MARINE SCIENCES RESEARCH CENTER
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THE URBAN ENVIRONMENT AND WASTE DISPOSAL

Notes Prepared for the
Consiglio Nazionale Delle Richerche
New York State Conference on
"Public-Private Partnership for Urban Revitalization"

6-8 November 1991

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INTRODUCTION

The earliest cities appeared in Mesopotamia sometime between 3000 and 4000 B.C. They were built on the plains close to the Tigris and Euphrates Rivers. The city of Ur with a population of about 24,000 people had canals, harbors and temples. Other cities established during the third millennium B.C. have been excavated at Memphis and Thebes along the Nile, at Mohenjo-Dara in the valley of the Indus River in Pakistan, and along the Yellow River valley in northern China. All these cities and many others were built -- both physically and economically -- on fertile alluvial plains that were easily irrigated and in their prime were highly productive (Reader 1988).

Cities freed ever increasing numbers of people from the burden of finding food for themselves. According to Reader (1988 p. 223) cities removed the burdens of feeding and managing small groups of people and released the creativity and ingenuity of people: "Michelangelo to paint, Newton to ponder, Hitler to scheme." Trade, crafts, and the arts proliferated; methods of transportation and communication were refined; patterns of economic control, social administration, intellectual activity and religious

obligation emerged (Reader 1988, p 223).

The influence of cities has been extensive and pervasive; extending to the most distant sources of energy and raw materials upon which they depend -- food, fuel, raw materials and wealth. Cities are open systems. According to some, the single best word to describe cities is "dependence." A city cannot be a self-sustaining entity. It depends upon imports and exports. Among the major exports of all cities are wastes.

The problems of urban waste disposal are problems of long-standing. They are components of a set of problems associated with getting people, food, water, energy, and raw materials into cities and people, finished products and wastes out. The problems have grown in complexity as cities and surrounding suburbs increased in population and in areal extent. But the problems today pale in comparison with those of the Industrial Revolution. During that period there was little infrastructure to deal with the wastes of rapidly growing urban populations. The problem is being repeated today in cities in some developing countries and in many older cities in developed countries there are problems associated with aging infrastructure. While cities have been criticized for their handling of wastes, they have been the innovators in the search for creative solutions. This is particularly true in the case of wastewater.

The waste products that cities have to deal with include:

- municipal solid waste (garbage and trash)
- municipal wastewater
- sewage sludge
- cellar dirt -- street sweepings and construction and demolition debris
- industrial wastes
- ash from burning fossil fuels and MSW

Disposal strategies that were acceptable for individuals and for small groups were not acceptable for large groups of people in high concentrations -- the strategies were not appropriate to cities. This means that the effective and efficient handling of a city's wastes required an organized approach. For most wastes, except municipal wastewater, there are two fundamental approaches: by contract with one or more companies or by creating municipal departments. The two approaches are not exclusive, of course, and many cities combine them. The first strategy has the potential for abuse, for graft, for payoffs and for political patronage -- real or perceived. It also has the potential for providing better service at lower cost.

The waste problems and the responses of different cities to those problems have been fundamentally the same from city to city and from country to country -- at least in what has become known as the developed world.

Because of the limits of time, I will concentrate my comments on urban municipal solid wastes (MSW) and on municipal wastewater.

POPULATION AND URBANIZATION

Cities are concentration of people. The waste problems of cities differ from those of other segments of society because of their large populations and their high population densities. It is instructive to trace out the history of population growth and of urbanization and to examine the projections for the future. Figure 1 is a graph of the change of the world's population from the year 1 A.D. to the present and projections out to the year 2000. There has been an enormous growth in the world's population over the past 200 years. The population explosion has occurred partly because of major advances in the control of diseases and partly because of expanded food supplies: both have resulted from technological advances.

In the year 1 A.D. the world population was roughly 250 million. By 1850 A.D. it had reached about 1 billion and 100 years later, 1950, it had reached 2.5 billion. Between 1950 and 1987, the global population doubled from 2.5 to 5.0 billion. This increase -- this doubling -- in the span of less than 40 years equaled the total increase in the world's population since the time the human species first emerged more than 1 million years ago until the middle of this century.

