosives	x				x		x	x	x		
Rubber and plastics			x			x		x	x		x
Battery		x					x	x	x		x
Pharmaceutical	x							x	x		
Textile				x	x				x		
Petroleum and coal	x		x				x				
Pulp and paper								x	x		
Leather				x					x		x

<sup>a</sup> Including polychlorinated biphenyls.

<sup>b</sup> For example, acrolein, chloropicrin, dimethyl sulfate, dinitrobenzene, dinitrophenol, nitroaniline and pentachlorophenol.

turbulence to flocculate the precipitate, and passed through a sedimentation tank and then through a rapid sand or multimedia filter. Instead of the classic coagulants, lime can be added to the water. When lime is added to water or wastewater, it reacts with bicarbonates present to form a precipitate of calcium carbonate, and with the phosphates to form a precipitate of calcium phosphate. None of these substances form flocs and they settle much too slowly; however, the addition of excess lime above the amount necessary to precipitate carbonates and phosphates leaves a residue of dissolved calcium hydroxide in the water, causing an increase in pH. When the pH rises above 9.5, magnesium precipitates in the form of  $Mg(OH)$  flocs. Complete removal of magnesium from the solution would require a pH of 12, but usually there is sufficient  $Mg^{2+}$  in the water to enable the formation of enough flocs, even at a pH lower than 11.5, to sweep the precipitated carbonates and phosphates out of the water during their sedimentation. If the  $Mg^{2+}$  content of the water is too low, it may be necessary to add  $Mg^{2+}$  or some other coagulant such as an  $Fe^{3+}$  or  $Al^{3+}$  salt. Usual doses are several hundreds of mg of lime per litre (depending on the hardness of the water) and, if necessary, a few tens of mg of coagulant per litre.

One of the advantages of lime over other precipitants is that no anions such as chloride or sulfate are added to the water. Subsequently, not only phosphate elimination, BOD reduction and suspended solids reduction take place, but many heavy metal ions present are precipitated and removed together with the lime sludge; besides, more or less complete disinfection of the effluent is possible, depending on the contact time.

After lime treatment, polishing ponds, where the high-lime effluent is simply detained for a period of 1–2 weeks, provide for desorption of free ammonia at high pH and for recarbonation by absorption of the carbon dioxide available in the air. Additional functions of polishing ponds are: removal of organic and inorganic colloidal particles; continuation of slow-reaction chemical processes such as precipitation of calcium carbonate and phosphorous compounds; further removal of bacteria and viruses; and equalization of the variable quality of high-lime effluent, which is highly dependent on the operator's ability to determine and maintain optimum values of the major operational parameters (mainly pH and magnesium concentration). Water produced in this way, after disinfection, is suitable for a wide range of industrial uses.

Chlorine is the most commonly used disinfectant. Effluent that is low in organic content and ammonia 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. Carrying out chlorination as the last treatment step, when the water is of highest quality, minimizes the danger of producing chlorinated organics and thus meets the latest recommendations for optimum chlorination practice.

Complete disinfection of wastewater depends upon optimizing the unit processes of chemical coagulation, sedimentation and filtration (which in

themselves provide substantial reductions in bacteria and viruses) to produce minimum water turbidity in order to ensure maximum contact between any remaining pathogens and the disinfectant added. Several investigators have pointed out the close relationship between virus removal and turbidity reduction. The excellent clarity obtainable with proper coagulation and filtration of wastewater enhances chlorination efficiency so that viruses cannot escape chlorine contact by being encapsulated in particulate matter. Viruses, because of their small size, are protected more easily in a coating of turbidity-contributing matter than bacteria. For effective disinfection, turbidity must be kept below 1 NTU (Nephelometric Turbidity Unit), and it should preferably be kept as low as 0.1 NTU.

Reclaimed water derived from sewage effluent also contains a much higher concentration of dissolved salts than the supply from which it was derived. The dissolved ionic solids content of water increases up to 150-300 mg/l at each use. For a few industrial applications, it might be necessary to remove most or all of this material.

