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PROBLEMS IN COMMUNITY WASTES MANAGEMENT

H. M. ELLIS, W. E. GILBERTSON,
O. JAAG, D. A. OKUN, H. I. SHUVAL & J. SUMNER

WORLD HEALTH ORGANIZATION
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CONTRIBUTORS

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WORLD HEALTH ORGANIZATION

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PREFACE

The World Health Organization is becoming increasingly concerned about the serious implications for health of the wastes-management problem now facing developing, as well as more highly industrialized, countries. The rapid growth in the world population density as a result of urbanization, industrialization and technological development is making the satisfactory management of liquid and solid wastes a vast and complicated problem. Wastes management implies not only technical aspects of storage, collection, treatment, disposal or re-use of wastes, but also the equally important economic, legal, administrative and educational considerations.

The growing use of water for municipal, industrial and agricultural purposes has resulted in an increase both in the volume of the waste water produced and in the chemical complexity of the pollutants it contains. To meet the rising demands for water, direct re-use of waste water for agriculture, industry, recreation and even municipal water supply in areas of water shortage is already practised in some countries. The implications for health are obvious.

The uncontrolled discharge of waste water can spread diseases such as typhoid fever, cholera, dysentery, staphylococcal infections, infectious hepatitis and some vector-borne diseases. Sewage effluents discharged into rivers may not be free from viruses even after secondary treatment and chlorination and are a potential health hazard to communities downstream using the same river as the source of their water supply. There is also growing public health concern over the long-term physiological effects of certain of the trace chemicals found in waste water, many of which are not removed by conventional sewage treatment or water purification processes. Highly persistent detergents, pesticides and other toxic wastes are becoming a very serious problem in developed countries and will in time present a similar threat to developing countries. New and improved methods and processes for the removal of a greater proportion of such pollutants from waste water are therefore needed urgently.

While rivers may eventually regenerate once the discharge of untreated waste water is halted, the degeneration of lakes is more challenging in that the process is largely irreversible. The quality of lakes into which even so-called "completely treated" waste water is discharged has frequently deteriorated owing to increases in plant nutrients, such as nitrogen and phosphorus, leading to eutrophication.

With regard to solid wastes, the amounts produced by each person every day are everywhere increasing as a result of social, economic and technological changes. At the same time, there are significant and disturbing changes in the characteristics and composition of these wastes. Costs of collection, treatment and disposal are rising year by year and often represent a high proportion of municipal budgets. This situation has important public health, as well as economic, implications. Any solution to the general problem of solid wastes disposal involves deciding which part of the terrestrial environment — land, air or water — can accept the residues of human activities with least damage to the whole biosphere. Wastes must no longer be transferred from one part of the environment to another without adequate studies having been made and appropriate safeguards established. This is particularly important in view of the fact that some residues persist more or less permanently. It is obvious, therefore, that failure to deal satisfactorily with the flow of solid wastes contributes to pollution of air, water and soil and to the propagation of disease vectors. Unrestricted and haphazard disposal of solid wastes thus constitutes a clear threat to public health all over the world.

In recent years, WHO Scientific Groups and Expert Committees have reported on the broad aspects of water pollution and its control, emphasizing the need for improved conventional treatment methods, for new and more economical treatment processes adapted to local needs and resources, and for research on the re-use of effluents and by-products resulting from treatment processes. A WHO Scientific Group on the Treatment and Disposal of Wastes a held in Geneva in December 1966[a] *attempted to identify the most urgent problems in this field and to recommend sound approaches to their solution.*

Five of the six chapters in this volume of Public Health Papers *were originally prepared as working papers for the Scientific Group. It is hoped that the collection and publication of these contributions dealing with the management of liquid and solid wastes will stimulate governments to intensify their programmes dealing with the complex technical, legal, administrative and economic aspects of this world-wide problem.*

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[a] *Wld Hlth Org. techn. Rep. Ser.*, 1967, No. 367.

PRESENT AND FUTURE TRENDS IN MUNICIPAL DISPOSAL OF SOLID WASTES

WESLEY E. GILBERTSON [a]

Among environmental problems, none has been of greater historical significance than the disposal of solid wastes. The accumulation of domestic wastes around camps undoubtedly caused ancient nomadic tribes to move to clean, new sites, thus contributing to the dispersal of mankind. Archaeologists, excavating the refuse heaps of early settled communities, have found many useful clues to the social, artistic and technical development of the inhabitants. Down through the Middle Ages, slops thrown from doorways and windows were a constant hazard to town-dwellers, many of whom succumbed to the pestilences spread by garbage-fed rats, flies and other vectors of disease.

But today, the environment is being polluted, as never before, by the accumulation of solid wastes — a staggering burden born of affluence, nurtured by rising populations, fostered by technology, and all but neglected by society. People are not consumers but users, and the products they buy, whether newspapers or automobiles, are not destroyed but discarded. The manner in which these materials are discarded contributes to the pollution of the whole environment — the air, the water and the land.

THE EXTENT OF THE PROBLEM

The term "solid wastes" has recently been brought into use in order to differentiate between the present-day broad concept, involving waste management, and the previous emphasis on garbage and other household wastes. Solid wastes are now generally taken to include all non-gaseous, non-liquid wastes resulting from the wide range of community, industrial, commercial, and agricultural activities. Effective solutions to the problems of the storage, collection, treatment, conversion, re-use, and disposal of solid wastes clearly involve not only complex and challenging technical

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questions, but also difficulties of a political, financial and legal nature, and problems of public administration and co-ordination. Furthermore, lasting and satisfactory answers to solid-waste problems must avoid creating, or adding to, pollution of air, water and land, and other environmental health hazards. Thus, the solid-waste problem of any community, region or nation, has to be measured in terms of not one but many parameters.

Perhaps in no other activity affecting the environment have public attitudes exerted a greater effect than in the disposal of solid wastes. This activity has long been relegated to a subordinate position in the lists of priorities for public works requiring expert attention. In turn, the professional resources and effort devoted to solving the obvious problems have been inadequate. Today, even as some public groups are beginning to demand better methods and improved practices of solid-waste disposal, there is widespread resistance to the location of solid-waste handling or disposal plant in the vicinity of residential areas. Thus the poor image of solid-waste operations of the past, caused by lack of good-quality professional attention, is now delaying the application of improved practices.

QUANTITIES OF SOLID WASTE

It is safe to say that, everywhere, the amounts of solid wastes generated by every person each day are increasing as a result of social, economic and technological changes. Moreover, better quantitative data are now becoming available as a result of improved surveys. For example, the initiation about 20 years ago of scientifically planned surveys in some cities in the USA, encompassing all types of solid wastes, revealed a surprising discrepancy between the earlier "guess estimates" and the actual production. Prior to about 1945, it was assumed that solid waste amounted to 2.3lb–2.7 lb (1.0 kg–1.2 kg) per head per calendar day. Subsequent careful sampling and actual weighing in representative pilot areas revealed that the amounts of all urban solid wastes at time were closer to 3.3 lb–4.0 lb (1.5 kg–1.8 kg) *per capita* per calendar day.

Since then, improved standards of living, the growth of packaging of consumer goods, vast increases in the use of paper, paper products and synthetic materials, and the upsurge of building have combined to contribute larger volumes of urban waste, so that the current average amount is probably at least 5.4 lb (2 kg) *per capita* per calendar day. Recently, the annual increase has ranged between 1% and 2% per year. Similar upward trends have been observed in Western Europe, although there the quantities have been, and continue to be, roughly one-half to two-thirds of those in the USA.

In areas where intensive food-producing operations are conducted on a large scale, enormous quantities of waste are generated. Culls, peels, hulls, etc., derived from food canning, often amount to twice the *per capita* production of refuse in urban areas while animal wastes may reach 4 times the *per capita* urban quantities.

However, these data do not adequately take into account the additional solid wastes generated by agricultural and large industrial operations, nor the bulk of solid pollutants increasingly separated from air and liquid-waste streams by means of improved treatment processes designed to meet stricter standards. In the aggregate, these wastes could possibly amount to 1½–2 times the normal urban load.

CHARACTERISTICS OF SOLID WASTE

The most significant characteristics of solid waste are density, moisture, combustible and compostable content, and thermal values (Table 1). Each of these characteristics varies widely for the major solid-waste components, such as garbage, rubbish, street sweepings, bulky wastes,

TABLE 1. BREAKDOWN, BY PERCENTAGE OF TOTAL WEIGHT, OF COMBINED SOLID WASTES IN WESTERN EUROPE AND THE USA

Content of combined solid wastes	USA		Western Europe	
	Range (%)	Average (%)	Range (%)	Average (%)
Ash and furnace residue . . .	3 – 20	10	12 – 47	30
Free moisture	12 – 30	20	15 – 35	28
Combustibles	50 – 75	65	23 – 37	32
Non-combustibles	10 – 45	23	12 – 18	14

etc. However, since the general practice, both in the USA and Europe, is to collect and dispose of combined solid wastes without separating them according to kind or source (domestic, commercial, industrial, municipal), the characteristics discussed here refer to "as collected" mixed solid wastes. These characteristics are affected by seasonal and local variables, by type of collection system, standard of living, extent and type of commerce and industry involved, prevailing climate, and other considerations. Hence, the characteristics reported above are expressed in ranges of applicable values.

The weight or density of solid wastes has undergone drastic changes in the past generation. For example, the density of solid waste in the USA has decreased from about 350 lb/yd^3 (208 kg/m^3) to the present-day average of 215 lb/yd^3 (128 kg/m^3), the full range being 150 lb/yd^3 – 450 lb/yd^3 (89 kg/m^3 – 267 kg/m^3). In Europe, the average has dropped from 485 lb/yd^3 to 390 lb/yd^3 (288 kg/m^3 – 231 kg/m^3).

Current estimates of thermal values of refuse in the USA range from 3500 BTU to 6000 BTU (British thermal units) per pound (1944 kcal/kg – 3333 kcal/kg), the average being 4500 BTU/lb (2500 kcal/kg). The European range is 2000 BTU/lb – 3500 BTU/lb (1110 kcal/kg – 1944 kcal/kg), the average being 2700 BTU/lb (1500 kcal/kg). In short, both American and European refuse is increasing both in amounts produced and in calorific values, and is decreasing in density, moisture content and non-combustible content.

Some special wastes are beginning to pose ever-increasing problems. Oversized combustible material (waste lumber, trees and stumps, furniture, driftwood) cannot be handled by conventional methods while synthetics and plastics, such as polyvinylchlorides (PVC), can be destructive to disposal mechanisms and may greatly increase air pollution. Each of these categories requires special handling and processing. Oversize wastes now account for about 75 lb (34 kg) *per capita* per year in the USA.

Recovery of ferrous metals from mixed urban refuse can now be accomplished mechanically by means of magnetic devices, thus eliminating the need for manual picking. In the USA there is a market for burned-out tin cans for their value in copper reclamation.

ON-SITE STORAGE

Combined collections are eliminating the need for separate household receptacles, one for each of the major waste components. Metal collecting cans are going out of favour because of their noisiness, their liability to corrosion, their weight and unattractive appearance. Disposable bags made of high-wet-strength paper have been reasonably successful because of their cleanliness, light weight and one-way collection handling. However, the added annual cost and low fire- and chemical-resistance of such bags have been major disadvantages. On the other hand, the light-weight plastic container is fast growing in favour both in Europe and the USA because of its relatively low cost, good appearance, cleanliness, noiselessness, and reasonable resistance to chemicals and fire.

For multiple housing units and large blocks of flats, the trend is towards noiseless, fireproof, insect- and rodent-proof chutes, discharging by gravity into special large containers or compression units in the basement of the building. Properly designed and used, this on-site storage system is both economical and sanitary.

COLLECTION SYSTEMS

Except for commercial and industrial wastes, the collection of refuse by private contractors, on the basis of either a unit charge or a lump sum payment, is progressively being replaced in urbanized areas, both in the USA and Europe, by municipal collections. In those areas where collections are made by private contractors, including those serving commerce and industry, the disposal operations, with few exceptions, make use of facilities owned and operated by the municipality. In the interest of better management, greater dependability, and improved sanitation, private operators are being required to comply with standards established by publics agencies, and performance specifications are included in contractual agreements.

Only in rare instances have collection trucks been fully replaced by special systems such as home incinerators, garbage grinders, or the Garchey system. On-site, home incinerators can be designed and operated effectively with the minimum nuisance; in practice, however, they have been so often misused that they are now prohibited in many places. Garbage grinders (electrically driven comminutors) reduce kitchen wastes for gravity discharge into the community sewerage system and eventual treatment in the sewage-treatment works. Small, but definite, allowances should be made for water usage and increased digestion capacity in connexion with ground garbage. The Garchey system employs kitchen-drain waters to sluice the small-particle-size wastes for relatively short distances through subsurface piping into special central de-watering plants. The centrifuged refuse is then disposed of by conventional land-filling, incineration, or composting. Because of the problem of clogging, the applicability of the system to only part of the refuse, and the nuisance and operating costs of the de-watering plants, these systems have been used in only a few installations.

Each of the 3 systems described above will permit immediate, sanitary, on-site disposal of a portion of the solid-waste burden. All, however, have certain limitations in their application.

Collection trucks

The latest and best collection trucks are fully enclosed, with a low-lift, rear end, large loading hoppers and internal mechanical feeding and crushing mechanisms. The hermetic, dustless trucks used in Europe are specially useful there because of the greater amounts of ashes collected, but their use requires a greater uniformity in household refuse containers than other systems would need. The newer American collection trucks have capacities of 25 yd^3 to 30 yd^3 (19 m^3 – 23 m^3) and large end-hoppers for batch-loading, with extrusion mechanisms for discharging the loads. The higher cost of European collection trucks ($18 000 – $22 000) as compared with American trucks ($12 000 – $18 000) is offset by lower maintenance and amortization costs.

DISPOSAL SYSTEMS

As already noted, disposal facilities for other than special industrial wastes are mostly owned and operated by municipalities. In the USA, however, more and more of these facilities, particularly in the smaller towns and cities, are being financed, constructed and operated by semi-autonomous public agencies which serve several contiguous communities and charge regulated fees for solid-waste services.

Open dumping of solid wastes on land, though considered to be insanitary and unaesthetic, is still the most common disposal practice of all but the larger cities. In addition to harbouring rats, flies, mosquitos and other disease-carrying vectors, such dumps often burn, thereby creating serious problems of air pollution and safety, while drainage from dumps contributes to the pollution of surface and ground water. The former practice of some large coastal cities of dumping waste at sea has now been stopped by legislation. The use of refuse for feeding pigs, once widely practiced, has fallen sharply because of the added cost of the heat-treatment now required for the control of disease. The burning of refuse in apartment-house incinerators is being more closely controlled to prevent air pollution.

There are 3 generally accepted methods of treatment and disposal of solid wastes: composting, incineration, and sanitary land-filling.

Composting

Composting is the aerobic thermophilic decomposition of organic solid wastes to produce a relatively stable humus-like material. The principal by-products are carbon dioxide, water and heat — none of which is objectionable. The end product, compost, is a good soil builder or conditioner containing small amounts of the major plant nutrients (1.5 % – 2.0 % N, 0.5 % – 1.0 % P_2O_5, and 0.5 % – 1.0 % K_2O on a dry-weight basis) and its fertilizing value is about the same as that of farmyard manure. The temperatures produced during aerobic composting and curing — 140° F (60° C), or higher, over a period of several days — destroy eggs and larvae of flies, weed seeds, and pathogenic agents. Compared with normal, anaerobically digested sludge, compost has a less objectionable odour, is free from undesirable seeds, is not attractive to flies, and contains few or no disease-producing organisms.

Composting is feasible with ordinary mixed community refuse or segregated combustible refuse, including garbage. Refuse may be composted alone or combined with other predominantly organic wastes such as sewage sludges, crop residues, manures, meat and food processing wastes, and various other non-toxic industrial and commercial wastes. Separation must be practised with normal municipal refuse; however, all but about 25 % by weight can then be ground and composted. Refuse for composting should exclude bulky wastes, construction and demolition debris, and large metallic scrap.

The principal operating processes of the modern, mechanized and automated plants are as follows: (1) pre-sorting to remove bulky materials unsuitable for composting or salvage; (2) screening-out the fines and shredding the coarser components; (3) removing glass and metal fragments; (4) composting the organic material at accelerated rates in fully enclosed chambers for 1 – 3 days (including partial recirculation for seeding purposes) under controlled aerobic, moisture and temperature conditions; (5) completing the maturation in windrows for a further period of 3 – 10 weeks to produce a stable, odour-free end-product; and (6) the addition of chemical fortifiers (nitrogen, phosphorus and potassium) as requred, either during or at the end of the process, to obtain the required fertilizer characteristics.

In a survey of 21 composting plants in 10 countries in 1965,[1] cost and income data were collected from 14 composting plants in Europe and Israel. The plants employed either the Dano Biostabilizer, the Dorr Oliver Rasp, the ventilated cell, the Buhler–Dano combination or the Von Maanen process. The average cost of processing 1 short ton (907 kg) of raw refuse was $4.55, of which capital service (amortization, interest and rent) amounted to $1.76, and operating expenses to $2.79. The weight of compost produced was 46 % of raw refuse processed, and the average income from sales amounted to $2.73 per short ton (907 kg) of compost or 90¢ per short ton of refuse. None of the plants visited was able to cover its capital service costs and operating expenses through income from sale of compost and salvage, substantial prices for compost being obtainable practically only in Israel.

One American compost plant now being constructed for operation by a private firm will charge at the rate of $3.24 per delivered ton for up to 100 short tons (90.7 tonnes) per day.