Of the more than 5.2 billion people who now inhabit the earth, over 40% are under the age of 15. Thus, the stage is set for a continued mushrooming of the world's population. According to the Population Reference Bureau, the net rate of increase of the world's population is more than 10,000 people per hour. The United Nations estimates that by the year 2055 the earth's

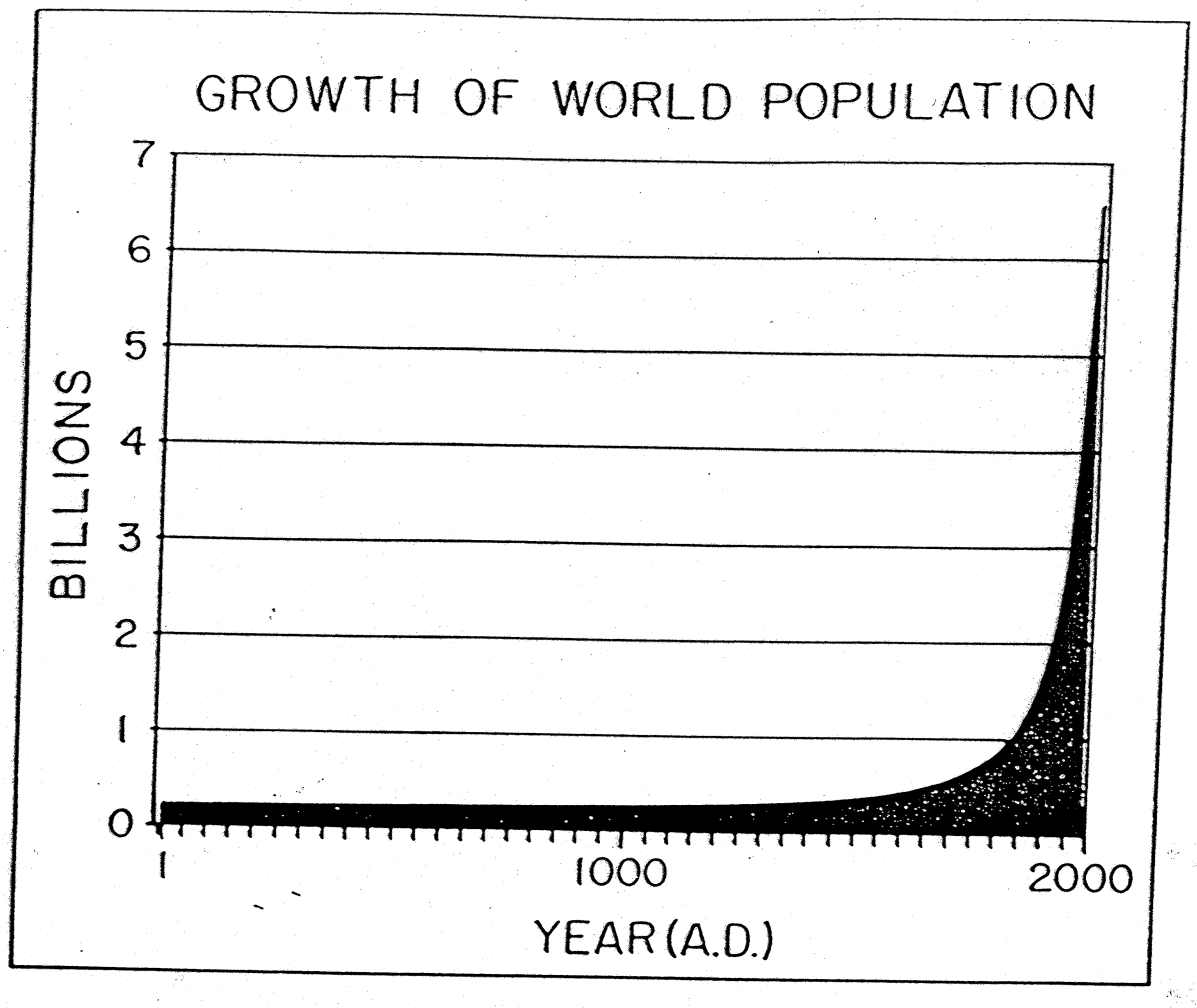

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Fig. 1. Growth of World Population, 1 A.D. to 2000 A.D.

population will increase to 8.5 billion before stabilizing at over 10 billion at the end of the coming century; 95% of the growth will come in developing countries, Figure 2.

Figure 2 is a plot of the population changes since 1750, the projected changes out to the year 2100 and the partitioning of the growth between developed and developing countries as a function of time. In 1950, the developed world accounted for about one-third of the world's population. Much lower birth rates cut that proportion to one-quarter by 1985 and it is expected to fall to one-fifth by the end of the century, and to one-sixth by 2025.

The mushrooming population will place enormous demands on the planet for food, shelter, energy and transportation -- the demands for these amenities is increasing even more rapidly than population. And the increasing population will produce increased wastes that will have to be dealt with. And, it isn't just the total population or the rate of population increase, but also the clustering of the population in cities.