Deminalization or desalination of wastewater can be effected by evaporation, electrodialysis, ion exchange and hyperfiltration. Evaporation processes deliver very pure water which, however, may still have a taste and odour, but the product water has a higher temperature than the feedwater and the costs involved are high. Electrodialysis and ion exchange only remove inorganic salts. Hyperfiltration seems to be the most suitable process, since it takes almost all substances out of the water. In hyperfiltration (reverse osmosis), water is forced under pressure through a semipermeable membrane pervious to water but not (or less so) to other substances. Even nitrates (not ammonia) are retained, which makes biological denitrification perhaps superfluous. Reverse osmosis also eliminates water hardness, which may therefore have to be adjusted, e.g., by a marble filter. The removal of dissolved solids is, however, a relatively expensive process and is unlikely to be economically justified in most cases.

If treated wastewater is to be considered for use in industrial food-processing plants, it must meet the standards applicable to drinking-water. In this case, adsorption on activated carbon has to be added to the previous treatments. Activated carbon adsorbs dissolved organic matter and helps to keep the colour, odour and taste under the threshold values. The use of activated carbon is complementary to the activated sludge process. Indeed, activated carbon more effectively adsorbs large organic molecules, many of which are not biodegradable, while small soluble organic molecules are more easily removed by the activated sludge process. Adsorption with activated carbon is very effective at pH values of between 6 and 8; at pH higher than 9 desorption can occur. This makes it necessary after the lime treatment to lower the pH to about 7, before pumping the water through the activated carbon column. Activated carbon treatment, by removing organic materials, enhances the efficiency of the disinfection process. In an activated carbon filter, biological growth also occurs.

Even better results can be obtained by ozonation. Ozone is a strong oxidizing agent for many organic substances; it improves taste and odour and causes substantial colour reduction. Many refractory substances, such as certain micropollutants which are not degraded by chlorine, are oxidized by ozone; it even breaks open ring compounds such as phenols. But precisely because of this, ozone is not suitable for use in the last treatment stage; refractory compounds can become biodegradable after partial degradation with ozone and cause bacterial aftergrowth in the mains. An activated carbon filter is therefore introduced after ozonation.

Ozone is also more effective than chlorine in destroying viruses. Because of the consumption of ozone by organic matter, satisfactory disinfection will be guaranteed only if, after an adequate contact time, there remains a residual ozone concentration. In practice, care is usually taken to ensure that after about 5 minutes' contact time the residual ozone concentration is still 0.5 mg/l. Because of the rapid decay of ozone, this means that ozone doses must be between 1.5 and 5 mg/l.

However, it can always be expected that some micropollutants will react with ozone much more slowly than the compounds causing colour, odour and taste, so it may be necessary to apply higher doses than those sufficient for removal of these characteristics. Also, because of its rapid decay, there is no residual ozone in the mains, so safety chlorination is always necessary as a last step in the water treatment scheme.

## 6.2 Examples

Municipal wastewater re-use is practised at many individual industrial locations; however, there are several examples of multi-industrial complexes utilizing municipal wastewater. At some of these complexes, a municipality may add advanced wastewater treatment processes in order to furnish water of a specified quality. At other locations the wastewater that is received from a municipality may be treated in a common advanced wastewater treatment plant which is operated according to some cooperative or contractual arrangement among the industries in the complex. Regardless of the common treatment employed, there may be certain unique requirements of an individual industry which necessitate additional special treatment.

An example of a multi-industry complex utilizing municipal wastewater is to be found near San Francisco, California (32, 33). In the San Francisco Bay area, five industries — Philips Petroelum; Shell Oil, Stauffer Chemical, Monsanto Chemical and Pacific Gas and Electric — have contracted with the Central Contra Costa Sanitary District for 64 142 m<sup>3</sup> of the treated wastewater per day. Water of very high quality was required and it had to be particularly low in phosphorus, suspended solids, and BOD. The treatment included lime and ferric chloride precipitation in the primary stage, followed by activated sludge, dual-media filtration and chlorination. The final treated

water has a BOD<sub>5</sub> of 2 mg/l, suspended solids of 1 mg/l, total nitrogen (as N) of 2 mg/l, and total phosphorous (as P) of 0.2 mg/l. Virtually all heavy metals are removed with the lime treatment.