Sanitary land-fill

Properly engineered, managed and controlled, sanitary land-fill operations can be successful and economical, besides meeting public acceptance and health standards. The basic requirements, according to present practice, are: thorough compacting of the refuse and prompt, progressive covering of the compacted and graded refuse with clean earth or similar organically stable materials; prompt quenching of surface and sub-surface fires; continuous maintenance of proper surface drainage to prevent the ponding of septic waters; surrounding the operational area with woven-wire fencing to confine windblown debris; circumscribing flat areas with earth berms to hide the operation; and taking strict measures to protect sub-surface aquifers from possible contamination by leached substances.

Sanitary land-fills have reclaimed thousands of acres of otherwise non-usable land for recreational and other developments. For sound, relatively large operations the capital costs (land purchase, site preparation and equipment) range from $0.50 to $1.10 per short ton (907 kg) of refuse disposed. The total operating costs, including the extra truck haulage in metropolitan areas but excluding amortization, range from $1.75 to $2.75 per short ton. Of course, if the reclaimed land is taken into account, the costs can be considerably less.

Some very good examples of the beneficial use of solid wastes for reclamation of land are provided by the filling-in of abandoned open-cast mines, quarries and gravel pits. Without reclamation, such places are permanent scars on the landscape; with proper filling they can be used for parks, industrial sites and even for residential development. Special precautions must be taken, however, to select sites in which the ground water would not be polluted by the fill.

It should be emphasized that this method is the only one capable of disposing of all types of solid wastes irrespective of size, moisture content and other characteristics. No secondary disposal is involved, and no special preparation of the refuse is required. The low costs and the other inherent advantages have made this the method of choice for most communities, provided, of course, that adequate land is available at reasonable cost and within reasonable hauling distances, and provided there is no danger of water resources becoming polluted. An essential aspect of land-filling operations is the planning for the ultimate utilization of the completed site.

Central incineration

Today's municipal incinerators are installations resembling power-plants and are designed to burn refuse under controlled, nuisance-free conditions at relatively high temperatures in order to reduce it to an inert, organic-free residue, which can then be readily disposed of in a land-fill. The major incinerator components and functions at present are:

Tipping and storage pits. Here the collection trucks discharge the solid wastes. They are watertight and there is now a tendency to construct larger pits that will hold enough material for 36 – 38 hours of incineration. The latest pits are operated with a slightly negative air pressure so as to control the inherent dust and odour problems.

Cranes. All new incinerators are of the bin-and-crane, rather than the floor-dump, type, and are generally equipped with 2 or 3 bridge-type cranes, each of at least 10 short tons capacity, to feed wastes into the furnaces. The crane buckets are large (5 yd^3 – 7 yd^3; 3.8 m^3 – 5.3 m^3) with grapples of either the clam-shell or the polyp (orange-peel) type.

Furnaces. Most incinerators have multiple furnaces and these tend to be of larger capacities than in the past. In the USA, for example, furnaces with a capacity of up to 400 short tons per day are employed, while more plants are being constructed to operate on a 24-hour basis. Provision is being made for longer retention periods in the furnace for flame burn-out and destruction of particulate matter and gases. The better furnaces are fully steel-sheathed on the outside to control dust. Water-cooled tube walls reduce air requirements and maintenance costs and at the same time increase the potential heat recovery. In the USA, about 20 % of the incinerators in use utilize the recovered heat in some way. The increasing calorific value of mixed urban solid wastes should open up new possibilities for heat utilization.

Removal of fly ash. All new plants constructed in the USA since 1959 have some system for removing fly ash. More complex and efficient systems are now replacing the simple dry expansion chambers of the past.

Treatment and disposal of waste water. The disposal of untreated waste water from wet scrubbers used to cause water pollution and there is now a definite trend towards the treatment and recirculation of waste water from incinerators.

Residues. A useful construction material can be obtained after the magnetic separation of ferrous metals, by crushing the clinkers and screening them for the required grades.

Both capital and operating costs for incineration of refuse are increasing as environmental standards rise and equipment becomes more complex and expensive to purchase and operate. Some ideas of comparative costs of incineration in the USA and Europe are given in Table 2.

TABLE 2. INCINERATOR COSTS IN EUROPE AND THE USA

Costs	Europe	USA
Capital costs, *per capita* served (range)	\$6.50 – \$19.00[a]	\$4.50 – \$10.00
Capital costs, per short ton per 24-hour capacity (average)	\$10,000[a]	\$7,500
Operating costs, per short ton (range)	\$2.25 – \$3.75	\$4.50 – \$8.00
Operating costs, per short ton (average)	\$3.50	\$5.50

[a] Includes the generation of steam and power.

SOLID-WASTE SUBSTANCES AND THEIR POSSIBLE USES

The following list shows some of the uses (excluding normal salvage) that can or could be made of solid waste materials.

Mixed organics	Animal feeding (after yeast digestion)
	Charcoal (for purifying air and water)
	Soil conditioning (compost)
	Soil covering to prevent erosion
Combustibles	Heat production
Fly ash	Light-weight aggregate for construction
Incinerator ash	Land-fill and cover material
Meat-plant residue	Animal feeding supplements
Poultry waste	Animal feeding supplements
Hardboard plugs	Soil conditioning
Tin cans	Copper recovery

LONG-RANGE TRENDS

The present trends can be expected to continue for some time to come. However, public and professional concern about environmental pollution is increasing greatly and this is likely to lead to the present standards being challenged, and to consequent innovation and development. Current research will open up new technical possibilities and the application of systems engineering is already widening the range of potential approaches.

It would be difficult to list all the advantages that may be derived from systems analysis of environmental problems, but some of the more important are:

(1) More effective evaluation of the inter-relationships between solid wastes and pollution of air and water, including the costs and benefits associated with shifting the waste-burden from one area to another.

For example, the residual pollution of lates and streams by sewage sludge containing nitrates and phosphates can be avoided by combining the sludge with processed solid wastes and using the mixture as a fertilizer elsewhere. Likewise, soil erosion, and hence silt pollution of streams, can be prevented by placing solid-waste organic cover material on denuded areas. A similar treatment of open-cast mines would reduce acid drainage.

(2) The comprehensive assessment of the possibilities of conversion, re-cycling and re-use of waste substances, including interchanges affecting the economic feasibility of various alternatives, and reduction of the amounts of waste to be finally disposed of into land, air or water.

(3) The analysis of complex systems with numerous social, political, ecological, and technical aspects.

(4) The analysis of wholly new approaches involving major innovations, such as the on-site processing of wastes and the provision of facilities for "model" cities.

Closely related, and indeed vital, to the development of systems approaches is the development of standards and criteria through widely ranging research. Technical guidelines, now largely absent or inadequate, are essential for the evaluation of alternatives and long-range planning. Studies will be needed to investigate and promulgate standards and criteria for solid-waste disposal in relationship to such factors as air pollution, water pollution, scenic beauty, conversion and re-use, and regionalization.

A third area in which improvements are not only likely, but essential, is that of *reduction at the source*. It is evident that most of today's consumer goods, and especially their packaging, are designed or produced without any concern for the problem of ultimate disposal. A recent study [2] showed that in 1966 about 46 million short tons of packaging materials were produced and sold in the USA alone. These materials included paper and paperboard, glass, metals, wood and plastics. Estimates indicate that the packaging materials component of solid waste will rise from 1 lb (about 0.5 kg) per person per day in 1966 to 1.6 lb (0.7 kg) per person per day in 1976. In estimating the cost of disposing of this solid waste, the fact that discarded packaging material makes up much of the litter that frequently fouls roadways, parks, beaches and other public places must be taken into consideration.

Studies are needed to determine the reduction of waste that could be achieved by the use of materials that undergo biodegradation and by changes in design without detriment to other desired qualities. Results of such evaluations would be very useful for establishing criteria and guidelines for use by various industries in preventing the generation of huge amounts of solid waste. An example of the importance of reduction at the source was the change-over from "hard" to "soft" detergents for reduction of water pollution.

In the past, solid-waste disposal has generally been considered less as a system than as a single act of disposal. Because of increasing environmental constraints and the beneficial uses to which certain waste materials can be put, a much greater variety of separate processes will undoubtedly be needed to make full use of the technical opportunities. In practical application, the linking together of these processes will lead to new engineering designs, better able to deal with actual waste situations. For example, shredding of solid wastes appears to be a useful procedure prior to land-filling to increase the density of the material. A combination of shredding and baling can not only improve control of nuisance caused by loose refuse but also facilitate handling by substantially reducing the volume.

Finally, all these developments taken together — systems analysis, standards and criteria, reduction at the source, and complex arrangements of processes — will clearly increase the need for technical manpower of high quality. Solid-waste engineering and the related technical disciplines will have to achieve a standard comparable with that of other disciplines concerned with the protection of human health and the preservation of the environment.

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A NEW APPRAISAL OF THE SOLID-WASTE PROBLEM

H. M. ELLIS[a]

THE BROAD PROBLEM

The object of a solid-waste service is to collect, transport or convey, and finally dispose of, waste in a hygienic and aesthetically acceptable manner at the lowest possible cost to the tax-payer. It appears that all over the world, especially in the technologically most highly developed countries, the amount of solid waste to be disposed of is increasing year by year and urban communities, in particular, are faced with the growing problem of dealing with the waste they generate.

How great, then, is the problem that faces the world? What has caused it, and what action is needed?

The population explosion

According to official publications of the United Nations,[b] the population of the world increased during the period 1960–64 at the rate of 1.8 %. It is now increasing every year by some 50 – 60 million and expectations are that by 1975 the rate will have reached 77 million and by the year 2000, 126 million. In short, during the period from 1950 to the year 2000 the population of the earth will have increased by 2 ½ times.[13] This amazing growth would in itself impose enormous problems but there are in addition a number of other factors that make the probable difficulties even greater; not the least of these is the rapid urbanization that is taking place all over the world.

Weight and volume of refuse

During the past few years there has been, certainly in the more developed countries, a marked increase in both the weight and the volume of refuse being produced, not merely by domestic users but also by trade and industry. This is due, in no small measure, to increasing prosperity

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[a] Lately Transport and Cleansing Officer, City and County of Bristol, England.
[b] See, for example, United Nations (1968) *Demographic yearbook, 1967*, New York, United Nations, and United Nations (1968) *Statistical yearbook, 1967*, New York, United Nations.

and higher standards of living leading to a much greater variety of consumer goods, mostly elaborately packaged and presented, being available. For example, it is estimated that in Great Britain the volume of refuse will, during the next 10–15 years, increase by some 3 % per annum and the weight by possibly 2 % per annum. These estimates agree with those made in other countries, such as the USA, Sweden, and the Federal Republic of Germany.

Changing character of refuse

The different percentage increases in the volume and weight of solid waste is due to the changing character of refuse, which itself is the result of a number of factors. High on the list is the rapid change in many countries from hard-fuel heating systems (coal, wood, etc.) to heating by means of gas, oil or electricity. As a consequence, the proportion of heavy material in refuse is drastically reduced.

The demand for consumer goods and the intense advertising and publicity given to various products result in a very large increase in the amount of packaging material being discarded. Despite the great impact made by plastics in the packaging industry, the use of, all other forms of packaging, with the single exception of timber, has also continued to increase.

Shortage of land

The additional weight and volume of solid waste has created, and will continue to create, many problems both of collection and of disposal. The rapid urbanization now taking place in many countries uses up vast areas of land for housing and industrial development and, while more refuse is created by these developments, there is a shortage of land for purposes of waste disposal. In this connexion, it is important to make an analysis of the distances that refuse can economically be transported to a disposal site, taking into account the costs of compacting the waste materials.

Composition of refuse

In very few countries has any serious attempt been made to analyse and classify the type of refuse being collected and disposed of. Work of this nature has been carried out in Great Britain for many years and there are a few other reports available, notably from parts of Western Europe and North America. These studies, however, relate mainly to domestic refuse and in most cases have failed to take any cognizance of trade and industrial waste or, indeed, the bulkier forms of domestic waste (old furniture, for example). Further, there appears to have been little attempt to change the form of analysis despite the marked change in the general character of the refuse.

The formulation of new and uniform methods of sampling and analysis are urgently required to give a comprehensive picture of the composition of all types of solid waste. This basic information is needed by the engineers and technicians responsible for planning future refuse-disposal projects and without it the planning cannot be fully effective.

Data on solid-waste disposal

The data available concerning the many aspects of the subject are quite inadequate in both amount and scope when considered in relation to the enormous outlay in manpower, transport, plant and equipment. Much more information is needed on the following topics, for example.

(1) The relationship in terms of labour-costs of storage at the source of production and the use of centralized vehicle-collection points.

(2) Reliable statistics on the optimum size of a collecting gang or crew in relation to vehicle capacity, and on the holding capacity of the vehicle that is most efficient under given circumstances.

(3) The relationship of collecting frequency to cost increase.

(4) When excessive hauls are necessary to either (*a*) a disposal point, or (*b*) a transfer station, the fair assignment of costs to collection and disposal.

(5) Accurate estimates of costs for the disposal of various forms of refuse and statistics concerning throughput and percentage reduction, etc.

PUBLIC HEALTH REQUIREMENTS

In the report of the WHO Scientific Group on the Treatment and Disposal of Wastes [15] it is stated:

> Another problem, of increasing importance, is that of the collection and disposal of solid wastes, including refuse from municipalities and solids resulting from the treatment of sewage and industrial wastes. Failure to deal satisfactorily with the never-ending flow of solid wastes constitutes a clear threat to public health and contributes to air, water, and soil pollution as well as to the propagation of flies, rodents and other vectors of disease. In spite of this danger, however, achievements in the management of solid wastes are small when contrasted with the advances made in the treatment of waste water

This is a very important statement; pollution of land, air and water is causing very serious concern in many places and while active steps are being taken in some developed countries, an enormous amount of work is still required in the developing countries. In some of the latter, garbage may be dumped into open drains, thereby creating not only a serious pollution problem, but also providing breeding places for disease-carrying insects.

AESTHETICS

Quite apart from the public-health aspect of waste disposal, these are aesthetic considerations. It has regularly been found that, with higher standards of living, the public is no longer willing to tolerate methods that in the past were quite readily accepted; this applies particularly to refuse tips (known in some areas as sanitary land-fill). No matter how well managed and controlled these may be, the presence of a tip within a relatively short distance of dwellings almost invariably results in complaints and objections. The fact that the objections may have no foundation whatever neither satisfies or placates the public, and the demand that consideration should be given to aesthetics is one that should not (and, in fact, cannot) be overlooked.

PUBLIC RELATIONS

Only a very small section of the public has any knowledge of what happens to the waste it produces and fewer still know anything about the cost of dealing with refuse although, most people will resent increases in their rates. A good public relations service is therefore a great asset in enlisting the help, tolerance and understanding of the community and, as such, it can amply repay the time, effort and money spent on it.

Today, as never before, opportunities to inform the public are readily available and full use should be made of the press, radio and television, special exhibitions, etc. Talks and lectures, illustrated if possible, to organized groups at schools, women's associations, clubs, etc., are useful activities.

ECONOMICS AND FINANCE

The refuse-collecting service in almost any town or city, large or small, accounts for a very large proportion of both the labour and transport employed by the municipality and, with the rapidly increasing quantities of material to be handled, this is bound to be a continually increasing proportion. In those areas where land is not available for controlled tipping, more costly methods of disposal have to be adopted and, as a result, the total expenditure on the solid-waste programme as a whole accounts for a very large part of the local authority's budget.

The WHO Scientific Group on the Treatment and Disposal of Wastes further stated:[15]

> The importance of the problem is emphasized by the fact that in the highly industrialized countries up to 20 % of municipal budgets are spent on the collection and disposal of solid wastes, and even more will be required if the job is to be done adequately.

As labour and transport costs will inevitably continue to rise, this percentage may well increase.

Analysis of the capital to cost relationship of labour and transport, based on operational research methods, might be expected to indicate cheaper, and probably more efficient, methods of dealing with our wastes. Investigation along these lines is, from an economic point of view alone, urgently required.

PRESENT SYSTEMS

Since numerous articles, monographs, and textbooks are available on practically every aspect of the refuse problem — storage, collection, transportation and ultimate disposal — it is not necessary to discuss technical matters here.

From time to time, groups of experts have held seminars, conducted extensive investigations, and reported on many of the varied problems, but most of these groups have concentrated on estimating costs and compiling statistics related to current practice or in suggesting or developing more sophisticated methods on the same basic lines.

It is true that reports of this kind have resulted in vast improvements; for example, *A code of practice dealing with the design of refuse chutes and chute chambers*,[2] publicized the necessity of planners and architects consulting with cleansing officers in matters relating to the storage of refuse, plastic dustbins, paper and polythene sacks, methods of transportation, methods of tipping refuse,[1] etc.; but at the same time, some reports have led to the creation of more problems.

Refuse collection

The introduction of bulk containers, while reducing manpower to a minimum, has resulted in a 7- or 8-ton vehicle being used often to transport less than ½ ton of refuse.

Progressive development in the design of collecting vehicles has moved first to compression plates, then to continuous loading, and now to mechanisms for crushing or grinding that to a certain extent pre-treat the refuse prior to its disposal. This new emphasis has resulted in much higher standards of maintenance being required, with the result that not only have vehicles increased very substantially in cost, but the proportion of vehicles needed in reserve to allow for maintenance and repair of the fleet is also greater. In some cases, the reserve is known to be as high as 20 %; obviously, this is a serious economic consideration for a municipality.