The rate of urbanization from 1850-2000 for the world as a whole, and for the more developed and the less developed portions of it are summarized in Figure 3. It is clear that more developed regions are more highly urbanized than less developed regions. Unfortunately, projections beyond 2000 are not available, but because more than 95% of the world's population growth will occur in less developed regions, it is reasonable to expect a continued

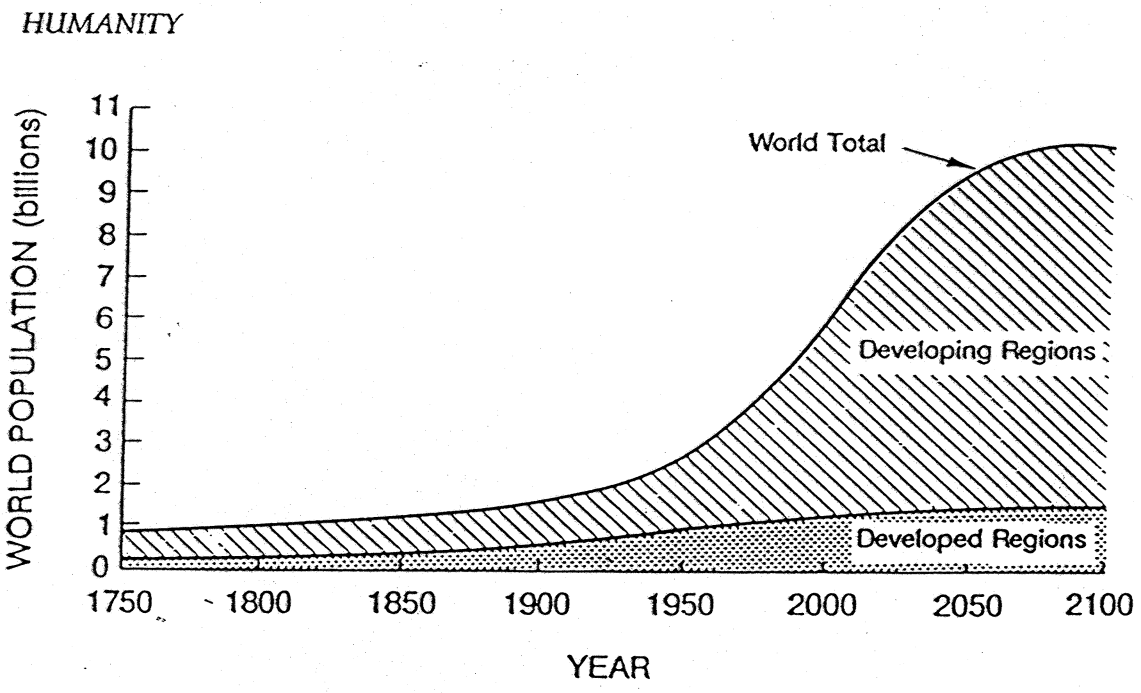

Fig. 2. Change of World's Population from 1750-2100. (T.W. Merrick et al. 1986. "World Populations in Transition," 42(2), Fig. 1, p.4)

rapid increase in their rate of urbanization. Many of the cities in developing countries do not have the infrastructure to deal even with their present waste problems. Unless steps are taken promptly, the impacts on the urban environment could be devastating. For cities in coastal urban areas, there will be special environmental problems -- particularly eutrophication and contamination of coastal waters receiving inadequately treated wastewater. Most of these problem cities can be identified now. They should be and appropriate steps should be taken to prevent unnecessary and undesirable environmental degradation. If these problems are not anticipated and planned for now, the environmental problems of cities during the Industrial Revolution could be repeated.

Most of the old great cities of the Middle Ages such as Cologne and Milan had populations of less than 50,000. Populations of the cities of the Italian Renaissance were less than 150,000. Today's 85 largest cities all have populations greater than 2 million; the top 11 have populations greater than 8.5 million and the top 6 have popuations greater than 10 million, Table 1. The growth of cities is not uniform; it occurs in spurts. Interesting examples of this phenomenon are the capitals of Spain and Italy.

TWO MAJOR URBAN WASTE DISPOSAL PROBLEMS

Two of the major waste disposal problems facing the world's cities are municipal solid waste and municipal wastewater. In the following sections, we examine each of these briefly.

Municipal Solid Waste

Although not all countries define municipal solid waste in exactly the same way, there is general agreement that municipal solid waste is what is usually referred to as garbage and trash.

It is nearly everything we throw away. In the definition used by the U.S., it includes residential, institutional and commercial wastes: wastes from homes, restaurants, shopping malls, offices and schools; wastes generated by municipal public works, such as street sweepings and tree branch trimmings; and some industrial wastes, such as corrugated cardboard and other packaging, cafeteria wastes and paper towels. Municipal solid waste does not include construction and demolition debris, scrap or medical wastes.