An industrial group in Monterrey, Mexico, has formed a non-profit-making association for the purpose of solving its common water-supply problem (34). This group, known as Agua Industrial de Monterrey, operates a modern wastewater treatment plant which supplies the water needs of the member industries. The industries involved are engaged in the manufacture of sponge ion, dyes, insecticides, paper, plastics, steel and other products. Agua Industrial de Monterrey collects the wastewater from the city of Monterrey, treats it, and supplies it to the several industries. There are two types of industry member: (1) those who receive the chlorinated final effluent, and (2) those who receive raw wastewater and have their own treatment plants. Members contribute to the operation of the association according to the type of water taken.

All of the industries except two use the chlorinated final effluent for cooling-water. One of the industries, after further treatment of the chlorinated effluent, uses it as process-water in pigment and dye manufacturing. The other industry, which manufactures different types of paper, uses the chlorinated effluent for process-water after further treatment.

In addition to the members of Agua Industrial de Monterrey, there are several other individual industries which utilize Monterrey municipal wastewater following treatment in their own plants. The reasons cited for the extensive re-use of domestic wastewater in this city are the water scarcity typical of an arid region, the extended drought of the 1940s, the rapid industrial development of the city, and the demographic explosion.

The full re-use of drainage water by the "Schwarze Pumpe" brown coal dressing-plant, GDR, is described by Schmidt and Clements (35).

Three open-cast mines discharge hourly 24 000 m<sup>3</sup> of acidic drainage water with a pH between 4.5 and 5.4 and an iron concentration of 35-65 mg Fe/l. After suitable treatment, this wastewater is entirely re-used.

The primary treatment procedure involves neutralization with carbide residue (crude Ca(OH)<sub>2</sub>), and additional hydrated lime to obtain a pH value of about 7.8. The total wastewater volume generated during brown coal dressing processes is re-used for the plant's own needs instead of being discharged, after treatment, into a watercourse.

The use of municipal wastewater by industry at Odessa, Texas, dates back to 1956. In that year an industry planning to develop a major petrochemical complex chose to use the wastewater as the primary source of water for its proposed plant (36). Since West Texas has only limited quantities of good water, domestic wastewater from the city was seen as the best possible source for this purpose.

The Odessa City Wastewater Treatment Plant includes primary clarifier, intermediate storage, aeration basins, secondary clarifier and chlorination

chamber. The effluent from the plant is transferred to a lagoon located within the industrial complex, from which it goes through additional treatment before being used within the complex for cooling and boiler makeup.

An additional feature of the industrial complex at Odessa is that all wastewater from processes within the complex is collected and treated for use in oil field secondary recovery operations. The water is, therefore, used three times before finally being discarded: from the source to the city for domestic use, from the city to the industrial complex for industrial uses, and from there to the oil field for petroleum operations.

Possibly the largest individual industrial user of municipal wastewater in the United States, and maybe in the world, is an integrated steel plant located at Baltimore, Maryland (37, 38). This plant has used wastewater for over 20 years and is virtually dependent upon treated municipal wastewater for its plant operation and expansion programme. A unique feature of the plant is that it is not located in a water-scarce area. Total requirements of the plant are almost  $2.8 \times 10^6 \text{ m}^3$  per day, of which  $378\,500 \text{ m}^3$  per day is treated municipal wastewater. Treatment by the municipality consists of primary settling, secondary treatment by trickling filters and activated sludge, and final settling. The treated effluent furnishing the steel plant is not chlorinated by the city. The industry chlorinates the wastewater before distributing it to the various parts of the plant.