Refuse disposal

Disposal facilities for refuse have greatly improved and mechanical plant has made possible the use of tipping sites which would formerly not have been considered suitable, but greater attention is now being paid to site selection; the location, geological features, drainage and effluent control, and planning of operations are all important factors.

Crushing and pulverizing, either as a pre-treatment for refuse to reduce the particle size prior to tipping or as an aid to effective composting, is rapidly being adopted and numerous types, sizes and capacities of plant to carry out this operation by either dry or wet methods, are available.

Incinerators are now largely automatically controlled and operated, and the gas-cleaning and dust-control equipment that is generally incorporated in the design has made it possible to install modern plant in built-up areas without creating nuisance.

SPECIAL PROBLEMS

Some relatively new problems of collection are now becoming evident; that of dealing with bulky refuse and scrapped motor-cars is one example. Living standards in the advanced societies have now reached a phase when large quantities of bulky refuse are produced; frequently it is old (i.e., disused) furniture and kitchen equipment. Fashion in furniture having become important, much modern furniture is built for a limited useful life.

Severe and justifiable criticism has been made about indiscriminate, unauthorized dumping of bulky refuse but much of this has undoubtedly resulted from the lack of a satisfactory collection service being provided by many local authorities. In a recently published a report by a Working Party on Refuse Collection set up by the British Government,[7] a strong recommendation was made that all local authorities should provide a free service for collecting bulky material; experience is already proving that this is not only desirable, but necessary. Suggestions have been made that such collections could be made together with the normal refuse service but, where the latter has been designed on a scientific work-study basis, the inclusion of bulky waste in refuse to be collected during a regular round would completely disorganize a service. An additional service is, therefore, needed for this purpose.

Motor-car scrap

The problem of dealing with scrapped and abandoned motor-cars is growing very rapidly. In his budget message in 1965, President Johnson estimated that in the USA there would be 5 million tons of motor-car scrap produced in the course of the year, while it is estimated in Great Britain that 7 million cars will be scrapped during the next 10 years.

About 90 % of old motor-cars are dealt with by scrap-metal merchants or motor-car dismantlers but it is estimated that about 10 % are abandoned and it has become so serious a problem that local authorities will have to accept responsibility for the removal of such vehicles. Abandoned cars are not only unsightly but are also a danger, especially to children who play around them. However, it is quite uneconomical for any single local authority to install plant for this purpose and the problem will, in all likelihood, have to be dealt with on a regional or semi-regional basis.

The latest fragmentation plants that have been installed in England, France and in the USA appear to provide an excellent solution, not only to this problem but also to those involving other bulky metal objects such as kitchen equipment. Co-operation between industry and local authorities will be necessary since futher, and possibly greater problems will arise if the motor-car industry, for example, develops plastic bodies for motor-cars on a large scale.

Agricultural wastes

Agricultural wastes take many forms and in some areas, owing to the changing patterns of the agricultural industry, such wastes are becoming a major challenge. This applies particularly to the intensive rearing of poultry and to the pre-packaging and canning of foodstuffs.

It is evident that more research needs to be done in this field. A national conference on solid-waste management, held at Davis Campus, University of California, USA, in 1966, was devoted mainly to this subject.

Mining spoil and chemical wastes

Vast quantities of material are dumped annually by the mining and chemical industries and while, in the main, these wastes are not a direct health hazard, they are extremely unsightly and may create pollution problems. Owing, however, to new industrial technology, many dumps are now being re-processed for the recovery of valuable materials and the problem may solve itself in time.

However, the chemical industry also, produces increasingly large quantities of toxic waste, usually in liquid form. These wastes present a very serious pollution hazard and it is evident that extensive research on their disposal is required. The British Government set up a special scientific group to make an intensive study of the toxic waste problem several years ago and their report may be expected to be published soon.

Camping sites

A problem of some significance is one that has arisen during the past few years in connexion with very large holiday camps. These camps, which are invariably situated either in attractive country areas or on the coast, have had a "mushroom" type of development and few of them have been adequately planned from a sanitation point of view. Serious consideration should be given to recommendations on minimum standards and acceptable methods of dealing with both sewage and solid waste from holiday camps.

NEW OR SUGGESTED SCHEMES FOR THE DISPOSAL OF SOLID WASTES

Over a relatively short period, the problems associated with solid wastes have emerged or developed as a great challenge to continuing human progress. From a routine service of collecting and disposing of refuse that was comparatively stable in content and of fairly high density, collection has, within a few years, become complex, costly and the quantity, variety and volume of waste to be handled is growing at an alarming rate. Further, there is ample evidence that neglect of the changing circumstances has resulted in serious health hazards, due to the pollution of water and air, being created.

Public officials and manufacturers of equipment have devoted much effort to the improvement and development of existing methods, but there are limits to both time and money that can be spent in this way. Except for the production of compost, the use of heat from waste-incinerators, and the recovery of limited quantities of materials for re-use, little effort has been made to find ways of using waste. Some examples of unorthodox solutions and entirely new methods will now be described.

Vacuum transportation

The most revolutionary recent system for transporting waste to collection or disposal points is the pneumatic-suction system developed in Sweden and installed initially in a large hospital. The system provides for the transportation of refuse by chute and pipeline to a point where it can either be handled conventionally or be incinerated on the site. It is claimed that the suction in the system is so great that the refuse actually floats within the pipeline and that wear due to abrasion is negligible. The installation is costly but the system has the advantage of eliminating the need to store and collect refuse. Thus, taken over the life of a large building, the capital outlay, together with the vastly improved hygienic conditions, may well be justified.

At the decision of the municipal authorities of Sundbyberg, a suburb of Stockholm, Sweden, a similar system was installed in a housing scheme comprising some 5000 new dwellings, mostly in the form of flats. The Westminster City Council in London has also decided to use this new method for dealing with refuse in a large housing project.

Water-borne disposal

It has been claimed that water-carriage is the cheapest means of transportation for refuse and during the last few years a detailed investigation was carried out at Hanover, Federal Republic of Germany, into the possibility of macerating refuse and conveying it, mixed with water, in pipelines to the coast. A series of pumping stations would be required along the pipeline.

Maceration is, of course, already used to some extent by domestic sink grinders but the difficulty in this system is that too much water may be needed. It has been claimed that many of the existing networks of sewers are of a sufficiently large diameter, or have an adequate fall, to take the added volume of solids, but much more investigation is required before any large scheme can be tested.

Baling waste for disposal

A Japanese company has, at a development cost of over £1 000 000, built a very large, multi-cylinder hydraulic press for baling and wrapping crude refuse. Capable of processing 150 long tons (i.e. 1000 yd^3; 765 m^3) per 8-hour day, the throughput is claimed to be condensed to 25 6-yd^3

(4.6-m^3) blocks having a density of 1 ton per cubic yard (about 1330 kg/m^3). Before they are extruded from the press, the blocks are automatically sealed in light steel cladding that has been corrugated in the process and is capable of being welded. As a final step, in order to eliminate all possibility of pollution, the bale can be hot-dipped in bitumen. This ensures complete freedom from any objectionable characteristics and enables the blocks to be stored without putrefaction or the emission of odours.

The idea of baling refuse has often been considered in the past, and the densities claimed for the process are quite feasible. Using pulverized refuse, a similar density was obtained in Bristol, England, in an experiment carried out a few years ago using merely a twin-screw waste-paper baler. Automatic wrapping and ultimate sealing is, however, an innovation and should permit the use of refuse blocks in many areas where the disposition of refuse would otherwise be unthinkable.[6]

The capital cost installed, with foundations and building, would be approximately half the cost of an equivalent copacity incinerator, or $2,500,000. This is based on a two-shift capacity of 300 tons. Operating costs related to Canadian labor and material rates, would be about $2.50 per ton, or 32 cents per cu. yd. This cost covers maintenance, operating labor, steel supply, electricity and 20 miles of bale transportation.

It is reported that the Government of the USA has ordered a press to be installed for experimental purposes and the results will, undoubtedly, be watched with great interest.

As with many other projects, cost comparisons are not easy, but it would appear that if the English practice of amortizing machinery over a 15-year period is followed, the inclusive costs for operation and amortization, taking current high rates of interest into account, would be little, if at all, lower than for incineration.

Incineration at sea

Feasibility studies are being undertaken in several countries to determine if it would be possible to carry refuse to sea and burn it in the ship. Since there would be no problems of pollution, either of air or water, the incineration equipment could probably be less complicated than that required for a land-based installation.

It is obvious that one of the problems which would almost certainly arise would be delays occasioned by rough seas and this could well involve capital expenditure for the provision of large bunkering facilities where refuse might be stored for several days before it could be shipped.

Destructive additives, etc.

It is known that some plastics can be degraded by micro-organisms, and if the problem of disposal becomes too great some governments may demand that manufacturers incorporate destructive additives into the plastic used in some forms of packaging. Recently, a paper has been produced synthetically which is almost instantaneously soluble in water.

This is a field to which more attention will have to be given. In England, the Working Party on Refuse Collection recommended in 1967 [7] that:

> The Government should review with trade and industry the possibilities of limiting any excessive use of packaging and of choosing packaging materials which are not difficult to salvage and dispose of.

These examples indicate a new approach to the problem set by packaging materials. Some ideas may appear to be impracticable, but it is encouraging that many suggestions now being treated as serious possibilities and eventually major departures from what have been, for so long, accepted practices will emerge.

Utilization of solid waste

Production of ethyl alcohol. Under the direction of Dr A. Porteous, a research project has been started at the University of Glasgow, Scotland, with the object of producing industrial ethyl alcohol from refuse with a high paper content.[1] The aim is to determine whether the process will be applicable to refuse in Britain, having regard not only to a high paper content in the refuse, but also to competitive refuse disposal costs in conventional methods such as landfill, incineration, etc.

Animal feeding. It is reported[10] that experimental work is being done on the conversion of waste paper into cattle food. With the objects of better refuse disposal and the production of cheaper meat, this research is being conducted at different centres in the USA: North Carolina State University, University of Denver, Colorado, and the Solid Wastes Program[a] laboratory, Cincinnati, Ohio.

In the course of the experiments, paper and other cellulose waste is subjected to the attack of aerobic bacteria and certain enzymes obtained from wood-devouring fungi. If these experiments are successful, it is hoped that the cellulose will be converted to protein.

Solid waste as a fuel. One of the contracts recently awarded by the United States Public Health Service is for a design and feasibility study

[a] Now, Bureau of Solid Waste Management, Environmental Control Administration, Consumer Protection and Environmental Health Service, US Public Health Service.

to find a way of using solid waste as fuel in a jet engine for generating electric power. It is stated:[7]

> Under the technique, community solid wastes consisting chiefly of paper products and some metal and glass are fed into a shredder which reduces it to a uniform size, then into a dryer where moisture is removed, using waste heat from the jet engine. The homogenous mixture is then injected into a combustion chamber and burned together with high pressure air to produce hot, clean filtered gas. The gas is then passed through a jet engine turbine to drive the engine's compressor and through a second gas turbine to drive an electric generator.

Some difficulties have been experienced at European incinerators with the extensive corrosion of boiler tubes by hydrochloric acid as a direct result of burning polyvinylchloride (PVC) waste at high temperatures. This is likely to be a growing problem. In view of this experience, it will be interesting to learn whether the feasibility studies mentioned above show that the hot gases can be sufficiently well filtered to prevent major problems arising in a jet engine.[9]

FUTURE PLANNING

Integration of services

During the past decades, one of the almost universal weaknesses in sanitary services has been the tendency to treat every aspect of waste disposal as a separate problem. Thus, there has grown up in most of the developed countries, a situation where Refuse, Sewage Systems, Water Pollution and Air Pollution are services separately operated and controlled each having its own legislation and with little or no co-ordination of, or co-operation between, services.

In recent years, some attempts have been made to combine the disposal of sewage sludge and refuse, mainly by composting, but in some countries current integration of the services is being discussed in some detail since it is realized that this can often be achieved with benefits all round.

In Geneva, Switzerland, the new sewage works and the new refuse-incineration plant, while separately sited, are under a single controlling authority and designed so that the same barges for bulk transportation can be used to carry both sludge and refuse, either combined or separately, with the object of allowing mixed solids to be incinerated together.

It is now clear that if refuse disposal is to be carried out efficiently, hygienically and economically, heavy capital outlay will be called for, whatever system of disposal is adopted. Incineration calls for particularly expensive plant and small units will be quite uneconomical to operate. Attention is therefore being given in England either to joint schemes or to *ad hoc* authorities. An outstanding example of this is the recent setting up of the Greater London Council, one of whose responsibilities is waste disposal in the whole of the Greater London area, the population of which numbers some 8 million persons. To carry out this work, a Department of Public Health Engineering has been established to look after sewage, refuse disposal and river pollution; the senior officers of the department are classed as Public Health Engineers.

It is possible that by combining the smaller local authorities in England into larger units, a development expected to take place in the fairly near future, organizations based on the London plan for dealing with community wastes will be more widely adopted. Before such large-scale schemes are begun, pilot studies will be called for, but the cost of such studies should quickly be recovered.

ADMINISTRATION AND MANAGEMENT

Solid-waste services, whether operated by public authorities or by contractors, are now very big business enterprises and must be approached as such in almost every aspect of their operations. If it is accepted that public health is the first consideration, and that aesthetic requirements also have an important bearing on the way in which the functions are performed, it is essential that every advantage should be taken of new equipment and methods to ensure that the highest standards of efficiency are achieved within the financial framework alloted to these services.

Much excellent work has been, and is being, performed by men with a great deal of practical experience who have the ability to instill an enthusiasm for the work into the staff they control. But the growing size and complexity of the problem that solid wastes now present, together with the very big requirements in terms of manpower, plant and materials, show that the older, rule-of-thumb methods are no longer sufficient.

During the last few years, primarily because computers are increasingly used for operational studies, new techniques have been developed to provide information, the value of which no authority with responsibility for disposing of waste can afford to ignore.

Legislation

Most of the developed countries have legislation governing the various functions of bodies concerned with solid wastes. The legislation varies from requirements for the provision of storage containers and the responsibility of authorities to collect and dispose of refuse, to standards for controlling pollution. It is desirable that much of this kind of legislation should be agreed on at an international level.

Some of the functions of a local authority, and indeed of the public itself, in relation to solid wastes are governed only by local acts and these are not always either adequate or well framed. The practice of issuing model by-laws that can be adopted by local authorities for legal purposes is one that should be encouraged.

Now that it is becoming accepted that the regionalization of refuse disposal is necessary, legislation should be introduced to permit the disposal of refuse from one area in an area administered by another authority, provided that there were no detrimental effects in the disposal area.

Finance

Sound financial policies should be adopted, and capital expenditure programmes (covering a period of several years) and annual budgets should be prepared. To do this, statistics of many kinds are required to provide the necessary information for an adequate costing system. It has been mentioned previously that some authorities are now spending up to 20 % of their budget on the waste-disposal service and this alone indicates how vital it is to have a really efficient control system so that expenditure can be kept within reasonable bounds.

To use computers effectively to obtain a wide range of costs and statistics depends upon the accurary of the basic information. Since the coding of this information for computer programmes is usually done by officers at the lower end of the managerial or administrative scales, it is essential that the code list should be kept as simple as possible.

Aids to management

There is now a multiplicity of scientifically based operations and control methods, some quite independent but others that are interdependent or overlapping. Together, they have variously been described as organization and method, work study, systems analysis, operational research, critical path analyses, etc. Several of these operations that are probably the most valuable in the study of waste-disposal services will now be dealt with specifically.

Organization and method. This is not only a study of an existing organization but also of the methods being applied and it is found most useful in connexion with administration rather than with practical matters. The system analyses the records kept, the use made of such records, and whether or not the cost of keeping them can be justified. All too often, records are kept merely for their own sake and may never be used.

For example, is it necessary to record how frequently a particular street is swept? Is it necessary to keep a record of all servicing and repairs carried out on a particular refuse collection vehicle? Is it necessary to list how many waste-containers per hour loaders in different gangs are emptying, particularly as distances and loads differ so greatly?

In both national and local government there has in the past been a laudable attempt to keep records or statistics of all activities. A more modern approach is to keep adequate records but not to waste time and money on details that involve an expenditure greater than the expected saving. This is a principle that has been applied in business and commerce for many years.

Work study. As an aid to efficiency in practical operations, work-study technicians are now being employed very extensively in some countries. Work measurement is used as an aid to organization, operations and cost effectiveness, and for assessment of bonuses.

A highly specialized scientific approach is required, that is a development of the former time-and-motion study technique. All processes or functions are measured against a basic 100 and counted in standard minutes; the standard for working time is taken as that of the normal walking pace of a man. Time studies, of all the operations that a man performs are recorded with stop watches and allowances are then made: for time taken from the depot to the starting point of the work, for travelling time to and from disposal points, for meal breaks, personal needs and washing before meal breaks and before finishing for the day, etc. These allowances are included in the programme and a standard performance is then formulated and agreed. Any work done in excess of the agreed performance may qualify for bonus payments.

Where computer facilities are available it is advisable to consult a senior programmer and, possibly a statistician so that all records and data are in a suitable form for programming. Taking the collection of refuse as an example of the method; from the detailed information obtained in the study, i.e., walking time to and from the vehicle to the container, lifting and then emptying the container and subsequently replacing it, the most economical number of men in a gang or the most suitable size of vehicle can be estimated.

Another example is the servicing of a vehicle — testing and checking the performance of each part, greasing, oiling, topping-up batteries, etc. Studies could be made to determine the best method of approaching the work, the sequence of operations and whether the introduction of new equipment will result in the work being speeded up, and to prescribe the time to be allowed to the operator.