The constituents of municipal solid waste can be categorized either on the basis of materials or products (Table 2).

countries. If we assume that all non-OECD countries generate MSW at a rate of about 0.25 metric tons/person/yr., we have 16% at 0.5 tons/person/yr. + 84% at 0.25 tons/person/yr. which yields an annual production of MSW by the planet of 1.5 billion metric tons! Even if this figure is too high now, it soon will not be because of the increase in the world's population.

The best estimate of MSW generation by the US for 1990 is about 160 million metric tons for gross discards of MSW -- before any recycling. This total translates into a per capita production of about 1.6 kg/person/day or 580 kg/person/yr. These are averages and include residential and commercial components. In major metropolitan areas like New York, Boston, Chicago, Los Angeles and Detroit the rates can be as much as twice the national average. For example, for the New York City-Long Island region the per capita MSW generation rate is about 3.2 kg/person/day or 1.2 metric tons/person/yr.

Estimates of MSW generation rates on a per capita basis for a few countries for which data are available are listed in Table 4.

TABLE 4

Estimated MSW Generation Per Capita for Different Countries (kg/person/day)

Country	Gross Discards	Net Discards	Year
US	1.6	1.5	1986
West Germany	---	1.2	1984-85
Sweden	---	1.1	Early to mid 1980s
Switzerland	---	1.0	---
Japan	---	1.4	1987

(US OTA, 1989)

Composition

The composition of municipal solid waste varies from country to country and within countries from region to region. The differences among countries are due in part to differences in the way the term "municipal solid waste" is defined. Differences in composition among countries -- and within countries -- are due also to differences in life style.

The most recent data for the average composition of gross discards of municipal solid waste (before recycling) in the U.S. are summarized in Figures 4 and 5. Table 5 indicates how the composition of the MSW stream in the U.S. changed between 1970 and 1988.

The largest increase in the contribution to the composition of the U.S. municipal solid waste stream came from plastics. Plastic wastes more than quadrupled over the past two decades, increasing from 2.7 million metric tons in 1970 to 13.0 million metric tons in 1988. In 1990 the U.S. discarded an average of about 90 kg of plastic per person; about 27 kg of which were packaging. The big increase in plastic waste stems in large part from the increase in single-use throwaway items. For example, in 1987 approximately 2 billion disposable plastic razors, 16 billion disposable diapers and 1.6 billion disposable pens were used in the U.S. -- not to mention the large numbers of plastic soft drink containers and styrofoam cups and clamshell containers.

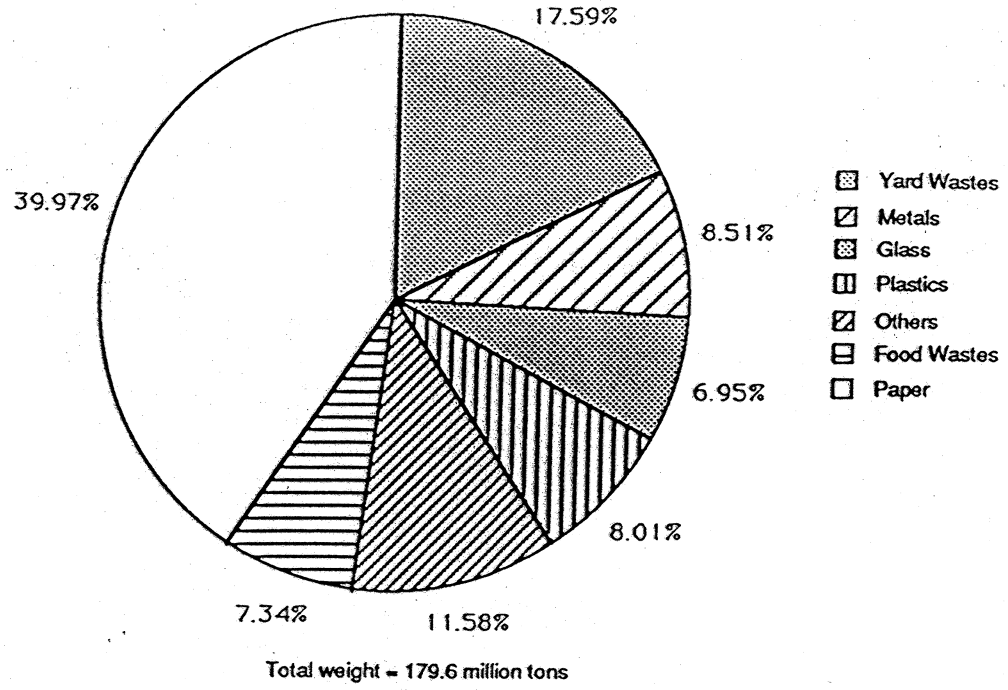

Fig. 4. Materials Generated in MSW by Weight, 1988.