The water is used within the plant for almost all purposes except direct chemical processes (at the coal chemical plant) and places where extremely large volumes of once-through water are required (such as at blast furnaces). Typical uses are roll cooling, descaling, sluicing, gas scrubbing, pickle liquor dilution, slab and coil cooling, and indirect cooling in heat exchangers. The one major problem within the plant due to the use of treated municipal wastewater is foaming. In most cases, this can be eliminated by using suppressant sprays or anti-foaming agents.

At the time of reporting (1973), the average cost of the treated wastewater was approximately 2 cents per cubic metre of water circulated. Assuming city water were available, it would have cost approximately 20 cents per cubic metre. The use of the municipal wastewater is thus extremely attractive from a cost standpoint.

## 7. SLUDGE

### 7.1 Pollutants

Many treatment processes remove unwanted pollutants from sewage by transferring them to the sludge without destroying them. This is obviously

true for heavy metals which cannot be destroyed but may sometimes be converted to other forms by chemical treatment; it is also true for refractory or nonbiodegradable organic compounds to a greater or lesser degree; chlorinated pesticides, for example, are transferred to the sludge with only minor degradation. Infectious organisms are also transferred to the sludge by primary treatment with little loss of infectivity.

In many cases primary treatment will remove about half of the solid matter in sewage and will also remove about half of the toxic chemicals and infectious agents. Since the volume of settled sludge is about one-half of one per cent of the volume of sewage, each constituent that is transferred to the sludge will be concentrated about a hundredfold.

Biological treatment exerts a definite inhibitory or toxic action on some micro-organisms; for example, up to 99% of bacteria and viruses may be destroyed by activated sludge treatment (39, 40). Such biological action has only a minor influence on the infectivity of the sludge even though it is useful from the point of view of the treated water. Tenfold variations in micro-organisms are well within the normal variations and, unless the waste-activated sludge is handled separately, it will be infected by the organisms removed in the primary sludge.

In most communities that practise sewage irrigation, sludge is also disposed of on land. The degree of treatment given to the sludge before disposal varies just as much as does the treatment given to the water. The most common treatment given to sludge is anaerobic digestion, which may be carried out in Imhoff tanks or digesters. These may be unheated, heated to the mesophilic range at about 35° C or to the thermophilic range at about 55° C, and they may be stirred and operated in one or more stages. Each one of these separate modes of operation has an influence on the biological and infective nature of the sludge.

## 7.2 Treatments

### 7.2.1 *Time and temperature*

The two most important factors controlling the survival of organisms which cannot multiply outside their natural environment are time and temperature.

The rate at which micro-organisms die depends on the temperature and other properties of the medium. If 10% survive 1 hour, there will be only 1% after 2 hours and 0.1% after 3 hours. A 10° C increase in temperature will increase the rate of destruction 2–20-fold, depending on the species and the temperature. Pasteurization of milk, for example, is carried out for 30 minutes at 63° C but equivalent disinfection at 80° C requires only 15 seconds.

Even at normal ambient temperatures micro-organisms die at a steady slow rate. In one study, viruses mixed with surface soil decreased in numbers

about tenfold each month under northern winter conditions (41). At a temperature of 30° C the time would be reduced to a few days. Time, in cooperation with temperature, is thus a very effective treatment for micro-organisms. Storage for a few months can be much more effective than chemical disinfection in removing pathogens from sludge.

### 7.2.2 *Digestion*

Anaerobic digesters provide an inhospitable environment for most pathogens and rates of decay are such that only a few days should be sufficient to reduce them to negligible numbers. Since digesters are operated for periods of 10–30 days it has frequently been assumed that pathogens will not survive. Actual measurements show the contrary; digested sludge is, in fact, a reliable source of viruses and pathogenic bacteria (42). The reason must be sought in the mode of operation of anaerobic digesters. To avoid chemical shock from the sudden production of volatile acids, most digesters are fed frequently, from one to several times a day. Digesters are also mixed so that any sludge withdrawn contains some of the fresh sludge that has just been added.

In the United Kingdom, storage for periods of one year is considered to provide adequate disinfection for digested sludge (43). In a warmer climate, the time might well be reduced to 2–3 months if experimental data show that key organisms are adequately reduced in number.