The procedures used in work studies are often regarded with mistrust by the employees, who should always be kept well informed. To this end, it has been found advantageous to give elementary training in work-study principles and procedures to representatives nominated by the men themselves.

Operational research and systems analysis. Both these terms really mean much the same thing. The techniques involved here are more elaborate than in work study but the factual information obtained by work study can be used to help in the construction of a computer model representative of the constituent activities of the service. Such an analysis has already been used on one or two occasions in England in order to reorganize refuse-collection rounds.

Now that refuse disposal is being approached on a large scale, it is economically necessary for the location of disposal sites to be as near as possible to the area where the refuse is produced. It is probably in this field that operational research is most valuable when used in a pre-investment study. All factors that are likely to arise over a number of years — population growth, location and types of industry, amounts of refuse likely to be produced, etc. — are taken into account. These data, together with statistics on existing conditions, are then used in a mathematical model which can be analysed by computer.

Recently, the Local Government Operational Research Unit in England [8] was given a brief to study methods of organizing the disposal of refuse, including tipping, composting, pulverization and, especially, incineration, in the Tyneside/Wearside area and to identify the most economic methods. The Unit was also asked to postulate alternative theoretical models to show the number and location of plants, the sequence of and installation, that would achieve to best economic results, taking into account regional priorities and the needs of a comprehensive programme of land reclamation.

The area concerned included approximately 100 existing collection rounds in a complicated population — distribution pattern and many possible sites for refuse plants. To find the answers, working models were devised along the following lines:

> ... to imitate the operation of a refuse-collection-and-disposal system in a geographical system representing Tyneside/Wearside. On being told how many plant, of what type are to be considered and where, the machine works out the total weekly cost of that particular arrangement. In this way, the cheaper arrangements could be found by a succession of trials.
>
> In practice, a second computer programme is used which has the ability, on being told how many plant of what type, to work out, automatically, the best places to put the plants to obtain the cheapest arrangement. By using this model and the earlier one together, it is possible to calculate the costs of systems using, say 2, 3, 4, 5, 6 and 7 *properly located* pulverisers, incinerators or controlled tips. The number of plants having the least cost can then be selected.

By changing the preliminary information given to the computer, it can be made to repeat these calculations for any date in the future, but the accuracy of its answers is only as good as the forecasts used to prepare the information and the assumptions inherent in the model.

A large-scale study has also been made in the Fresno area of California as part of a US Public Health Service Research Program.[12] The programme is intended to provide a scientifically based technology for improving the organization, operation and management of collection and disposal of solid wastes, avoiding the errors and inefficiency of the past and at the same time avoiding wastage of manpower or uneconomic use of vehicles, plant and machinery.

Another example of the application of operational research is in assessing the economic radius at which collecting vehicles can operate in known traffic conditions when considered against the cost of transfer loading.

The following quotation summarizes the position:[5]

Limited air, water, and land resources must be exploited to support man's increasing numbers and sharply growing demands at the same time that they are expected to assimilate the steadily expanding spectrum of wastes that he generates. How to control this assault of man upon himself ... is one of the greatest challenges of our era.

The best hope for the preservation of our environment and for lasting solutions in its management lies in the area of systems analysis and engineering.

It is again reiterated that with the vast sums of money now involved, both capital and operating costs, modern methodology, harnessing the best available techniques, must be adopted.

Critical path analysis. This technique is not so readily applicable to solid waste services as it is to some of the major manufacturing industries, but it can be useful in some of the larger municipal organizations. It is designed to achieve maximum productivity by planning and co-ordinating the work flow, to eliminate loss of throughput time by ensuring that all functions are performed in the correct sequence, and that the materials required are in their proper place at the right time. It is, therefore, suitable for application in vehicle repair shops and for new construction work such as coach-building.

EDUCATION AND TRAINING

The general public

A well-informed public can do much to help the smooth operation of a solid wastes service, particularly as regards refuse collection and street cleansing. As is so often the case, the best and most successful results are achieved by training children. Well-presented lectures in schools and organized visits to refuse-disposal sites, with perhaps a chance to ride on one of the vehicles, can arouse in children an enthusiasm and an understanding that they will probably never forget.

Advice to the adult members of the general public by means of talks, window displays and exhibitions on the work of a department can be invaluable. All too frequently, the public is not aware of the services that are available or, indeed, to which it is entitled. It is this kind of ignorance that leads to the indiscriminate dumping of refuse which not only offends the eye, but can also involve serious health hazards. Time, money and effort devoted to the education of the public in matters relating to the proper disposal of waste of all kinds will therefore be very worthwhile.

Senior executives

Although a number of institutes have been set up in various parts of the world to foster the work of solid-waste collection and disposal, very few of them are professional in character but in Great Britain professional examinations were first instituted over 50 years ago. These examinations are at present attracting more candidates than ever before because an intensified effort has been made to interest the advanced technical colleges in the subject, with the result that many have introduced training coures. In 1964, Professor George H. Deming of New York visited Europe, and Great Britain in particular, to study training schemes. In a report to the Division of Environmental Engineering and Food Protection, Bureau of State Services, US Public Health Service, Professor Deming stated:[3]

> The British system of further (higher) education at the junior, technical and area college level has made significant contributions to training of personnel for the public cleansing service and other governmental functions. In most instances, the program of the college has benefited greatly from close liaison with the professional association at the planning and operational stages.
>
> British training programs for public cleansing personnel have tended over the years to emphasize more and more a broad-based curriculum including the study of applied law, personnel management, and administration as well as technical and scientific preparation...
>
> Post-entry professional training for those seeking higher administrative posts is generally available in Great Britain. Such training opportunities are open normally to those who possess qualifications certified by professional certification as well as to those having educational prerequisites...

The authorities in the USA were not slow to act on this report and several universities are now running long-term courses. The Bureau of Solid Waste Management of the US Public Health Service has inaugurated short but comprehensive courses and the American Public Works Association has sponsored the formation of a new Institute for Solid Wastes which, it is understood, is likely to conduct professional examinations.

The World Health Organization also has arranged several training courses on this subject in the Region of the Americas, a Short Course on Solid Wastes Collection and Disposal in Damascus, Syria, in May 1968, and others are planned in various parts of the world.

Another form of training that has been successful in Great Britain is the indenture system. To indenture a person as a trainee involves a form of legal agreement by which the employing authority undertakes to provide the trainee with all the training he needs to qualify as a public cleansing officer and to allow him time off work with no loss of pay to attend courses at a technical college on at least 1 day a week in order to obtain mechanical engineering qualifications. The parents undertake to see that their son diligently applies himself to the training and further education. Under this system, a young man with a good educational background, whose scholastic achievements include an acceptable standard in mathematics, physics or chemistry, probably another science subject, and a good ability to communicate in English, both spoken and written, is accepted into a cleansing department as a trainee. He is indentured according to his age for between 3 and 5 years, during which time he receives training in all branches of the work undertaken by the department and he will be sent on visits to other cities. The trainee, for his part, must obtain a higher national certificate in mechanical engineering and, subsequently, pass the examination of the Institute of Public Cleansing. The engineering studies are undertaken partially during day-release from work and partially at evening classes. This kind of scheme has been in operation long enough to have proved its value and there are now a number of senior officers in various departments who started their careers in this way.

Junior executives

As in most undertakings, more personnel in junior than in senior executive grades are needed by waste-disposal services. These administrative, technical and supervisory officers, often the backbone of the service, are not all equipped to progress to higher grades, nor would many of them desire the degree of responsibility that further promotion would bring.

Nevertheless, the duties and functions of junior grades necessitate a standard of knowledge, particularly concerning the new techniques being introduced, that can only be obtained from a certain amount of training.

The Institute of Public Cleaning in Great Britain has accepted this fact and has taken steps to arrange for training courses.

The manual worker

An elaborately organized and directed service enjoying all the advantages of the latest scientific and engineering techniques will fail in its purpose if the manual worker does not perform his task efficiently. These men also require training. This training may be only a simple explanation of why the job has to be done or what the public (which pays) expects from the service. On the other hand, a bulldozer operator on a controlled tip may have worked formerly only on civil-engineering projects and as the techniques of dealing with refuse and of servicing the machines are very different, some special training may have to be given.

A short course of introductory training for manual workers employed in solid-waste services will probably be amply re-paid by their better co-operation and more effective work.

RESEARCH

The present position

Until very recently little or no attention had been paid to scientific research in the field of solid wastes but the need for this kind of research has now become apparent. The most outstanding example of the recognition of this need is the fact that the USA is spending $60 million on it over a period of 4 years. This appropriation was a direct result of the report of the Environmental Pollution Panel of the President's Science Advisory Committee.[14] Of 86 recommendations made, 47 were specifically related to studies, research and development, many of them in connexion with solid wastes.

The British Institute of Public Cleansing has for a number of years had a Research Committee which devotes itself to studying scientific aspects of the work and to publishing monographs in which the findings of these studies are reported. Recently, the governmental Working Party on Refuse Collection, in its report,[7] discussed the possibility of a refuse research centre and suggested that:

> Work on the composition of refuse requires painstaking analysis which could suitably be guided by statisticians; a costing review can best be undertaken by council treasurers in conjunction with cleansing officers ... design of on-site disposal methods and vehicles are engineering matters; and some matters could be for consultants.
>
> A research centre competent to tackle all these subjects and others related to them, including refuse disposal and street cleansing, would be large and expensive. ... If their experience showed that a research centre was necessary, they would be able to offer valuable advice on its scope.

It went on to recommend that:

> ... the right way to begin is for the Ministry of Housing and Local Government to appoint a small research committee who would keep themselves informed of any research projects on public cleansing which might be in progress, consider what might need to be done to ensure the success of worthwhile projects; decide what others ought to be undertaken, and co-operate with the Ministry and probably with the Ministry of Technology in getting desirable research undertaken by competent organisations.

In the Federal Republic of Germany, the Central Office for Waste Disposal, Federal Health Office,[a] has also set up a small research organization to deal with all aspects of solid wastes.

Subjects requiring investigation

Amongst the many subjects that should be investigated are three that are interrelated and basic. They are as follows:

Refuse analysis. To fully appreciate the problem, a new standard method is required that should be capable of assessing and analysing in detail the relative percentages of trade, industrial and domestic (including bulk refuse) wastes, their volumes and weight. The moisture content should be shown, as well as an indication of the weather conditions immediately before and during the period of analysis.

Intelligent appraisal, following detailed enquiries of the probable changes in the nature, weight and volume of refuse at, say, 5- or 10-year intervals over the next 30 years should then be made, taking account of both improving living standards and population growth.

The cost in terms of manpower and finance, if a major breakthrough (comparable, perhaps, with the development of water-carriage of sewage) is not achieved should be estimated. This should take note of the present, and probable future, percentage of total available manpower that the service absorbs, and the way that future costs are likely to rise according to (1) higher standards of education resulting in fewer people being willing to undertake unskilled tasks so that a premium value is put on labour; (2) normal wage increases; (3) a shorter working week and longer paid holidays, a trend that is inevitable with the greater use of automation in industry.

When the results of such an investigation are available, it will probably be shown that a system that may now be regarded as a very expensive capital project is, in fact, a sound, forward-looking investment.

Other subjects for investigation. A list of some other subjects for investigation is given below; a number have already been mentioned.

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[a] Zentralstelle für Abfallbeseitigung beim Bundesgesundheitsamt.

(1) The ratio of cost increase to collection frequency.

(2) The degree to which the frequency of collection affects the volume collected.

(3) Accurate comparative costs for the various methods of refuse disposal.

(4) Efficient on-site methods of dealing with solid wastes at holiday camps.

(5) Multi-storey dwellings: on-site compaction and on-site grinding.

(6) Behaviour of plastic refuse sacks on tips.

(7) The relative effectiveness of different forms of pulverization and their operational costs.

(8) Tipping of pulverized refuse: (*a*) rate of temperature rise; (*b*) period required for ultimate stabilization; (*c*) need for covering material with pulverized refuse.

(9) Research into the relationship of the cost of long-distance transportation of refuse balanced against the improved capital value of the derelict land that could be recovered

(10) Incinerators: (*a*) optimum and minimum economic size; (*b*) effect of varying operational periods on refractory linings; (*c*) gas-cooling methods — cost/efficiency ratio; (*d*) air-cleaning methods — cost/efficiency ratio; (*e*) heat utilization for drying sewage sludge, new methods of incinerating solid waste, etc.

(11) Research into the possible increase of incineration throughput, in terms of weight per unit of grade area, if refuse is first pulverized. Would different methods of feeding such refuse, refuse over the grade, e.g., blowing the pulverized achieve better results?

(12) Macerated water-borne refuse: specific gravity in relation to fall and diameter of pipeline; volume of water required.

(13) What is the percentage of additional capital cost that should be charged against a permanent dwelling in which is incorporated a new labour-saving solid-waste system? Should any percentage be borne by the local authority? This involves finance, data, amortization rates, estimates of average labour costs over a period of several decades, etc.

(14) What particular constituent or constituents of refuse could be made bio-degradable, and what proportion of total refuse would this be? Here, much detailed investigation into the origin of the waste and the purpose for which it had been used, would be needed.

(15) Management aids: the extent to which systems analysis, systems engineering and value engineering can be used.

INTERNATIONAL CO-OPERATION

An adequate system for the collection and disposal of solid wastes is a fundamental public health requirement. Without such a service, the incidence of pollution and the rapid breeding of disease vectors such as flies and rodents could result in an intolerable burden being placed upon the medical services. But the rapidity with which the waste problem is growing, not only in size but also in complexity, is now causing concern in many countries, both developed and developing. Lack of disposal sites or facilities, the ever-increasing quantities, variety and volume of the wastes, together with demands on financial and manpower resources that are now becoming difficult to meet, are all factors contributing to the this serious situations. In most cases, local resources are quite inadequate for broad-based programmes of research and training to be undertaken and it is in this field that assistance is required.

The position has already been understood at international levels and some serious attempts are being made to help. The International Association of Public Cleaning (INTAPUC), an organization now having members from most of the major countries, promotes an international conference at 4-yearly intervals, at which papers are read and discussions take place on refuse problems in various parts of the world and the steps that are being taken to effect a solution. The proceedings are published in 3 languages and are excellent works of reference. The Association also translates and publishes details of the research work published in various languages. INTAPUC hopes eventually, using accumulated funds, to grant scholarships to promising young officers who would benefit by a period of training in another country.

The International Research Group on Refuse Disposal (IRGR) is another body which until now has dealt exclusively with refuse disposal and also holds conferences on problems connected with refuse disposal at 4-yearly intervals. These conferences are arranged to alternate with those organized by INTAPUC. Agreement has recently been reached on a constitution under which the two organizations will be merged to form the International Solid Wastes and Public Cleansing Association (ISWA).[a] This development should result in full co-operation between scientists and practising public health engineers (or whatever other title they may be given) and thereby assist materially in the general endeavour to improve services.

Other forms of international co-operation with developing countries might include (1) the arrangement of lecture courses, including, if possible, some practical demonstrations; (2) inter-regional conferences of a few

[a] The two bodies will amalgamate to become the International Solid Wastes and Public Cleansing Association on 1 January 1970. — ED.

senior officers from each of two or three regions at which exchanges of information on common problems could take place; (3) regional training courses for promising junior officers — perhaps leading to more advanced fellowships for the best students; (4) the organization of short visits by small teams of experts; and (5) the installation in a suitable township or suburb of a "model" system that could be used as a demonstration centre.

In developed countries, inter-regional conferences and study groups might be organized to exchange information and to study and criticize developing projects.

If some or all of these new approaches succeed they will be of immense value, particularly to the developing countries. While the circumstances and problems in most countries will differ in certain respects, most of the same principles will apply. With sound advice and adequate technical assistance, the developing countries will be enabled to move on to more hygienically and scientifically based systems without passing through some of the intermediate phases that in many developed countries have proved so costly and often, particularly in respect of pollution, hazardous.

Reference centres

A WHO International Reference Centre has recently been designated at the Federal Institute for Water Supply, Sewage Purification and Water Pollution Control, Zurich, Switzerland[a] and the later establishment of national and regional reference centres, each co-ordinating its work and collaborating fully through the International Reference Centre, will ensure that data and reports of research and other investigations are quickly made available in all countries.

Among the many functions of the WHO International Reference Centre are the following:

(1) To collect, evaluate and disseminate technical and scientific information on wastes-disposal practices.

(2) To test the practical usefulness of new methods and procedures evolved for the collection, processing, re-use or disposal of liquid and solid wastes.

(3) To conduct research investigations, experiments, pilot demonstrations and other studies on wastes-disposal practices.

(4) To collaborate with, and give the maximum of technical assistance to, WHO regional reference centres and national reference centres that

[a] World Health Organization (1968) *WHO International Reference Centre for Wastes Disposal* (unpublished document WHO/WD/68.4 Rev. 1).

may be set up in the future and other national institutes and laboratories studying methods for treating and disposing of wastes.

(5) To train personnel, particularly for developing countries, and to prepare manuals for training courses, seminars, and field developmental investigations in waste-disposal techniques.

Thus, by facilitating the exchange of information on successful practices and by eliminating duplication of effort, the Centre will contribute to the most efficient use of the limited number of scientific, technical and administrative personnel at present employed in wastes-management work.

CONCLUSIONS

The wide range of subjects mentioned in this chapter as warranting research or investigation is, though not complete, a sufficient indication of the size of the problem. Many developed countries are now fully aware of the need for more research and better dissemination of information on matters concerning the disposal of wastes, and some countries are already taking action. It should be remembered that an intelligent inquiry into the causes of failure will often teach more than a successful outcome in some particular scheme.