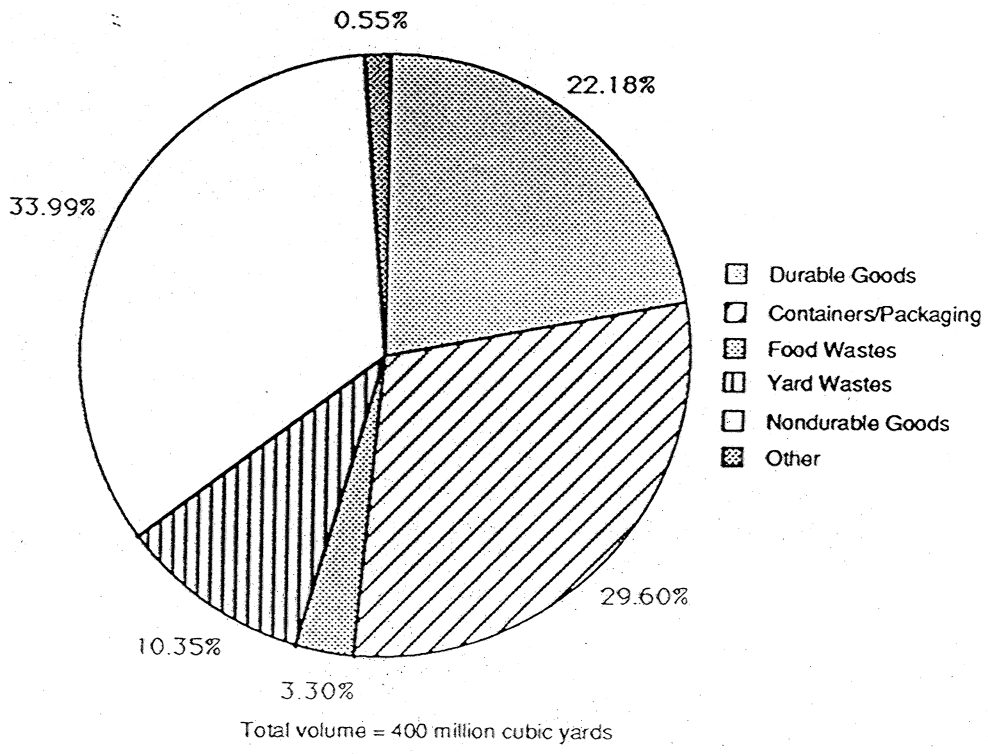

Fig. 5. Products Discarded in MSW by Volume, 1998.

TABLE 6

Products Discarded into the US Municipal Waste Stream

1960 to 2000 (in percent of total discards)

Products	1960	1970	1980	1990	2000
Durable Goods	11.1	12.4	13.8	13.6	13.6
Non-Durable Goods	18.5	19.0	22.1	25.8	28.1
Containers and Packaging	29.4	34.9	32.2	30.5	30.0
Other Wastes	41.0	33.6	31.4	30.1	28.1
Total Wastes Discarded	100.0	100.0	100.0	100.0	100.0
Energy Recovery	---	0.4	2.1	8.9	19.0
Net Wastes Discarded	100.0	99.6	97.9	91.1	81.0

The composition of gross municipal solid waste discards by the U.S. is variable, but as a general rule, more than half (by weight) is paper products and yard waste. The composition of the United States municipal solid waste stream is not typical of other countries, however. In China and the Netherlands, for example, approximately 50% of the gross waste stream is organic matter. In Egypt, organic matter accounts for 70% of the total.

An indication of the differences among cities in a number of different countries is presented in Table 7. These data are for gross discards and come from municipal solid waste incinerators operated by the Sorain-Cecchini Sp.A. Corporation, an Italian company with headquarters in Rome.

TABLE 7

Municipal Solid Waste Composition:

Sorain- Ceechini Facility Locations and

for Comparison Southern California

% By Weight

	Rome	Milan	San Paulo	Oslo	Southern California
Paper/Cardboard	25.0	20.0	21.0	38.2	40.5
Film Plastic	3.5	5.0	2.6	4.7	2.0
Hard Plastic	3.0	5.0	1.7	1.8	5.4
Ferrous Metal	2.5	4.0	4.1	2.0	5.0
Textile/Leather/ Wood	3.0	5.0	7.0	9.4	18.1
Organic Matter	53.0	41.0	57.0	30.4	19.6
Non-Combustibles (Glass, Non Ferrous Metal, Sand, Grit, Etc.)	10.0	10.0	6.6	13.5	9.4