### 7.2.3 *Drying and composting*

Drying beds provide both solar heat and time as well as a dry environment to destroy vegetative forms of bacteria and many viruses. Dried municipal sludge has not in the past been considered to be a significant source of pathogenic organisms. However, the dust from machine-dried sludge has been responsible for respiratory distress among sewage plant workers (44).

Composting of sludge, alone or with other wastes, can provide excellent disinfection of the inner portion of an active pile where temperatures typically exceed 55° C and may reach 70° C. Care must be taken to ensure that all portions of the mass reach the desired temperatures. This can be done by a careful mixing programme or by composting with forced aeration under a cover of porous material such as cured compost (45).

### 7.2.4 *Lime stabilization*

An alternative treatment to digestion is lime stabilization. Treatment with lime sufficient to raise the pH above 11.5 stops bacterial activity and kills vegetative forms (46). Some spores, cysts and eggs may survive, as will mycobacteria, which are protected by a wax-like coat.

If sludge is mixed with quicklime (CaO) instead of slaked lime, the heat of slaking may be sufficient to bring the sludge to pasteurizing temperatures (47). Approximately 0.1 kg of CaO is required per kg of water in the sludge to reach 55° C. When sludge has been thickened to 20% solids this corresponds to 400 kg CaO per tonne of sludge solids. If the lime-sludge mixture is kept warm for a few hours, most pathogenic micro-organisms will probably be destroyed. There are insufficient data available at present to determine whether this process destroys all cysts, eggs and spores.

Wet sludge mixed with slaked lime receives only the benefit of a high pH without a useful increase in temperature. The high pH will not penetrate into dense objects such as grease balls, so disinfection may not be complete. The stabilizing action of high pH is slowly destroyed, first by hydrolysis of fats and proteins and absorption of CO<sub>2</sub>, and then, as the pH starts to drop, by alkali-resistant bacteria. Respiration by these bacteria rapidly neutralizes the adjacent sludge and putrefaction soon sets in.

Lime-stabilized sludge will eventually putrefy if kept wet in a lagoon; however, it will not do so if it is spread on the land and mixed with the soil or allowed to dry out so that air can penetrate it. The free alkali of a limed sludge is soon converted to calcium carbonate by CO<sub>2</sub> present in the air or produced by micro-organisms.

### 7.3 Checklist of treatments for infectious agents

Suggested treatments to control viruses in sludge are given in Table 3. Very similar considerations apply to other pathogens.

## 8. GENERAL COMMENTS

Wastewater re-use often takes place in an indirect and covert way. However, serious health hazards are associated with such practices, particularly in the case of crop irrigation with insufficiently disinfected sewage. A planned system of wastewater re-use in those arid and semi-arid regions of the world where domestic sewage is available, or will become available in the near future, will be beneficial to the local economy as well as to public health. Within a scheme of planned wastewater re-use, crop irrigation in combination with artificial groundwater recharge is a feasible option. In particular, those re-use systems are of interest which combine the natural potential for disinfection of water during underground passage with the need to use bacteriologically safe water for irrigation of crops to be eaten raw.

The use of artificial recharge wells should be discouraged in cases where advanced treatment systems, resulting in very low levels of suspended solids

Table 3. Suggested treatments of sludge from a virological point of view for different purposes

Treatment	Incineration	Landfill	Soil injection	Forest application	Surface spreading on fields				Parks and playgrounds	
					Crops not eaten by humans	Crops eaten/cooked and fish culture	Crops eaten raw	Grassland application		
Raw primary and/or secondary	X		X	(X)						
Anaerobic digestion		X		X	X	X		X		
Drying beds		X		X	X	X		X		
Lime stabilization		X		X	X	X	(X)	X		
Composting		X			X	X	X	X		X
Pasteurization and other heat treatment								X		X
Irradiation								X		X

X = effective treatment

(X) = probably effective, needs further testing

in the water, cannot be considered. On the other hand, bank filtration techniques as practised in the Rhine Valley may provide a simple and reliable treatment for lagooned secondary effluent which is to be used for crop irrigation purposes.