However, adequate finance is a major requirement for research and determines the extent to which a certain study or investigation can be developed. Both national governments and international organizations can help in this respect and the establishment of regional, national and international reference centres, by fostering research and disseminating information, will meet a need that has been retarding progress for too long.

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REGIONAL APPROACH TO INTEGRATED WASTES MANAGEMENT PLANNING

J. SUMNER[a]

The possibilities of dealing with liquid and solid wastes in an integrated service are discussed in outline in this chapter. The types of waste to be considered are domestic sewage and similar liquid wastes normally accepted into public sewers, and domestic solid waste and commercial waste of a similar nature. Toxic wastes, both liquid and solid, and other special categories of agricultural and industrial waste would need special consideration.

REGIONAL APPLICATION

From both a technical and an economic point of view there is a limit to the distance over which both liquid and solid wastes may reasonably be transported. For sewage, there is normally little to be said in favour of providing long lengths of unproductive sewer merely to centralize sewage treatment at one site. There is little economic sense in transporting liquid wastes in sewers over long distances when this could be done, after treatment, by a river or stream. From the point of view of river management it is normally better to discharge treated effluent into a stream in smaller quantities at a few points than to discharge large quantities at a single point. This does not mean that a single plant is never a much better answer than a number of smaller ones; in the right conditions, it is. As a general rule, however, it is suggested that sewers should not normally be extended outside the urban area they serve. A possible maximum distance might be about 5 miles (8 km); certainly no more than 10 miles (16 km) except where there are special local circumstances.

Present methods of transporting solid wastes to the final treatment or disposal points involve carriage by road, rail and barge. Transportation by road is the most popular means, and refuse is carried for distances of up to about 20 miles (32 km), either in ordinary collecting vehicles or

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in bulk-haulage vehicles after reloading. Barges are used in suitable circumstances for similar or greater distances. Transport by rail has never been very popular and on the whole has proved to be inflexible and fairly expensive, but it can be used.

The distance that solid waste is transported for final disposal will normally depend on the cost of transportation and the probable cost of dealing with the waste without further treatment (by controlled tipping or sanitary land-fill) compared with the cost of incineration or composting in plant located within the area of collection, and the eventual disposal of the residues. Assuming that facilities exist for disposing of solid wastes by controlled tipping, it follows that any system of integrated waste disposal should preferably not be more expensive than treating and disposing of the two wastes separately by conventional methods would be, unless there are special compensating advantages in an integrated system.

It seems quite clear that any system involving the combined treatment of sewage and solid waste at a single site will not cost less to operate (in terms of cost per ton) than the incineration of solid waste separately. Therefore, regionalization of the service (in terms of solid-waste disposal). should be limited by the extent to which solid waste can be delivered economically to the site for combined treatment without transfer-loading into secondary transport. The average maximum distance that refuse-collecting vehicles might be expected to travel to the disposal point would be 5 miles (8 km). This distance is the same as that suggested for transportation of liquid wastes.

Transporting both liquid and solid wastes for distances of about 5 miles (8 km) would, in an urban area, meet the requirement of a population of about 1 million persons. A service for a population of this size might very well represent the maximum capacity that should be provided in any single combined treatment plant and, on balance 2 or 3 smaller plants with the same total capacity would probably be favoured, depending on local topography and other conditions. In very large cities, a number of plants with capacities equivalent to the waste output of about 1 million persons would be required.

From an administrative point of view there appears to be no case in urban areas for the jurisdiction of the controlling authority to extend beyond that in which the technical facilities for disposal of wastes are found. In rural areas, however, it may be necessary for the controlling authority to have jurisdiction over much wider areas in order to justify the employment of adequately paid and properly trained and qualified staff, including maintenance staff.

COMBINED TREATMENT OF SEWAGE AND SOLID WASTES

If solid wastes are to be delivered to the combined disposal site by road, then integration of treatment and disposal is limited to (1) composting the solid waste with sewage sludge arising from conventional methods of sewage treatment and (2) incineration of sewage sludge together with solid waste.

Composting

Mechanical composting of waste materials is already carried out in several countries. It is first necessary to sort the solid waste to remove metals, glass, plastics, stones, etc., or to pulverize it so that hard inert materials are finely ground to a powder. Depending on the relative composition of the solid waste, as much as half of it by weight may not be compostable; this fraction has either to be tipped (disposal in sanitary land-fill) or incinerated.

Methods of mechanical composting are fairly complex. They range from attrition of the suitable fraction of solid wastes in revolving drums using sewage sludge to provide the moisture necessary for the metabolism of the micro-organisms responsible for breaking down the organic matter, to a type of digestion in static tanks or towers provided with some means of agitation. In all systems, aerobic fermentation is encouraged by providing a controlled supply of air, and grinding is usually necessary either before or after the composting.

There is controversy in many countries about this system of integrated waste disposal, in which it is necessary first to de-water the sewage sludge in order to incorporate all of it into the solid wastes arising from the same community. The system is claimed to be successful in some countries but in others it is reported to have failed economically. Generally, compost produced from town wastes is not in great demand; its value is as a humus or soil conditioner but the content of plant nutrients is not very significant and some anxiety has been expressed about possible toxic conditions produced in soils by continued application of municipal composts. Demand is likely to be seasonal, and substantial storage capacity is usually necessary. The cost of disposing of solid waste by composting can be high; even higher than by other methods. The present trend for solid waste to increase in volume and to contain more and more paper, plastics, metals and glass, will tend to operate against the use of this system.

Incineration

Some incineration of sewage sludge is carried out but it is on a limited scale because it is expensive in comparison with other methods of disposal.

Where it is practised, the sludge is usually de-watered in the first place by mechanical methods and heat is applied only when the moisture content has been reduced to less than 50 % or 60 %. Raw sludge has a calorific value of about 5000–6000 Btu/lb (2777–3333 kcal/kg) of dry solids and with a sufficiently low moisture content this is more than sufficient to support incineration without assistance from other fuels. At a temperature of 1400° F (760° C) sludge can be incinerated without odour nuisance and the volume is reduced (from that of raw sludge) by over 90 %.

Solid wastes also have sufficiently high calorific values (3000–45000 Btu/lb (1666–2500 kcal/kg) to support incineration without assistance and this method is used in a number of towns and, especially, large cities in several countries. In the modern incinerators now available, the waste is reduced to an almost inert residue equal to about 15 % of the original volume and 35 % – 40 % of the original weight. In some cases, the heat is utilized directly for heating buildings, etc., or for generating electricity, but it is doubtful whether this is always done economically.

To incinerate sewage sludge together with solid wastes of the type considered here, it is desirable that the sludge should be pre-dried as much as possible. If it could be dried to a moisture content of about 40 % the calorific value of the solid waste would be improved and there would consequently be more heat released during the incineration and a higher ratio of sludge to solid waste could be used. In practice, a sludge with high calorific value (high volatile content) might be satisfactorily incinerated if it contained up to 65 % of moisture but a sludge with a low calorific value would need to be dried to about 35 % of moisture. One way to do this might be first to de-water the sludge to a moisture content of about 70 % and then, before incineration, reduce the moisture to 40 % or 50 % using some of the heat produced by incineration. The heat-drying might involve difficulties with sludge caking on driers but if a moisture content of 40 % – 50 % could be achieved, it should then be possible to mix the sludge with solid waste in storage hoppers, using a grab to feed the incinerators.

Alternatively, the heat from a conventional solid-waste incinerator might be used to dry, and subsequently incinerate, sludge in a conventional sludge-incinerator installed in line. For the two kinds of waste arising from the same community, this appears to be a practicable scheme with sludge containing about 92 % moisture without any other source of heat. For smaller quantities it would be practicable to pulverize solid waste and feed it together with wet sludge into a conventional sludge-incinerator, though in this case some assistance from another heat source might be necessary. These possibilities have not been considered further, nor has the effect of such a system on any other possible method of utilizing heat from the incineration of waste, but the probable advantages of dealing with sludge and solid waste together in this way would appear to be a saving in other costly methods of de-watering and drying sludge and a large reduction in the volume finally to be disposed of — probably by tipping. Further investigation would be required to ascertain whether there would be any over-all financial saving.

ALTERNATIVE METHODS OF TRANSPORTING SOLID WASTES

As the difficulties of collecting solid wastes by traditional methods increase owing to labour shortages and traffic congestion, and as the public demand for improved methods of storing and collecting refuse increases, it becomes necessary to consider alternative ways of conveying solid wastes to some central treatment or disposal point. Apart from on-site incineration, which now requires re-appraisal in relation to the control of air pollution, the only practical alternative appears to be to convey wastes in pipes, either hydraulically or pneumatically.

Discharge of solid waste into sewers

To a very limited extent, solid waste is already being discharged into sewers. Where it is permitted, this practice is limited to the disposal of organic wastes (mainly kitchen wastes) by grinding them in a small machine fitted below a kitchen sink and then flushing the ground material into the sewerage system. The fraction of solid waste dealt with in this way averages no more than 15 % by weight of the total waste produced by an average family and thus constitutes no more than what one might call a "fringe benefit". It is no solution to the problem since the remaining 85 % has to be dealt with in other, more conventional, ways.

Domestic solid wastes mainly consist of vegetable matter, paper, cardboard, metals, glass, plastics and mineral matter (ash, etc.). Because of their high densities, metals, glass, stones, ash, etc., would not readily be conveyed hydraulically in gravity sewers. Subject to adequate grinding before their discharge (machines more efficient than those now in use would have to be designed), it is thought that paper, cardboard, vegetable and organic material could be discharged and conveyed in sewers (except perhaps in separate sewerage systems) without any great difficulty; but plastics would be excluded.

Based on a probable average output in 10 years time of 2 lb (about 1 kg) of domestic solid waste per person per day, containing more and more paper, plastics, metals, etc., and less ash, the amount discharged into sewers might be 1 ½ lb (0.7 kg) per person per day at an average moisture content of 30 %, i.e., about 1 lb (0.45 kg) dry weight per person. This, on the same basis, compares with 0.15 lb (0.07 kg) per person of dry solids in sewage sludge.

This would then be a reasonably acceptable solution for the removal of solid wastes from buildings; only 25 % by weight (and much less by volume) would remain to be collected perhaps once a month or even less often, depending on the storage facilities available. Of course, other bulky solid waste such as discarded furniture, washing machines, refrigerators, etc., would need to be collected in the same way as before. However, the volume and weight of sludge to be dealt with at the treatment works would increase by 6 times, apart from substantial increases in the organic and chemical pollutants in the water which seem probable. While conventional methods of sewage treatment would perhaps still be applicable, the capacity of the plant would need to be increased, approximately in proportion to the added load.

The principal difficulty in conventional sewage treatment today is probably the satisfactory treatment and disposal of sludge and if the amount were to be increased by 6 times, the increase would need to be justified on other grounds. One advantage could be that the sludge would dry more easily since the contribution from the solid waste would be mainly organic. But perhaps the greatest advantage would be largely to eliminate the present methods of collecting and storing solid wastes.

Can this dual system be economically justified? The least expensive method of treating and disposing of sludge is to spread it in a liquid state on land after digestion. When this can be done, it appears to cost about £8 – £9 per dry ton for final disposal only. On the same basis, the cost of conventional methods of refuse collection and disposal might be little more than half. It seems unlikely, therefore, that the disposal of solid wastes by discharge into sewers will be acceptable unless and until the difference in costs can be considerably reduced. When this might be cannot at present be foreseen but in some countries the shortage of labour and traffic congestion on the roads may make it necessary to adopt alternative solutions, along the lines suggested here.

Pneumatic conveyance of solid wastes

This is a more radical approach to the conveyance of solid wastes. It involves the installation of a separate pipeline system and, to that extent, integration with the liquid-waste transportation system is not achieved; but integration could follow at the disposal point, at least to the same extent as with any other method of conveying each waste separately.

Refuse is moved by vacuum-suction along pipes up to 2 ft (50–60 cm) in diameter that are connected by valves to vertical chutes or other devices in buildings, into which the residents place their solid wastes. Turbines create the vacuum-suction in the pipes when valves are opened. Waste is removed as necessary throughout the day and transmitted to the disposal point. In Sweden, where the system was originally developed, pipelines of 8200 ft (2500 m) and over are planned.

There is, of course, no need to separate solids from water; all that is necessary is the provision of a suitable filter to arrest dust and grit before the exhaust air is discharged into the atmosphere. This is a principal advantage, but another is the apparent ability of the system (based on limited experiment only) to deal with all solid domestic waste, except very heavy and bulky items.

A disadvantage is capital outlay since a new and entirely separate pipeline system is required. For this reason, pneumatic conveyance could at this stage be considered only for installation in new towns or in redeveloped areas of old towns. Subject to more experimentation, however, pneumatic conveyance may prove to be a more desirable (though more expensive) solution to problems inherent in present methods of collecting solid waste, the cost of which will continue to increase, or in the discharge of solid wastes into sewers which, at best, will only deal with about 75 % of the output of solid waste.

CONCLUSIONS

The present trend is for domestic solid waste to increase in quantity and to change in character and, since the trend is expected to continue, the use of composting as a method of dealing with refuse and sewage sludge in combination is likely to fall while the use of incineration rises. Thus there appears to be a case for further investigation into possible methods of incinerating sewage sludge together with solid domestic waste.

The use of sewers to convey solid waste (after adequate grinding) might be practicable for about 75 % of it, plastics being excluded, but the difficulties and cost of the subsequent treatment of the water and, more particularly, the sludge could render the scheme unattractive to municipalities. There might be a case, however, for considering further the possibilities of conveying solid wastes pneumatically for subsequent combined treatment with sewage sludge.

Any integrated system of dealing with wastes is likely to receive more careful appraisal when it is considered on a regional basis but there are limits to the extent to which regionalization of these environmental health services is practicable.

PRESENT TRENDS IN RESEARCH ON WATER AND SEWAGE

PROFESSOR O. JAAG[a]

The development of processes for the protection of water and the purification of sewage is following a number of clearly defined trends. In this chapter, some of the more important trends are described.

EVALUATION OF THE DEGREE OF POLLUTION OF A BODY OF WATER

In recent years there has been increased discussion in all parts of the world on general considerations concerning the assessment of pollution in a body of water, on methods of evaluation and on the graphic representation of such pollution. Actually, the saprobic system, established empirically on the basis of numerous observations by Kolkwitz & Marsson [4] and revised by Liebmann,[5] should be submitted to a thorough analysis and be supported by the findings of experimental research. It is of particular importance to establish a sensible and reliable relationship between the biocenosis and the chemistry of a body of water.[3] Moreover, the circumstances under which such a method of evaluation may be applied should be indicated more clearly than has been done so far. Although the saprobic system was established originally for running waters only, Kolkwitz himself subsequently applied to stagnant waters the formulae he had developed for various degrees of pollution. How far this transposition is justifiable should be determined by thorough investigations.

The saprobic system should be submitted to further analysis, especially with respect to the biological role of particular plants and animals. Certain important problems concerning the determination of substances harmful to, or restricting the development of, particular organisms also require investigation. It was also shown by Ambühl[1] and Zimmermann[10]

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independently that the effects of currents on the ecology have not been given adequate attention in the analysis of polluted water.

Generally speaking, the biological picture should be studied as a whole and the interdependence of nutritional and environmental factors should be clarified experimentally for each form of life characteristic of a given saprobic stage. In Europe, these problems have already been considered in the course of a number of scientific meetings of which the following were some of the more important:

(1) The symposium on the saprobic system held at the Italian Institute of Hydrobiology, Pallanza, Italy, from 25 March to 27 March 1963.

(2) The International Congress of Limnologists held in Warsaw, Poland, in August 1965.

(3) The symposium on "Problems of Saprobity" convened at the School of Chemistry and Technology in Prague, Czechoslovakia, on 25 April 1966.

Efforts are now being made to develop a better knowledge of the biological and chemical processes occurring in polluted water so that the degree of pollution of a body of water may be more accurately evaluated. Moreover, the necessity for uniformity in expressing the degree of pollution must be stressed. Basic documents for this purpose were designed some years ago.[5]

The saprobic system in its present form contains excessively long lists of organisms for the 4 types of water quality. Not only are the names of representative plants and animals included in the lists but also those of a number of less significant organisms. Consequently, the system as a whole should be revised and condensed.

CAUSES AND EFFECTS OF THE EUTROPHICATION OF BODIES OF WATER

Water pollution, and more particularly the pollution of lakes, is finally related to the destruction of their chemical and biological balance. The quantity of organic matter derived from large numbers of plants and animals growing in a lake may exceed the potentialities for its degradation under natural conditions, that is to say, aerobically. The mineralization process is thus anaerobic and leads to the production of toxic substances such as hydrogen sulfide, ammonia and methane that transform the lower levels of the lake into a lifeless environment.

For the time being, there are still major differences of opinion about the nature of the eutrophizing substances, more particularly with respect to their origin and significance. Some authors consider phosphorus compounds to be determinant and restrictive in the production of plant life, while others believe that nitrogen compounds are just as harmful and responsible for eutrophication and its subsequent effects. More recently, however, substances other than those already mentioned have been implicated in the increased production of organisms in stagnant waters; they include vitamins, hormones and other growth-promoting substances.

In assessing eutrophication, special attention should be given to a detailed analysis of the chemical substances involved and of the physical conditions that promote their activity. There is already much information in the literature on the role of particular substances or groups of substances in regulating biological production. However, the factors responsible for promoting the growth of algae must be more accurately identified and classified on the basis of actual experiments.