Disposal Strategies

Although data are soft, they indicate that in 1990 the United States landfilled about 75 to 80% of its gross municipal solid waste stream, incinerated about 10 to 13% and recycled about 10 to 13%. The percents of the total waste stream that are incinerated and recycled in the U.S. are both increasing. These trends are the result of pressures to close existing landfills, the difficulty in siting new landfills, and an increasing environmental awareness of the importance of recycling. Landfilling will remain the preferred ultimate disposal options for small communities, but many cities, particularly coastal cities, must look to incineration or to

export. In the U.S. there is a growing intrastate and interstate traffic in municipal solid waste. According to the OTA (1989) some 28,000 tons of garbage travel the highways of the U.S. everyday. Most states that export also import. New York and New Jersey -- two of the largest exporters -- are exceptions. Neither of these states imports any garbage. Figure 6 summarizes the interstate traffic of garbage in the United States in 1990. There is a very small export of garbage by the U.S. to other nations.

There are relatively few data to document worldwide practices in municipal solid waste disposal. Some countries, for example, Japan and a few European countries, burn most of their MSW, but worldwide the total reliance on incineration as a waste disposal strategy must be less than 10% of net discards. The disposal options of selected countries are summarized in Table 8. The data are for net discards -- discards after recycling. When the totals do not approach 100%, it is not clear what happens to the balance of the MSW. In Italy, for example, the UNEP data indicate that 38% of the net waste stream is landfilled and 20% incinerated for a total of 58%. Where does the other 42% go?

Worldwide landfilling is the overwhelming first choice as the disposal option for MSW; incineration is a distant second. Composting and animal feed are farther down the list. In many developed countries, the percentage of the waste stream that is incinerated is increasing and in a few, it is the preferred option.

TABLE 8

DISPOSAL OPTIONS OF MSW OF SELECTED COUNTRIES

(% of Net Discards for Most Recent Year, 1979-83)

Country	Landfilling	Incineration
North America		
Canada	96	4
Asia		
Japan	32	65
Europe		
Austria	57	19
Belgium	58	25
Finland	92	8
France	43	45
FGR	76	21
Hungary	99	---
Italy	38	20
Norway	90	6
Spain	83	6
Sweden	52	38
Switzerland	20	77
UK	69	10
Oceania		
Australia	98	2

Source: UNEP

The percentage of the waste stream that is being recycled is also increasing in many developed countries. Efforts at source reduction -- the elimination of wastes in the first instance -- have been less successful, but are gaining in popularity.

Recycling rates vary widely from country to country, in part because of recycling practices and in part because of differences in how recycling data are defined and reported. For example, the U.S. does not include junk automobiles in recycling, Japan does. The recycling rates for OECD countries for paper and glass are summarized in Table 9.

TABLE 9

Recycling by OECD Countries

Country	Paper & Cardboard(%)	Glass (%)
Australia	31.8	17.0
Austria	36.8	44.0
Belgium	14.7	39.0
Canada	18.0*	12.0*
Denmark	31.0	32.0
Finland	30.0	20.0
France	33.0	26.0
FRG	41.2	37.0
Greece	---	---
Ireland	15.0	8.0
Italy	---	---
Japan	49.6	54.5
Luxembourg	---	---
Netherlands	50.3[a]	62.0
New Zealand	19.0	53.0[b]
Norway	21.2	---
Portugal	38.0*	14.0
Spain	44.1	22.0
Sweden	40.0	20.0
Switzerland	38.0	47.0
UK	27.0	13.0
USA	20.0	8.0
Average	(31.5)	(29.8)

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* - Estimate

a - Recycled From Paper Industry Only

b - Includes Reusable Bottles

NEW YORK CITY'S MSW PROBLEM -- A 1991 PROFILE

Population and Population Density

New York City has a population of about 7.3 million people living in 5 boroughs -- Manhattan, Brooklyn, Queens, Bronx and Staten Island. The population density of New York City as a whole is nearly 9100/km^2 and it reaches a density of more than 25,000/km^2 in Manhattan. This is the highest population density of any city in the world.

MSW Generation

New York City produces about 27,000 tons of MSW/day. The per capita generation rate is 3.3 kg/day or about 1.2 metric tons/yr, one of the highest rates in the world.

Collection of MSW

About 50% of the City's MSW is picked up by the New York City Department of Sanitation. The remaining 50% is picked up by private carters.

Recycling

In 1990 New York City recycled about 9% of its gross waste stream. The City plans to increase the rate of recycling to 25% by 1997. It will be a very difficult goal to achieve.