Unless it is shown to be free from pathogens, wastewater should not be used to irrigate crops that enter the kitchen in the raw state, even if the food is to be cooked, because of the risk of cross-contamination.

The re-use of wastewaters for industrial purposes involves decision making in each particular instance. The choice of treatment methods and the desired treatment efficiency depend on the user's requirements. It is often sufficient to employ biological treatment alone or combined with an additional unit process such as filtration, disinfection, etc. In other instances, it will be reasonable to differentiate the applications of the unit processes. However, increasing the treatment efficiency increases the treatment costs in an exponential manner, especially when refractory substances have to be removed. It is natural that in the case of wastewater re-use, decision making must involve a cost-benefit analysis. However, in arid and semi-arid areas, the problem of how to supply water deficit is of prime importance, taking precedence over economic considerations.

Sludge, especially primary sludge, contains one-half or more of the pollutants in sewage, and these are concentrated by a factor of about 100. Digestion does not adequately remove pathogens because old sludge is contaminated with fresh. Storage, preferably at elevated temperatures, provides good control of pathogens. Drying, composting and stabilization with quicklime may all be used to control pathogens but they do not destroy toxic chemicals.

Various treatment processes to meet given criteria for wastewater re-use are set out in Table 4.

## 9. CONCLUSIONS

The reclamation of wastewater represents a positive contribution to solving the problem of water resources, particularly in semi-arid areas, and should therefore be encouraged.

The industrial re-use of properly treated sewage (except in the food industry) does not pose a significant risk to health and should be encouraged.

Wherever treated sewage is re-used, adequate technical safeguards to avoid cross-connexions must be employed.

Water re-use by aquifer recharge can be carried out without risk to public health by the method of surface infiltration into suitable soil, provided that the water is retained a long time in the ground and is extracted at a distant location.

Table 4. Suggested treatment processes to meet the given health criteria for wastewater re-use (48)

	Irrigation			Recreation			Municipal re-use		
	Crops not for direct human consumption	Crops eaten cooked, fish, culture	Crops eaten raw	No contact	Contact	Industrial re-use	Non potable	Potable	
Health criteria (see below for explanation of symbols)	A + F	B + F or D + F	D + F	B	D + G	C or D	C	E	
Primary treatment	●●	●●	●●	●●	●●	●●	●●	●●	●●
Secondary treatment	●●	●●	●●	●●	●●	●●	●●	●●	●●
Sand filtration or equivalent polishing methods	●	●	●	●●	●●	●	●●	●●	●●
Nitrification						●		●●	●●
Denitrification								●●	●●
Chemical clarification						●		●●	●●
Carbon adsorption								●●	●●
Ion exchange or other means of removing ions								●●	●●
Disinfection	●	●●	●●	●	●●	●	●●	●●	●● <sup>a</sup>

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.  
 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.  
 In order to meet the given health criteria, processes marked ●● will be essential, and further processes marked ● may sometimes be required.  
<sup>a</sup> Free chlorine after 1 hour.

Source: WHO Technical Report Series, No. 517, 1973 (Reuse of effluents: methods of wastewater treatment and health safeguards: report of a WHO Meeting of Experts).

Because infiltration through surface soil combines biological treatment and filtration, land disposal of untreated municipal sewage does not represent a health risk if the unconfined (phreatic) aquifer is not used for domestic water supplies and if no raw vegetables or fruits from the application site are brought into food preparation areas.

Reclamation of sewage by irrigation of crops, in contrast to land disposal, can also provide a useful source of plant nutrients if salts and other phytotoxic elements are kept at acceptable levels.

The use of treated wastewater on crops to be eaten or handled raw can pose a health risk in areas with a low level of technology, since there can be no assurance that treatment is always adequate.

Efficient disinfection by chemical agents or ultraviolet light requires high-quality effluent with low turbidity and organic matter.

Additional research and epidemiological investigation are needed to determine the efficiency of different methods for disinfection by physical and chemical methods as well as by natural biological methods such as lagoon treatment and soil infiltration.