Once the growth-promoting effect of particular compounds and groups of substances has been clarified, the origin of the nutrients themselves should be investigated. This will involve a study of the eutrophizing substances as a whole, and also of the contributions made to the total amount by (1) the natural erosion of rocks; (2) agricultural practices; (3) woods and desert regions; and (4) domestic and industrial waste water.

Although phosphorus and nitrogen compounds can be eliminated to a large extent from the effluents of water purification plants, there is little that can be done to limit the discharge of eutrophizing substances into bodies of water in agricultural areas, nor can any control be exercised on eutrophication nutrients derived from natural erosion.

TECHNIQUES FOR THE REMOVAL OF NUTRIENTS

The technical bases for the removal of nitrogen and phosphorus compounds from water are widely known today and have been fully tested. However, some practical details and a few questions concerning the applicability of the processes have not yet been fully clarified. Some of these are now discussed.

Removal of phosphorus

In sewage that has undergone preliminary treatment, a total phosphorus content of 6 mg – 10 mg per litre is to be expected under prevailing conditions in Switzerland. After biological filtration, some 3 mg – 7 mg of phosphorus per litre remain in the effluent, of which 85 % is orthophosphate. Thus, between 20 % and 40 % of the phosphorus is removed and well over half the original amount is left in the effluent. The only methods available at present for the complete removal of phosphorus are based on chemical precipitation processes. For this purpose, the cations Fe^{3+}, Al^{3+} and Ca^{2+} are the most important, since they form almost-insoluble phosphate salts. The use of 20 mg – 30 mg of Fe^{3+} per litre of water leads to the removal of 95 % of the total phosphorus while the pH is maintained at 7.5. In the USA similar reductions have been obtained with 20 mg/l of Al^{3+}.

Both Fe^{3+} and Al^{3+} can be used in simultaneous or in subsequent precipitation. By simultaneous precipitation is meant the addition of the precipitant directly to the aeration tank or to its effluents. Subsequent precipitation of the biologically purified sewage which has undergone secondary treatment takes place in special sedimentation tanks (cyclators). So far, there are no experimental results for simultaneous precipitation with aluminium. However, the Fe^{3+} method has been applied in practice [6] and in specific comparative investigations in which strict comparisons with the subsequent precipitation method were made.[9] With 30 mg/l of Fe^{3+}, subsequent precipitation yielded an effluent with a total phosphorus content of 0.26 mg/l (95 % elimination), whereas simultaneous precipitation eliminated 87 %. It appears, therefore, that subsequent precipitation makes better use of the precipitant than does simultaneous precipitation but, compared with the biological method, precipitation with 30 mg/l of Fe^{3+} yields twice the volume of sludge. Subsequent precipitation produces a large volume of hydroxide sludge that is difficult to handle and for which no suitable de-watering process has as yet been devised.

Phosphate can also be largely eliminated with Ca^{2+} but this method calls for a pH of 10.5. which requires large amounts of $Ca(OH)_2$ if the water is very hard. Detailed investigations made by Professor K. Wuhrmann have shown that under existing conditions in Zurich, for example, a combined precipitation with Fe^{3+} and lime can yield excellent results and the amount of sludge produced is much lower than that produced by Fe^{3+} or lime alone.

Taking the cost of the process and the difficulties of operation into consideration, combined precipitation with Fe^{3+} and lime is probably the most advantageous method available today. However, this applies only to a subsequent precipitation process and therefore investment in additional precipitation plant is required.

Removal of nitrogen

For the removal of nitrogen from sewage the only biological means available is microbial denitrification.[8] Prolonged retention of sludge first promotes the transformation of most nitrogen compounds into nitrates or nitrites; in a subsequent anaerobic stage, nitrates and nitrites are reduced to elementary nitrogen by respiratory processes.

All treatments applied to the effluents of sewage plants to reduce their nutrient content entail an increase in the cost of sewage disposal, both in respect of capital and operational costs. On the basis of cost estimates made by Hanisch [2] and from data supplied by Swiss treatment plants, Professor Wuhrmann has computed the operational costs. The prerequisites were total biological purification of the sewage with a 5-day biochemical oxygen demand (BOD_5) in the effluent of about 15 mg/l and reduction of total nitrogen and total phosphorus to a maximum of 3 mg/l and 0.5 mg/l, respectively. Denitrification to this level involves only a negligible rise in cost, whereas the elimination of phosphorus by any means is considerably more costly. The difference in operational costs entailed by the removal of phosphorus through simultaneous or subsequent precipitation lies within the margin of error provided by this estimate. According to Professor Wuhrmann, the total removal of nutrients in a subsequent stage, with all the additional advantages of a lower degree of organic pollution in the final effluent, would entail a 50 % rise in the annual operational costs of a traditional sewage plant. Hence, on the basis of actual operational costs, removal of nutrients involves a 65 % – 75 % increase in total costs.

As for the general problem of eutrophication and its prevention, the Organization for Economic Co-operation and Development (OECD) has already launched a far-reaching survey.

OECD invited Dr R. A. Vollenweider, an expert in the field, to collect and review the available literature and to report on the problems connected with the presence of phosphorus and nitrogen and their relation to eutrophication. Unlike earlier publications, this report deals with eutrophication from a quantitative point of view and Vollenweider[7] concludes that eutrophication is to be considered as a world-wide problem. Eutrophication is due not only to rapid population growth and increases in the population density, but it is the result of intensified human activities in general. Therefore, it is very likely that almost all bodies of water will soon be affected. In the discussion on ways and means to arrest this development, due regard is given to the elimination of phosphorus and nitrogen from waste waters. A review of the situation at the present time indicates that elimination of phosphorus and nitrogen from effluents will be only one step in a series of remedial measures. Emphasis should be given to comprehensive management of water resources in the broadest sense rather than to an attack on some discrete sources of pollution.

TREATMENT OF SEWAGE SLUDGE

A fourth problem calling for swift action and a satisfactory solution is the safe disposal of sewage sludge. The agricultural utilization of both fresh sludge from the settling tanks and activated sludge from the digestion tanks of treatment plants is meeting increasing difficulties on account of the insanitary condition of the sludge. Ways and means must therefore be found to disinfect the sludge or to provide for its incineration. Partial solutions have already been devised but a few vital problems still call for careful study.

At present, heat treatment of sludge is the method of choice. However, there may be other ways, possibly less expensive, that would lead to the same results. De-watering, of either the fresh or the digested sludge, is no doubt a special problem in this respect since a certain degree of drying is required both for composting and for incineration. A variety of de-watering and drying systems are in use at present and research is needed on ways of making these methods safer and more economical.

In many parts of the world, there is increasing awareness that supplies of safe water, or of water that can be treated for re-use, are not inexhaustible and that they should be used with great care if they are to continue to meet the many and various demands made on them. Long-distance water pipelines are an unmistakable indication of the present situation and the requirements of industry and municipalities for safe water are increasing year by year.

Consequently, research on water resources and water economy should stress the urgency of the problem. Municipalities and industries must be made aware of *the need to limit, as far as possible, the amounts of water they use* so that all centres of production and residential areas may be supplied with adequate quantities of water of a satisfactory quality. A number of industries, steel works for instance, have already found an acceptable solution in the recycling of used water. Similar water-saving schemes should be considered for all branches of industry and applied wherever possible.

At the same time, efforts must be continued to obtain potable water for community supply from salt water. At present the cost of desalination is still too high. However current research in various parts of the world should eventually lead to a process that could supply water for drinking and for community use at a price corresponding to that paid for water obtained from surface or ground-water sources.

Artificial rain, retention weirs for municipal and industrial water, reduc tion of evaporation from reservoirs and the recharge of ground water aquifers from surface water run-off, are some of the ways in which the general problems of ensuring adequate supplies of good water may be solved.

As far as the treatment of sewage is concerned, measures have already been taken in many places to facilitate microbial degradation processes by asking specific industries to manufacture "soft" rather than "hard" detergents. New research is required, however, on the mineralization and removal from waste water of substances derived from the chemical industries that cannot easily be degraded. Similar problems arise in protecting drinking water and community water supplies from insecticides, fungicides and herbicides that are injurious to health but widely used in most parts of the world.

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ADVANCED TREATMENT OF WASTE WATER: RESEARCH NEEDS

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The needs for waste-water management and research vary widely throughout the world, depending upon (1) density of population; (2) intensity and extent of industrial development; (3) climate and topography and the resulting availability of water resources; (4) economic development; and (5) the level of training and education of technical personnel. Consequently, no single programme of research will be suitable for all countries. The research discussed in this chapter is intended to serve as a catalogue of needs from which specific activities may be selected and adapted to local situations. Problems may be identified and thereby provide a basis for a discussion of research needs and help to suggest other critical fields of research. This chapter is not intended to be exhaustive or limiting, but rather to provide a preliminary exploration of the extensive research required for the management of waste water in various parts of the world.

REDUCING COSTS OF WASTE-WATER DISPOSAL

Many countries of the world are only now beginning to provide community water supplies on a large scale. Sewerage and the treatment of waste water become problems when a piped water supply is made available. Many communities, large and small, do not yet have engineered systems for the collection of waste water and no treatment facilities of any kind. Here, one of the greatest needs for research lies in adapting the knowledge now available in the fields of sewage and waste-water treatment and disposal to the economic and manpower resources of the developing countries.[18] The simple exportation of technology from developed areas of the world to the newly developing regions is likely to prove far too expensive for a rapid and economical solution of the waste-water

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problem. Therefore, research is required to reduce the costs of collecting and disposing of waste water so that the largest number of persons can be provided with this service rapidly and at the lowest possible cost.

Sewerage

Examples of approaches that might be considered are the use of low-cost materials, including plastics, for sewerage. One interesting idea that offers considerable promise in tropical regions is the use of plastic pipe for sewering effluents from aqua-privies, with the latter providing for the removal of settleable solids, so that the sewers need not be designed to maintain the high velocities of flow required in conventional sewerage systems.[18] This allows the sewers to be installed at much flatter gradients and to be operated flowing full so that uniform gradients are not necessary. This type of system costs considerably less than conventional sewerage.

In areas where a completely new sewerage system is required and where plumbing systems have not yet been installed, investigations might be made into the possible separation of various classes of waste within the housing unit, so that faecal material can be separated from waste water and disposed of separately. In Sweden and Mexico, a separate vacuum system has been introduced for these wastes, thereby reducing the consumption of water and permitting waste water that is free from faecal material to be readily re-used.

Stabilization basins

One of the most widely adopted solutions to the low-cost management of waste water has been the use of stabilization basins, known also as lagoons or oxidation ponds. Although they have been extensively used in industrialized countries in situations where the area available is large and where communities are small, stabilization basins can also be useful in countries where economic resources are limited, since they require a minimum of mechanical equipment and can be installed with hand labour alone. However, inasmuch as the energy input to such basins is derived from sunlight and wind, it is clear that research would be needed in each area where the use of such basins is being considered, so that loadings and size of units can be adapted to the local climatic conditions.

Conventional treatment

For large communities and where climatic and topographical conditions are unsuitable for stabilization basins, more conventional types of treatment facilities may need to be introduced. In industrialized countries, the use of mechanical equipment for saving labour is easily justified since it has been estimated that an investment of about $250,000 would eliminate the need for 1 employee for 24 hours.[7] For developing countries, on the other hand, the cost of mechanical devices tends to be high, and requires foreign currencies that may not be available, whereas labour is generally plentiful and the cost low. It would therefore be appropriate in such countries to adapt treatment methods to designs requiring a minimum of mechanization. Also, under these circumstances, it becomes feasible to take more time for treatment in order to achieve greater efficiency. In industrialized countries research efforts have been devoted to limiting the size of treatment plant in order to improve the economy of the treatment. The size of installations is generally not a serious problem in a developing country where units are not being equipped with mechanical devices. A fruitful avenue of research, therefore, would be the development of conventional methods of treatment at the lowest cost. For example, it would not be inappropriate to improve the design of Imhoff tanks and intermittent sand filters. These are generally too expensive for industrialized countries and accordingly very little research has been done on these time-honoured, but largely abandoned, methods of treatment.

Regulation of flow

In general, treatment facilities are designed to protect receiving waters during periods of reduced flow which may be of short duration and may occur infrequently. Treatment requirements may be reduced by regulating river flow by the use of impoundments or, more economically, by regulating the discharge of waste water through regulating basins. Discharge may be reduced or cut off entirely during periods of reduced flow or during periods of intensive stream use — for recreational purposes, for example. The accumulated waste water would be discharged during periods of high flow or at times when lower standards of water quality were acceptable. Such an operation can be made almost fully automatic by monitoring the flow and quality parameters of a receiving stream to control the quantity and quality of the waste to be discharged.[8]

Solutions of this kind depend upon accurate knowledge of flow and quality characteristics of both the waste water and the receiving streams. These characteristics vary widely at different times and different places, and considerable research is required to determine these important factors when facilities are being designed for a new area.

Disposal at sea

For communities located on or near the coast, allowing waste-water to flow into the sea offers an economical method of disposal as long as it can be done without interfering with other uses of the coastline and nearby waters. However, outfalls are expensive and research into improved methods for dispersing waste water in the sea without nuisance would be useful.

IMPROVING THE EFFICIENCY OF CONVENTIONAL METHODS OF DISPOSING OF WASTE WATER

Greater efficiency of treatment

Population growth and the trend of movement to cities and metropolitan complexes has resulted in great demands on water resources both for water supply and for waste-water disposal. Within urban complexes, industrial development also requires great amounts of water from the limited resources for processing, cooling and dilution of wastes. Consequently, one of the major research needs is to increase the efficiency of waste-water treatment so that the residual wastes are kept within the limits that receiving waters can accommodate, without interfering with other uses of the water. Conventional methods of biological treatment at best reduce biochemical oxygen demand (BOD) and suspended solids by about 90 % – 95 %. Consequently, in a city with a population of 1 000 000 persons and an industrial waste load equivalent to a further 1 000 000 persons, the residual organic wastes discharged after conventional treatment would be equivalent to the untreated waste water from a community of 100 000 – 200 000 persons. Where the receiving waters are to be used for a community drinking water supply or for recreation, the need for more effective treatment is evident. In many places in the United Kingdom effluent standards have been raised from the original Royal Commission values of 20 mg per litre of biochemical oxygen demand and 30 mg per litre of suspended solids to 10 mg per litre of each. In the USA, some authorities are beginning to require so-called "tertiary" treatment of waste water.

The nature of the process whereby organic and colloidal matter is removed from waste water is such that the relative proportion of waste removed decreases with each additional unit of treatment applied; consequently, new or improved methods must be developed. Among the processes that show promise, and into which further research is warranted, are (1) filters for adsorption, making use of specialized media such as activated carbon; (2) ion-exchange; (3) ultra-filtration using membranes of various types, many specially created for treating water and waste water; (4) reverse osmosis; (5) micro-straining; (6) foam and sedimentation separations using polyelectrolyte aids; (7) ozonation and other methods of oxidation and disinfection, including ultrasonics, and (8) distillation processes of various types. Among the more promising approaches that could be used in countries where space is adequate and the climate suitable, is the use of maturation or fish ponds in which ultimate stabilization is allowed to take place. An extensive literature on many of the processes mentioned here is available.[13, 16]

Another requirement for improved efficiency of waste treatment is an increasing need to reclaim waste water for other uses, primarily in industry and agriculture. Where water is scarce, waste water has been reclaimed for recreational purposes — in the Santee Recreation Project in California, for example [5] — and in a very few instances for water supply. The re-use of waste water for drinking water is, of course, the practise in every instance where waste water is discharged into rivers whose waters are later abstracted for water supply and the only real difference is that when water is taken from a river there has been dilution of the waste water. The problem remains essentially the same, however.

The recharge of underground aquifers by treated waste water, with the intention of abstracting water subsequently for re-use, offers considerable promise; the quality of water is improved during infiltration and waste water drawn from the ground is aesthetically more acceptable to the public. The system also provides valuable storage capacity. However, considerable research is needed in each area where this approach is contemplated, to determine the quality of waste water that would be acceptable for recharging aquifers.

Removal of non-degradable organic matter

In addition to removing the last traces of biochemical oxygen demand and suspended solids it has also been found necessary in many situations, to remove persistent "refractories", that is, organic matter that breaks down slowly and therefore leads to difficulties in using the water for many purposes. Of the widest concern, mainly from aesthetic considerations, have been the alkyl benzyl sulfonate (ABS) detergents or surface-active agents and it has been suggested that the use of materials of this type might be prohibited and that more easily broken down, so-called "soft", detergents might replace these substances. However, soft detergents are only relatively so, and there is considerable concern about the nature of their degradation products. Research to identify these products, and to ascertain their significance, will certainly be required.

A similar problem, but one that is much more difficult to control, arises from the widespread use of biocides in agriculture. Many of these substances are persistent and enter the food chain, finally accumulating as a body burden in man; the chlorinated hydrocarbons are particularly troublesome in this respect. Research is needed both to determine the long-term significance of these organic materials and to establish methods for monitoring their presence and the presence of their degradation products.

Removal of nutrients

The removal of organic matter may not be sufficient to prevent the deterioration of receiving waters through eutrophication. When there is increased demand by population and industry on limited water resources, the highest degree of treatment may not be sufficient to protect the waters from a spiraling cycle of food supply and rapid growth of organisms at all trophic levels, resulting in the water's becoming unfit for many uses, particularly for recreational purposes and water supply.[9] The tragedy of eutrophication, by contrast with ordinary pollution, is that once it has become established, it is virtually impossible to reverse the process, even if the source of nutrients is eliminated. Although research is now being conducted into the removal of the key elements, nitrogen and phosphorus, from waste water, research is required in each situation to indicate which element is the controlling factor so that it may be removed or reduced; it is seldom necessary to eliminate both of the elements. Where it is found to be impossible to remove sufficient of these nutrients to prevent the cycle of eutrophication from starting, generally because of the introduction of these elements from fertilizers as well as from waste water, it may be necessary to divert the waste water and run-off from direct entry into a body of water. Measures of this kind have already been instituted in Yugoslavia at the Plitvice Lakes, and more recently in Bavaria, Federal Republic of Germany, and have been proposed for Lake Tahoe, one of the important recreational lakes in the western part of the USA.