TABLE 11

OECD COUNTRIES, POPULATION & SEWAGE SLUDGE (1984-88)

Country	1988 Population (Millions)	Sewage Sludge (1000 tonnes/yr)
Australia	16.53	(704)+
Austria	7.60	1,350
Belgium	9.92	18
Canada	25.95	500
Denmark	5.13	82
Finland	4.95	137
France	55.87	600
FRG	61.20	1,591
Greece	10.01	(426)+
Iceland	0.25	570
Ireland	3.54	(150)
Italy	57.44	(2,477)+
Japan	122.61	2,003
Luxembourg	0.37	11
Netherlands	14.76	250
New Zealand	3.29	45
Norway	4.20	70
Portugal	10.41	(443)
Spain	39.05	10,000
Sweden	8.44	372
Switzerland	6.62	255
Turkey	52.42	(2,233)+
UK	57.08	(2,432)+
USA	246.33	8,400
TOTALS	823.97	34,939 (Adj.)

+ = calculated from other data in the table

TABLE 12

DEFINITIONS OF MUNICIPAL TREATMENT LEVELS

Treatment Level	Treatment Requirements
Primary	Approximately 30% removal of BOD and 60% removal of TSS
Secondary	Removal of both BOD and TSS to levels of 25-30 mg/l, but not less than 85% removal; pH between 6.0 and 9.0
Tertiary	Removal of both BOD and TSS to levels less than 9 mg/l, or removal of over 95% of BOD and TSS; additional requirements for removal of nutrients (e.g. nitrates, phosphates) onsite-specific basis

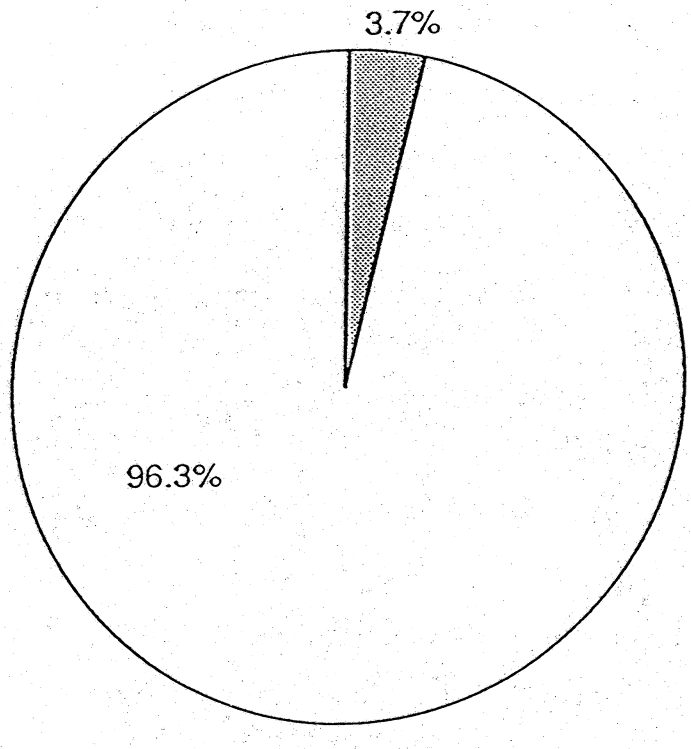
SOURCE: U.S. Congress, Office of Technology Assessment, *Wastes in Marine Environments*, OTA-O-334, April 1987.

Over 15,000 POTWs currently operate in the United States and each year they treat and discharge approximately 36 million cubic meters of wastewater. More than 2,000 POTWs (15%) are located in coastal counties and they discharge about one-third of the nation's municipal effluent. POTWs also produce increasing amounts of sewage sludge. The total amount of sludge generated by all U.S. POTWs more than doubled during the last decade, and almost 40% originates from POTWs located in coastal counties.

Only about 2% of the nation's total wastewater effluent is not discharged into surface waters. This fraction is used to irrigate or fertilize agricultural and forest lands, or for groundwater recharge, industrial uses, aquaculture, and underground injection to prevent saltwater intrusion.

The most common way of disposing wastewater effluent is to discharge it through pipelines into nearby surface waters. Almost 600 POTWs discharge effluent directly into estuaries or coastal waters. Although these POTWs represent only 4% of the nation's total (Figure 7), they account for about one-fourth (8.7 million cubic meters annually) of all municipal effluent (Figure 8) because many of them serve large urban areas. Of the 8.7 million cubic meters they discharge each year, about 8 million cubic meters of effluent (or 92%) are discharged annually into estuaries.

There are five major sludge management methods -- land application, landfilling, incineration, distribution and marketing, and ocean disposal.