In the absence of complete medical and epidemiological information, public health officers may overestimate the treatment required for the safe re-use of wastewater.

From a public health point of view, successful wastewater irrigation projects show that good agricultural practices, proper water management and a high degree of reliability and safety in the irrigation system are as important as proper treatment prior to re-use.

Projects for the re-use of sewage are incomplete without adequate provision for the safe disposal of sludge.

## 10. RECOMMENDATIONS

1. WHO should prepare revised guidelines and, if possible, a code of practice covering the health aspects of water re-use technology, with emphasis on surveillance and monitoring requirements.
2. WHO should encourage medical and epidemiological studies of the health risks associated with water re-use.
3. WHO should encourage research on effluent disinfection and technical evaluation of the various methods available.
4. Sanitary engineering curricula should include consideration of treatments related to the re-use of sewage.

5. Water resource managers should choose water sources most appropriate to each use of water; where possible, they should reserve water from the least contaminated source for potable supplies and avoid squandering high-quality water on less demanding applications.
6. Management of wastewater re-use should be integrated with the treatment authority to ensure proper regulation of agricultural practices from a public health point of view.
7. Water resource development, water supply, sewage treatment and disposal and wastewater reclamation should be well coordinated in the planning stage at interministerial level.
8. Due consideration should be given to the occupational health of workers in sewage treatment plants and land application sites.
9. Health services should strengthen epidemiological monitoring where re-use of sewage is practised, while not overlooking small-scale and informal rural projects.
10. The use of treated sewage on crops to be eaten or handled raw must be discouraged wherever proper surveillance and monitoring cannot be guaranteed.
11. WHO and FAO should continue their collaboration with regard to the health aspects of agricultural use of sewage.
12. Wastewaters of different types (domestic sewage, stormwaters, industrial effluents) should be collected separately where this practice will facilitate treatment for discharge or eventual re-use.
13. Highly-polluted effluents from industry should be pretreated before discharge to avoid interference with the treatment of domestic sewage.
14. The international reference centre for community water supply (Voorburg, Netherlands) should consider in its programme on appropriate technology the possibilities for cooperation with national universities in evaluating locally available products, such as clay, which could be used for water purification.

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## Annex I

### LIST OF WORKING PAPERS

- |                         |   |
|-------------------------|---|
| ICP/BSM 003(5)/6        | Health problems associated with the reuse of sewage and the impact of hazardous chemicals, by E.S. Kempa                |
| ICP/BSM 003(5)/7        | Sanitary and treatment requirements for industrial reuse and landuse and land disposal of sewage, by A.A.J.M. Van Haute |
| ICP/BSM 003(5)/8        | Chemical requirements for reuse of sewage in irrigation and in artificial aquifer recharge, by A.C. Chang and A.L. Page |
| ICP/BSM 003(5)/9        | Reuse of treated sewage for aquifer recharge and irrigation, by B.C.J. Zoeteman   |
| ICP/BSM 003(5)/10       | Treatment requirements for sludge disposal, by R.B. Dean  |
| ICP/BSM 003(5)/11       | Health problems associated with the reuse of sewage: I. Bacteria, by E. Lund  |
| ICP/BSM 003(5)/12       | Treatment required for industrial reuse of sewage, by E.S. Kempa  |
| ICP/BSM 003(5)/13       | Wastewater reuse for groundwater recharge and irrigated agriculture, by T. Asano and R.P. Ghirelli                      |
| ICP/BSM 003(5)/14 Rev.1 | Reuse of municipal wastewater in agriculture, by C.C. Harlin  |
| ICP/BSM 003(5)/15 Rev.1 | Reuse of municipal wastewater in industry, by C.C. Harlin   |
| ICP/BSM 003(5)/16       | Health problems associated with the reuse of sewage: II. Viruses, by E. Lund  |
| ICP/BSM 003(5)/17       | Health problems associated with the reuse of sewage: III. Protozoa and helminths, by E. Lund                            |

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