Analysis and monitoring of water

Improved analytical methods are required to detect and identify the small residual amounts of organic matter and trace elements in waste water. Of equal importance, particularly where waste water is to be reused, is the establishment of a system for continuously monitoring the more significant characteristics. Analytical methods already available must be adapted for use in continuous monitoring programmes, and methods must be found for other contaminants that are significant and be made amenable to electronic measurement.

Furthermore, the measuring and recording systems must be compatible with computer techniques that will permit a search to be made for significant changes, otherwise the accumulation of data will be so great as to defy handling and interpretation. The monitoring system must also be compatible with the system of alarm and control used by water supply personnel. Thus, increased research effort in analytical chemistry and associated sciences is required.

Health aspects

In addition to the effect of the increasing numbers of chemical and other polluting substances in water and their interaction, the problem of their potentiation in man by contaminants from other phases of the environment, such as the air or food, arises. Dubos has summarized the situation succinctly as follows:[1]

> The pollution of air and water occupies a place of special importance in the field of environmental pollution because it affects everybody almost constantly and because it is rapidly increasing wherever life is governed by modern technology...
>
> The techniques of water purification that worked well at the beginning of this century are becoming inadequate wherever water pollution is intense, which means practically everywhere. An appalling amount of untreated or inadequately treated urban sewage is discharged to the waters along with wastes from (industrial) plants. In many cases the river water is then used for public consumption by communities downstream after a so-called purifying process, which often does not go beyond filtration and chlorination. While such procedures are usually sufficient to rid drinking water of coliform bacteria, they do not render it free of viruses or nematodes and they leave untouched most chemical pollutants...

RECLAMATION OF WASTE WATER

Since waste water is now being used for all types of water supply, including drinking water, recreational water, irrigation water for agriculture and water for industry, considerable research is needed on the health, aesthetic and economic implications of each of these uses. While industrial and agricultural water has been obtained from waste water for many years, and considerable experience has given confidence in its use, the reclamation of water for drinking and recreational purposes is a relatively recent development and studies must be made on the chemical and biological significance of such use, with particular reference to the transmission of pathogenic viruses.[11, 12]

Reclamation against desalination

The reclamation of waste water may offer a more economical means of providing water in arid areas than desalination processes since desalting requires a good source of water, even though it is saline. Waste water, on the other hand, is available wherever people are living. The solids that must be removed from saline water are 35 times greater in concentration than those generally found in domestic waste-water. Where water of a quality lower than that of drinking water quality is required, and such water accounts for most of the water used, reclamation is an attractive possibility that solves two problems the one time, namely, the disposal of waste water and water supply.

Hierarchies in water quality

Although any water can be restored to a satisfactory quality for any purpose, the merits of this approach need to be studied in each particular situation. When water reclamation is practised, a certain amount of additional ("makeup") water is required and the development of a system of supplies based on a hierarchy of water quality might very well be considered. The makeup water would be used for supplying water of the highest quality, namely, for drinking, cooking and other similar uses. Where this water is derived from reservoirs, it might already have been used for recreational purposes without affecting its subsequent use as drinking water. Domestic waste water might, in turn, be used for an industrial water supply or for irrigation.

Dual water supply systems are already being used where fresh water is very scarce, e.g., in communities around Lake Maracaibo, Venezuela, in Coalinga, California, USA and in Hong Kong. Research into the economics of comprehensive water utilization might reveal much more satisfactory approaches to the problem than the extensive treatment required to reclaim drinking water from sewage.[3]

Quality requirements vary with the uses to which the water is put, and it is unnecessarily expensive to reclaim water of a standard suitable for drinking or for other domestic purposes, when in fact it is to be used for purposes that can be satisfied with water of a lower quality. In a document prepared in 1958 by the United Nations Economic and Social Council (ECOSOC) it was stated: "No higher quality water, unless there is a surplus of it, should be used for a purpose that can tolerate a lower grade".[14]

MANAGEMENT OF SOLIDS IN WASTE WATER

In those parts of the world where water-carriage sewerage systems are not yet in use, the management of night-soil can be improved with respect to health, economic and aesthetic considerations. For regions where sewerage has not yet been introduced, research is justified into whether this type of approach, so widely adopted in industrialized areas, is in fact the most appropriate system for all situations. Where the economy can make use of night-soil, one might well question the construction of sewerage systems for diluting this waste organic matter with water and then requiring its separation later at high cost.

Where water-carriage sewerage systems have been installed, and of course this applies to most urbanized areas of the world, the problem of managing the solids separated from waste water continues to be pressing. Generally, where the economy can make use of the solids, the solution is not nearly as difficult as in industrialized countries where the solids have little economic value and are a burden to the waste disposal process. Research is required to develop efficient methods of de-watering sludge and stabilizing it both aerobically and anaerobically, and methods for drying and incinerating sludge. Many of these processes are mechanical and manufacturers of equipment must be encouraged to develop improved devices for this purpose. In smaller communities where shortage of land is not a great problem, aerobic and anaerobic stabilization of sludge may be helpful. Complete stabilization of sludge is not economic where space is limited and where populations are large and solids load high.

Alternative methods include (1) disposal on land, either as wet sludge carried by pipelines or tank trucks, or as dried sludge used for soil conditioning, (2) disposal at sea through long underwater outfall lines, or (3) diffusion into receiving streams where dilution of partially stabilized sludge is satisfactory.

Under the present economic circumstances in industrialized countries, and in view of the availability of cheap chemical fertilizers, the ultimate fate of waste solids must, in general, be destruction, generally by incineration, or their discharge into the sea. Many conservationists are dismayed by the loss of nutrients inherent in either system. On the other hand, the economic burden of preserving the nutrient values, should this be desired, cannot properly be allowed to fall on the community seeking to manage its wastes problems, but must be handled by some sort of national or regional subsidy. Research involving agricultural economists as well as engineers and scientists will be necessary to guide the ultimate planning of waste disposal facilities.

Furthermore, research might very well be undertaken into the possibility of integrating the disposal of solids from waste water treatment plants with solid refuse from community and industrial sources. These solids are generally compatible and this kind of arrangement would serve to reduce over-all costs and provide for a unit of sufficiently large size to justify high-quality technical supervision.

ADMINISTRATIVE SOLUTIONS TO WASTE-WATER CONTROL PROBLEMS

The disposal of waste water has become an increasingly important factor in the over-all planning for communities, regions and industries. In fact, disposal of waste water now largely determines the location of large water-using industries and often exceeds in significance not only markets but also the availability of labour and raw materials. Research directed towards the incorporation of water supply and disposal of waste water in comprehensive community planning is increasingly being undertaken in highly urbanized metropolitan areas. The establishment of pollution control authorities within ministries concerned with housing and urban development is a strong indication of the importance now given to this phase of metropolitan planning.

Regionalization

Historically, each community and industry has attempted to solve its waste-water problems locally. Regionalization, whereby several communities can co-operate in the collection of waste water and the installation of treatment systems, or industry call upon nearby communities for sewerage and services to treat and dispose of waste water, offers many advantages, and the economies brought about by the scale of the enterprise can be particularly significant. In general, it is estimated that a 10-fold increase in the size of a treatment facility can reduce the unit cost by approximately 50 %, while doubling the capacity of transmission lines can also reduce the unit cost by about 50 %. Of even greater significance is the fact that larger administrative units can employ the services of highly-qualified technical personnel, both for planning and designing a project, as well as for operating it. Even where facilities may be geographically too widespread to be physically connected, the ease of transportation and communication today makes it feasible to provide unified administrative and technical services.

Administrative research

Considerable research is required into administrative procedures for controlling pollution; no single administrative approach is likely to be useful in all countries. An example of this type of administrative research is that undertaken by the International Association of Legal Science and the International Institute of Administrative Sciences.[4] Studies into comparisons of standards between effluent and environmental or receiving waters are also justified. Effluent standards, the first introduce in water pollution control practice, are relatively simple to administer. However, they often impose unnecessary economic burdens on society at the expense of administrative convenience. On the other hand, standards for streams or other receiving waters, designed to maintain water in a condition appropriate to the uses to which it is to be put, can become a basis for the most economically sound solutions to waste-water problems. Research is required to assess the significance of clean waters as an amenity and to determine to what extend public and social demand can be interpreted in the formulation of water pollution control practices.

Present technical knowledge is adequate for the elimination or mitigation of most of the serious pollution problems, particularly outside the few major metropolitan complexes. However, the administration of pollution control regulations, the development of governmental agencies, and the problems of financing corrective measures — large sums of money being needed because of the years of relative inaction — constitute major hurdles. The initiation of large-scale pollution control programmes will be slow as long as the benefits from investment in waste-water treatment accrue to others rather than to those making the investment, as is generally the case today. In such instances, the drive for pollution abatement comes from the injured party through litigation — a slow and expensive procedure.

Economic controls

It is becoming increasingly recognized that the legal approach has serious shortcomings in controlling water pollution; economic controls, on the other hand, may result in self-administered management programmes. Systems of charges, whereby a person or organization causing pollution pays a fee to a water pollution control organization, whether municipal or regional, can provide a strong economic incentive to reduce waste. Such fees are assessed in accordance with the kind and amount of waste discharged. Further, the money collected from these charges can largely finance the pollution abatement programme.

Economic incentives have encouraged industry to re-use water and thereby reduce the waste load considerably. A certain steel mill is now able to operate with only 2 % – 3 % of makeup water, while a pulp and paper mill has reduced its discharge from 3000 to 200 gallons (13 638 litres to 909 litres) per minute.[10] In fact, this type of approach will encourage industry to design processes that involve no waste products.

The administrative and financial organization created in the Ruhr area of Germany more than 50 years ago showed what can be achieved by economic controls, but this example is only now being followed in other areas. Mere imitation is not sufficient, however; research is also necessary to adapt the approach to every situation.

Comprehensive management

Among the most promising approaches to waste water problems has been the integration, either on a local or a regional basis, of water resources management; all contributors of waste water, all water resources and all uses likely to be made of water being taken into consideration. It is now possible to evaluate an almost limitless number of alternative schemes by computer techniques and systems analysis. The current Delaware River Estuary study in the USA is an example of this approach and has itself involved an extensive research programme.[15] Systems analysis to achieve optimum economic advantage has become increasingly important as an aid to planning, both for individual waste disposal and for the integration of these systems with over-all metropolitan systems.

Research into other types of integration is also likely to be fruitful; disposal of water-carried ground refuse together with waste-water and the incineration of municipal and industrial refuse with waste-water sludge, are two examples. Further research on environmental pollution problems is needed where this is associated with the disposal of waste water; for example, air pollution resulting from incineration of solids or water pollution resulting from increased industrial processing of foods and the installation of household devices for garbage-grinding.[6]

FINANCING AND CONDUCTING RESEARCH

In all countries, large numbers of scientists and engineers are engaged in developing new products and new chemicals and associated with the manufacture of each new product are wastes of various kinds. As countries become industrialized, one of the signs of so-called "progress" is the shift of food preparation from the kitchen to the factory leading to the substitution of water-carried industrial waste for household refuse. Great efforts are made to create new products to satisfy consumer demand but the number of scientists and engineers engaged in dealing with wastes and waste water, or in solving pollution problems when they arise, is disproportionately small.

It is in just those places and situations where research is most needed that it is generally felt that it can be least afforded. Where programmes of capital construction for water supply and waste-water disposal are being undertaken and large sums of money are being invested, the shortage of qualified personnel to conduct these programmes and to operate the facilities when they are completed, creates a situation in which resources for research are almost entirely absent. Even in highly industrialized countries, resources for research in the field of the public services are often neglected, and it is neglect that has resulted in a relatively slow technological development in water supply and waste-water disposal services in contrast to the very rapid technological changes taking place in industry. Very large industrial concerns, whether private or public, find it necessary to allocate a portion of their earnings to reasearch; on the other hand, research in water supply and waste is undertaken only after routine responsibilities have been discharged, which means almost never. It is seldom that a commitment to research is a primary obligation of any section of the water-supply or waste-water services but research can be stimulated; it can be conducted at existing facilities and through the use of pilot plants at these facilities. Regulating agencies must be sufficiently flexible to permit innovation and research when waste-water pollution control programmes are undertaken. Research should be supported also within governments and universities, as well as in specialized laboratories, and this research, as an integral requirement for the provision of waste-water treatment facilities, should be financed by part of the funds used to pay for construction and operation.

A concomitant problem is the education and training of technical personnel to conduct research programmes. It is only in an atmosphere of scientific inquiry that research can prosper, and educational institutions must be encouraged to develop suitable training programmes for engineers and scientists concerned with water and waste-water technology. Because education in research is expensive, research in educational methodology is certainly warranted, particularly in the highly industrialized countries where big investements in research are now being made.

Utilization of research

Considerable research on the treatment and disposal of waste water and on water pollution is already being carried out, as the proliferation of research journals throughout the world shows. However the poor communication among countries has been an obstacle to the application of research findings from one part of the world to another, and of even greater importance has been the failure of disciplines to communicate with each other. Management of waste water can profit from developments in the chemical and biological industries and engineers and scientists from these fields should be encouraged to apply their knowledge to the water problems while those already engaged in water technology should be encouraged to familiarize themselves with a wide range of other technologies. With the expansion of activity, and the multiplicity of interests in aspects of water pollution by scientists from other industries, some organized retrieval systems must be established, both at national and international levels, if full use is to be made of research findings as quickly as possible. Such systems are already being developed and some are in use. The development of Reference Centres on both a world-wide and a regional basis will go a long way to towards easing these problems.[a]

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HEALTH FACTORS IN THE RE-USE OF WASTE WATER FOR AGRICULTURAL, INDUSTRIAL AND MUNICIPAL PURPOSES

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Shortage of water is becoming a major problem not only in semi-arid and arid areas, but also in countries with a temperate climate. The increasing consumption of water for domestic and industrial use, as well as for agricultural irrigation, means that many parts of the world are already facing the need to develop distant water resources — projects that involve laying expensive pipelines, sometimes hundreds of kilometers in length. This situation emphasizes the need to consider the utilization of urban and industrial waste water as a supplementary source of water in regional and national plans for water conservation and development.

After it has been adequately treated, waste water can be returned to the water cycle for direct or indirect use in agriculture or industry. If a particularly high standard of treatment is assured, it may be possible, in certain circumstances, to use reclaimed waste water for municipal or domestic purposes. Re-use of local waste water may often prove to be more economical than the importation of water over long distances and is at present less expensive than the desalination of sea water. Proper waste-water reclamation practices can also contribute to the control of pollution.

Careful consideration of public health implications is an essential part of the engineering and economic evaluation of waste-water utilization programmes, since aesthetic factors and possible microbiological or chemical pollution may influence the decisions.

Experience has shown that health requirements must be given very careful attention in order to ensure that adequate sanitary safeguards are provided. A project to re-use waste water must meet the strictest criteria in the interests of public welfare, and any benefits gained from the increased amounts of water should not be lost by excessive health risks to the population served by the project.

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DIRECT AGRICULTURAL UTILIZATION

The presence of pathogens

A major factor that must be considered in the early stages of planning for any programme to re-use treated or partially treated waste water directly for irrigation or other agricultural purposes, is the degree of contamination of the water with pathogenic organisms. Many studies have been carried out which show that domestic sewage, before it is treated, usually contains the complete range of pathogenic micro-organisms found in the community producing the sewage.[15, 24, 26, 34] In one such study, various species of pathogenic micro-organisms, such as the agents causing typhoid fever, bacillary dysentery, amoebic dysentery, ascariasis and other protozoan and helminthic diseases, were isolated from raw sewage as well as from the effluent of a high-rate trickling filter plant.[5]

The efficiency of treatment

It is generally accepted that the absence of coliform organisms serves as an indication of the bacteriological efficiency of waste-water treatment processes. In primary sedimentation, a reduction of between 30 % and 40 % in the number of coliform organisms is obtained, while in most full biological treatment processes the reduction is between 90 % and 95 %.[22] Stabilization ponds with a 30-day retention period have, in general, been shown to effect a higher reduction of coliform organisms — up to 99 %. One study has shown that reductions of 90 % - 99 % in the number of coliform organisms can be achieved in ponds with about a 6-day retention time and 99.99 % after a 28-day retention.[20]

A number of studies have been carried out to determine the efficiency of sewage treatment processes in removing specific pathogens.[23, 24, 34]. In general, the findings closely paralleled the removal rates for coliform organisms. However, for practical purposes, it cannot be assumed that even a well-run biological sewage treatment plant can consistently remove more than 90 % of the pathogenic organisms present in the raw sewage, unless heavy chlorination is applied. In the case of primary effluent, it is to be expected that a considerably lower proportion of pathogenic organisms will be removed.

Studies have also been made on the viability of various indicator and pathogenic organisms in the soil or on crops irrigated with waste water. The viability of such pathogenic organisms varies from several days to a few months, depending on the type of organism and their resistance to environmental factors — climatic conditions, soil moisture, amount of protection provided by crops, etc.[11, 13, 24, 25] Research has shown that salmonellae may persist for up to 70 days in soil irrigated with sewage under moist winter conditions, and for about half that period under drier summer conditions.[5] A review of the literature leads one to the conclusion that, despite the considerable reduction in the number of indicator or pathogenic organisms as a result of detrimental environmental conditions and biological competition, sufficient numbers of pathogens can survive under the conditions normally expected in agricultural practice to result in a potential health hazard if crops, recently irrigated with fresh or partially treated sewage, are consumed in an uncooked condition.

Regulations for restricted irrigation

In the light of this conclusion, some countries have drawn up health regulations to restrict irrigation with waste water to certain crops not used for human consumption, or to crops consumed only after cooking or processing. If such regulations are administratively feasible, and farmers can be educated to adhere strictly to them, potential public health hazards resulting from sewage irrigation can be limited. Enforcement of regulations of this kind in Israel despite their restrictive nature, has shown that large, well-organized farms irrigated with sewage can run a fairly balanced agricultural programme under adequate crop-rotation schemes.[16, 27] However, there is always a temptation on small farms to irrigate the more profitable vegetable crops with sewage, although the practice is forbidden by the regulations. In some areas, on the other hand, farmers are hesitant to initiate sewage-irrigation projects on aesthetic grounds or because of the agronomic restrictions on the types of crops that can be grown under the various irrigation regimes.

It has also been pointed out that even food crops that have been irrigated with sewage but consumed only after cooking, may nevertheless contaminate working surfaces or utensils in the kitchen, and thus lead to contamination of other foods. Despite these possible health risks, it must be stated that no clear-cut epidemiological evidence is available to indicate that the carefully regulated use of waste water to irrigate crops not used for human consumption, or crops consumed only after cooking and processing, has ever led to any outbreak of disease.

Another problem is to protect the health of the agricultural workers when sewage-irrigation is used. It has been reported from India that hookworm infection is much commoner among workers on sewage farms than among the farming population in general; the local habit of walking barefoot is a major contributory factor to this disease. On the other hand, a follow-up of the health of workers at sewage plants in the USA did not reveal any excessive risk of disease or disability in this group. Reasonable standards of personal hygiene appear to be effective in protecting the health of workers involved in sewage-utilization projects.

Treatment of sewage for unrestricted irrigation

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

A series of studies has been carried out to determine the feasibility of inactivating coliform and pathogenic organisms in sewage by means of heavy chlorination to provide a safer effluent for unlimited agricultural irrigation.[17] This study has shown that 20 ml of chlorine per litre must be applied to primary effluent for 6 hours to achieve a count of not more than 100 coliform organisms per 100 ml, while 8 mg of chlorine per litre will achieve the same results in 2 hours when applied to the effluent from a high-rate trickling filter plant. This treatment was also effective in inactivating amoebic cysts. Most species of bacteria pathogenic to man are considered to be more sensitive to chlorine than the coliform organisms and it may therefore be assumed that they will be killed by the treatment in much the same proportion.

Another related study, however, indicated that enteroviruses may not be destroyed to the same extent as coliform organisms, and in one case, despite a reduction in numbers of coliform organisms after heavy chlorination by a factor of 10^5 or 10^6, a considerably lower proportional reduction of poliovirus was obtained.[30] The epidemiological significance of such findings is difficult to evaluate since little work has been done on the transmission of enteric viral diseases by foods contaminated after irrigation with sewage.

Despite the limited information, it can generally be considered that only a limited health risk would result from unrestricted irrigation of agricultural crops with sewage effluents with a bacteriological quality approaching that of drinking water. It must also be pointed out that in many areas of the world where year-round or seasonal irrigation of crops is carried out, water may be drawn from rivers and streams that are often heavily polluted with treated or untreated sewage effluent;[8, 12] in most cases, the quality of such water is far below that required for drinking purposes. Restrictions have generally not been placed on the use of such surface waters for agricultural purposes and it is considered that the risk of irrigating crops with treated sewage effluent approaching drinking water standards would be no greater than the risk involved in the use of river water as practised all over the world. However, further studies will be required on the danger of contaminating crops by irrigating with reclaimed water.

Use of sewage in fish-breeding entreprises

Fish ponds can benefit from the addition of sewage in proper proportions since it is usually essential to add nutrient-rich materials to encourage the growth of plankton, a major source of food for fish. This system of utilizing sewage has been used by a number of small agricultural communities in Israel with excellent results. The extent to which the sewage must be treated depends on the dilution factor since there is a danger that fish ponds too heavily overloaded with sewage will suffer from oxygen depletion. However, raw sewage has been successfully applied to some ponds.

From the microbiological point of view, there are two potential problems. One is the possibility of transferring contamination from the external surface and the viscera of fishes grown in ponds of this kind to the kitchen. The other problem is a limited one that might be relevant in those areas of the world where schistosomiasis is endemic. In such cases, the snails that serve as the intermediate host of the schistosome might develop in the fish pond and become infected from the sewage. This in turn could lead to the infection of workers. The problem has been overcome in Israel by controlling snails in fish ponds.

Irrigation methods

Irrigation practices play an important role in programmes for minimizing the health risks involved in the use of waste water in agriculture.[13, 21, 32] Surface irrigation techniques applied to fruit trees can produce uncontaminated fruit presenting no public health risk. However, if spray irrigation is used, there is a definite possibility of contaminating the fruit. Similarly, certain vegetable crops might be successfully irrigated by the ridge-and-furrow technique, in such a way as to avoid any direct contact between the sewage and the crop. Little work has been done on the evaluation of health risks to agricultural workers exposed to the spray from sewage used for irrigation but it is a problem that deserves consideration.

In Israel, a number of projects for the agricultural utilization of waste water were initiated as early as 1948, and through the years the programme has developed to the extent that over 150 projects were in operation by 1967,[7, 31] and other major projects were under construction or being planned.[2] In 1956, the first National Water Plan [35] included the use of waste water as one of the sources of water in development schemes required to meet the needs of the country's agricultural and industrial growth. Thus, Israel has become one of the few countries in the world where the reclamation of waste water has become a matter of national policy. Today, almost 20 % of the sewage collected from urban areas is re-used in some form or other.

INDUSTRIAL UTILIZATION

In many areas, the use of municipal waste water in industry has been successfully practised but a number of problems exist from a public health point of view. Possibly the main problem concerns the danger of cross-connecting pipelines carrying treated sewage and those carrying safe water for use in food processing or for human consumption. The careful colour coding of pipes would be helpful in reducing such risks. Generally speaking, however, it would be sound policy to bring treated sewage into industrial plants only after it has been treated and disinfected to the highest possible degree, and has achieved a bacteriological quality approaching that of drinking water. Such a high level of treatment would reduce the risk of a major outbreak of disease occurring as the result of an accidental cross-connexion. If waste water is used for cooling purposes only, very few additional public health problems exist, although there are a number of engineering and hydraulic problems that must be overcome. For example, unless the sewage is adequately treated, the problem of slime control might become critical.

If the reclaimed waste water is to be used as process water in industry, special consideration must be given to possible public health implications, and particular care will have to be taken if treated waste water is to be considered for use in industrial food-processing plants. One of the most effective and economical ways of using waste water in industry is in the intra-plant re-use of treated and recycled industrial effluents. Generally speaking, public health problems involved in recycling industrial effluents are far less severe than those resulting from the use of municipal sewage;

nevertheless, care must be taken to prevent possible cross-connexions and the contamination of potable water used in the same plants.

MUNICIPAL AND DOMESTIC USES OF WASTE WATER

Restricted use of waste water

In this category there are two possibilities. One is the limited use of treated waste water for certain restricted municipal purpose such as fire-fighting, irrigation of parks, gardens and golf courses,[21] and for street cleaning. Treated waste water is also used in the USA in a number of recreational lakes. The Santee Recreation Project in California and another at Lancaster, California, have successfully developed treatment processes that produce water meeting the most rigorous microbiological criteria.[3, 18]

There is also the possibility of using treated waste water in public buildings, or even in homes, for the purpose of flushing toilets. The cost of dual water systems might make this use uneconomical but similar restricted utilization of waste water might be worthwhile in areas suffering from a severe water shortage. It should be assumed that even for limited municipal use, waste water would have to be treated and disinfected to such an extent that it would be safe from a microbiological point of view, although it might not meet all the chemical standards usually desirable for drinking water. The specifications for treatment would be rather strict because the danger of cross-connexions or the possibility of accidental use of treated water for drinking purposes is quite considerable.

Unrestricted use of waste water

A number of projects have been undertaken to reclaim municipal waste water for recycling in the general water supply system for unrestricted municipal and domestic use. A pioneer study was made of the possible health implications of the treatment and recycling of waste water in Chanute, Kansas, USA, in 1957, when this procedure was adopted to overcome a serious shortage of water resulting from a drought.[19] Studies have also been made in other parts of the world to determine the feasibility of treating waste water to a standard that would meet all the criteria for potable water.

A plant in Windhoek, South-West Africa, has been designed to reclaim waste water for municipal and domestic purposes and includes multistep treatment encompassing all the classical processes, as well as adsorption on activated carbon and stabilization in ponds.[10] The Advanced Waste

Treatment Program of the Taft Sanitary Engineering Centre in the USA has also developed plants which include conventional, primary and secondary treatment, coagulation, sedimentation and rapid sand filtration, carbon adsorption, electrodialysis and chlorination.[9, 33] A project for treatment and ground-water recharge of the waste-water of the Tel Aviv region in Israel for ultimate unrestricted utilization is also being developed.

Pilot studies have shown that in well-engineered and properly operated plants, reclaimed water of a quality equal to that of the original supply may be produced. However, stringent precautions should be taken to provide very wide margins of safety in the treatment processes, in order to ensure a uniform, safe effluent at all times.

Microbiological problems

From a microbiological point of view, one would expect the effluent from treatment processes to meet the normal bacteriological standards as well as newer criteria, such as adequate elimination of viruses. So far, the techniques available for the detection of viruses in large volumes of drinking water have been inadequate and it is difficult at the moment to evaluate the saftey of water known to be contaminated with small numbers of enteroviruses. Several studies have indicated that the number of coliform organisms is often an inadequate index for evaluating the viral content of drinking water, since coliform organisms are generally, more sensitive than certain resistant strains of enteroviruses to the treatment processes usually employed.

Research workers at the Hebrew University, Jerusalem, have made progress in developing a new technique for detecting viruses in water,[29] and have also shown that poliovirus can, under certain circumstances, be resistant to the heavy doses of chlorine that effectively reduce the number of coliform organisms.[30] This study was carried out in connexion with plans to treat the Haifa town sewage to a degree that would allow its unrestricted use for irrigating all agricultural crops.

The agent causing infectious hepatitis is thought to be particularly resistant to the treatment processes for sewage and water, and the possibility exists that this organism might, under certain circumstances, pass through a treatment plant designed to produce safe drinking water, unless particularly strict precautions were taken.

Chemical problems

Certain chemical problems will also have to be overcome since waste waters are rich in nitrogenous compounds, as well as in various organic and inorganic chemicals arising from industrial sources. In many cases, control of the chemical quality of the reclaimed water may become the critical factor in determining the acceptability of converting waste water for unlimited domestic use.[28] The waste water flowing in municipal sewers contains increased amounts of mineral substances derived from the various domestic and industrial uses.[6] The accompanying table shows the mean increment in the mineral content of waste water in 75 towns and villages in Israel.[14]

MEAN INCREMENT IN THE MINERAL CONTENT OF MUNICIPAL WASTE WATER IN ISRAEL

Mineral constituent	Increment[a]	
	mg/l	g *per capita* per day[b]
Nitrogen	40.0	5.00
Potassium	20.0	2.50
Phosphorus	7.0	1.00
Chloride	80.0	10.00
Boron	0.4	0.05
Sodium	80.0	10.00
Total hardness (as $CaCO_3$)	25.0	3 00
Total dissolved solids	370.0	45.00
S.A.R[c]	2.0	—

[a] The rise in electrical conductivity was 550.0 micromhos/cm.
[b] Assuming a production of 120 litres of waste water *per capita* per day.
[c] Sodium adsorption ratio

Increased quantities of nitrates and total dissolved solids can present health problems. Alkyl benzyl sulfonate (ABS) detergents have from time to time caused difficulty when a large percentage of reclaimed water was present in drinking water. However, with the development of the newer "soft" detergents, it may be expected that this problem, which is essentially of an aesthetic nature, will be overcome. Studies have shown that the level of detergent that may be found in waste water is far below that which could cause concern from a toxicological point of view. Insecticides and herbicides are appearing in waste water in ever-increasing quantities as a result of their widespread use in agriculture and waste materials from industrial plants may contaminate waste water with undesirable levels of various highly toxic chemicals.

Studies on the success of standard sewage treatment processes in removing microchemicals of a toxic nature are limited. It is clear, however, that most of the inorganic compounds are removed to only a limited extent by such processes. ABS detergents can be reduced by 30 % - 50 % by standard sewage treatment processes and by treatment in oxidation ponds, while higher proportions of the newer soft detergents can be removed. Little is known about the ability of the soil to remove micro-chemicals, though it may be a significant factor, particularly in projects involving the recharge of an aquifer with waste water. The removal of chemicals in water flowing through an aquifer is dependent, to a large extent, on the adsorptive and exchange capacity of the soil.[4] It appears that the newer, more advanced water reclamation plants, in which adsorption on carbon is included, can achieve the almost complete removal of most organic pollutants, as well as 97 % removal of total phosphate and 75 % of total nitrogen. However, the removal of dissolved minerals and trace chemicals, still presents a problem.[9, 33]

Aesthetic problems

In addition to the microbiological and chemical problems involved in re-using waste water, aesthetic factors such as taste, odour and appearance of the reclaimed water must be satisfactory. There is always likely to be an aversion to the consumption of even the most carefully treated and disinfected waste water, and the smallest aesthetic flaw in the quality of the water may lead to its total rejection. Although a number of proposals have been made to treat waste water in classical and special advanced treatment plant in order to produce a final product acceptable for unlimited domestic and municipal use, it is doubtful whether such installations provide, at the present time, a large enough safety factor to ensure adequate health protection for the consumer. Such mechanical plants may suffer from the many weaknesses due to engineering breakdowns and human error.

Ground-water filtration

In Israel it was decided to combine processes of engineered biological treatment of waste water with natural processes of ground-water filtration and storage, in an effort to reclaim annually 100 million m^3 (about 3500 million ft^3) of waste water from the Tel Aviv region for ultimate unlimited agricultural, municipal and domestic use. This type of procedure can be considered as indirect utilization of waste water, taking advantage of the storage capacity, natural treatment and dilution by rain water associated with natural aquifers.

The problems encountered in this project, as revealed by preliminary pilot studies,[1, 2] are primarily those involved in producing water that meets acceptable chemical standards. It has become apparent that the high nitrate content of the reclaimed water, which is about 3 times more than that acceptable in drinking water, is a limiting factor which will require the dilution of the reclaimed water with adequate amounts of low-nitrate water, unless economical methods are developed to remove nitrates. Generally speaking, however, it is felt that the procedure to be followed will provide adequate safety barriers which could not easily fail as a result of human or engineering deficiencies.[27] In particular, the long period of ground-water filtration and storage, for a minimum period of 400 days and an average period of 3 ½ years, will introduce a very dependable margin of safety. This long storage will serve not only as an effective means of eliminating many of the microbiological and chemical pollutants, but will also have an aesthetic and psychological advantage since, in the public's view, reclaimed water from such a project, being withdrawn from the ground, is not readily distinguished from natural water. Despite these safety features, the health authorities have approved only a limited first stage which will serve as a pilot scheme to enable a closer study to be made of any possible health risks that might arise.

The reclamation of waste water and its recycling as domestic drinking water may in time become an engineering reality. Advanced treatment processes will undoubtedly be capable, in the very near future, of eliminating all the pollutants found in waste water and restoring its quality to an acceptable level without resort to ground-water filtration and storage. Nevertheless, it appears that there are certain advantages to be gained from indirect utilization, since storage in a natural aquifer provides an additional margin of safety that would be difficult to attain, even in the best engineered plants.

THE NEED FOR ALTERNATIVE MEANS FOR DISPOSAL OF EFFLUENTS

Utilization of waste-water cannot be seen as a completely closed cycle but must include alternative arrangements for the disposal of effluents or for the concentrated pollutants removed by advanced treatments. For example, in many arid areas the irrigation season lasts for 150 – 200 days a year. Alternative sanitary disposal facilities are essential for the remainder of the year and may also be needed to deal with overflows of waste water or with all the waste water during engineering breakdowns that may occur during the irrigation season. This problem is particularly acute in semi-arid zones where disposal by dilution in rivers may not be possible during the dry season, when the rivers are dry or almost dry.[31]

Advanced waste treatment processes must also dispose of the concentrated pollutants in such a manner as not to cause further pollution of the limited water resources. These concentrated wastes may require special facilities for their ultimate disposal, such as discharge into wells sufficiently deep to preclude the contamination of aquifers, or into the sea- even if very long pipelines were needed.

As a matter of policy, health authorities must regard the adequate sanitary disposal of waste water during all the months of the year as a primary objective, with re-use as a possible supplementary benefit in an integrated water pollution control programme. With careful consideration of all the public health aspects involved, such integrated utilization programmes may provide both for the more effective control of water pollution and for the supply of significant quantities of additional water.

CONCLUSIONS

Waste water, after adequate treatment, can be recycled for use in agriculture and industry and, in certain circumstances, may in time become available for municipal and domestic use if a particularly high degree of treatment with adequate safeguards is provided.

In planning programmes for the utilization of waste water, the public health implications must be given careful consideration, since physical, microbiological or chemical pollution may place limits on the use of reclaimed water.

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