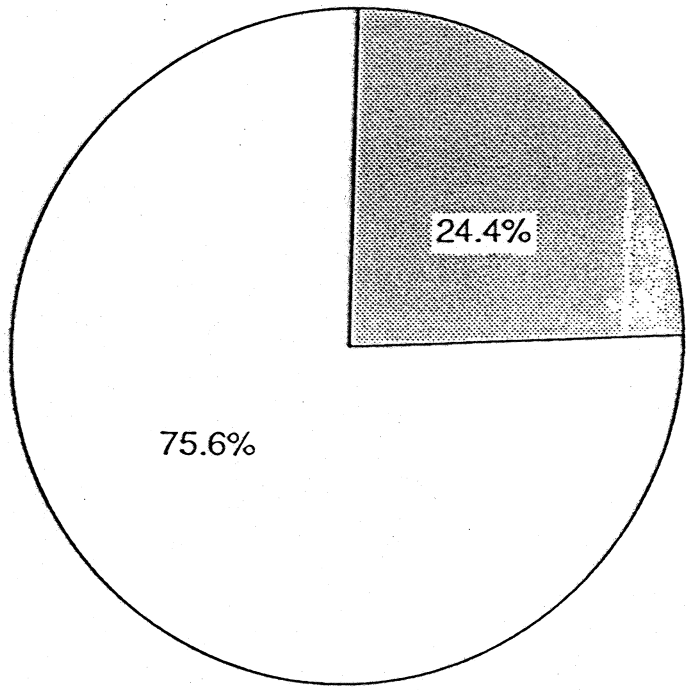


▒ # of POTWs discharging into estuaries and coastal waters (570)

□ # of all POTWs except above (14912)

(Source: Data from Office of Technology Assessment 1987)

Fig. 7. Partitioning of POTWs Discharging into Estuaries and Coastal Marine Waters of the U.S. and into Other Aquatic Environments.



▨ Percentage of POTW effluent discharged into estuaries and coastal waters (5.50 bg/d)
☐ Percentage of POTW effluent discharged into other aquatic environments (20.46 bg/d)
(Source: Office of Technology Assessment 1987)

Fig 8. Percentage of Wastewater Effluent Discharged by POTWs into Estuaries and Coastal Marine Waters of the U.S. and into Other Aquatic Environments.

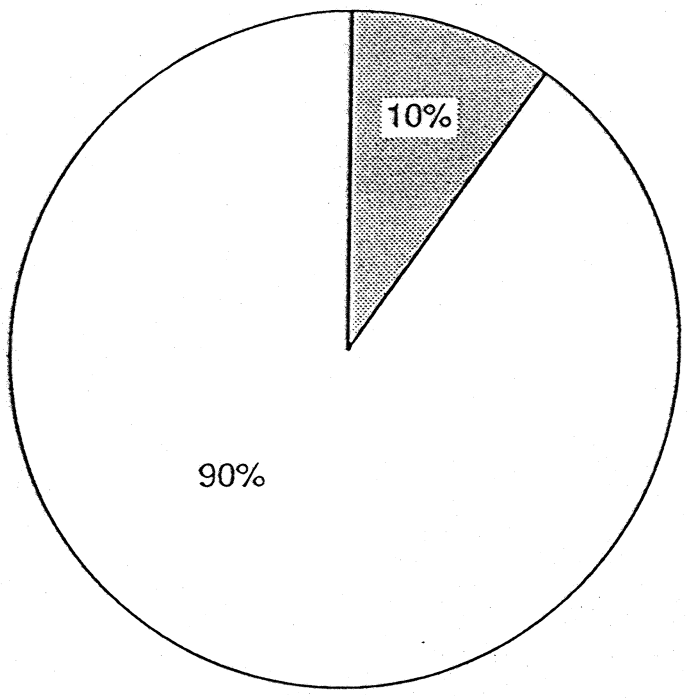
Most land-based disposal or treatment of sludge involves land application, the use of the sludge as commercial products for household or municipal use (known as distribution and marketing), landfilling, and incineration. These land-based options are used to treat or dispose of about 90% of the sludge generated in the United States (Figure 9). Up to one-half of all sludge is landfilled or put in surface impoundments, about one-fifth is incinerated, and about one-fourth is applied to the land (including distribution and marketing) (Figure 9). The use of these options varies geographically and with POTW size. In 1980, for example, coastal POTWs landfilled 54%, ocean-dumped 22%, and land-applied 5% of their sludge.

Small POTWs use land application or landfilling to dispose of almost three-fourths of their sluge, while large POTWs use a greater variety of methods, including incineration.

Sludge is disposed of in marine environments in two ways, by dumping from barges or ships or by discharge from pipelines. Discharges of sludge into estuaries and coastal waters take place only in southern California and Boston and total about 11,000 dry metric tons of sludge or solids each year.

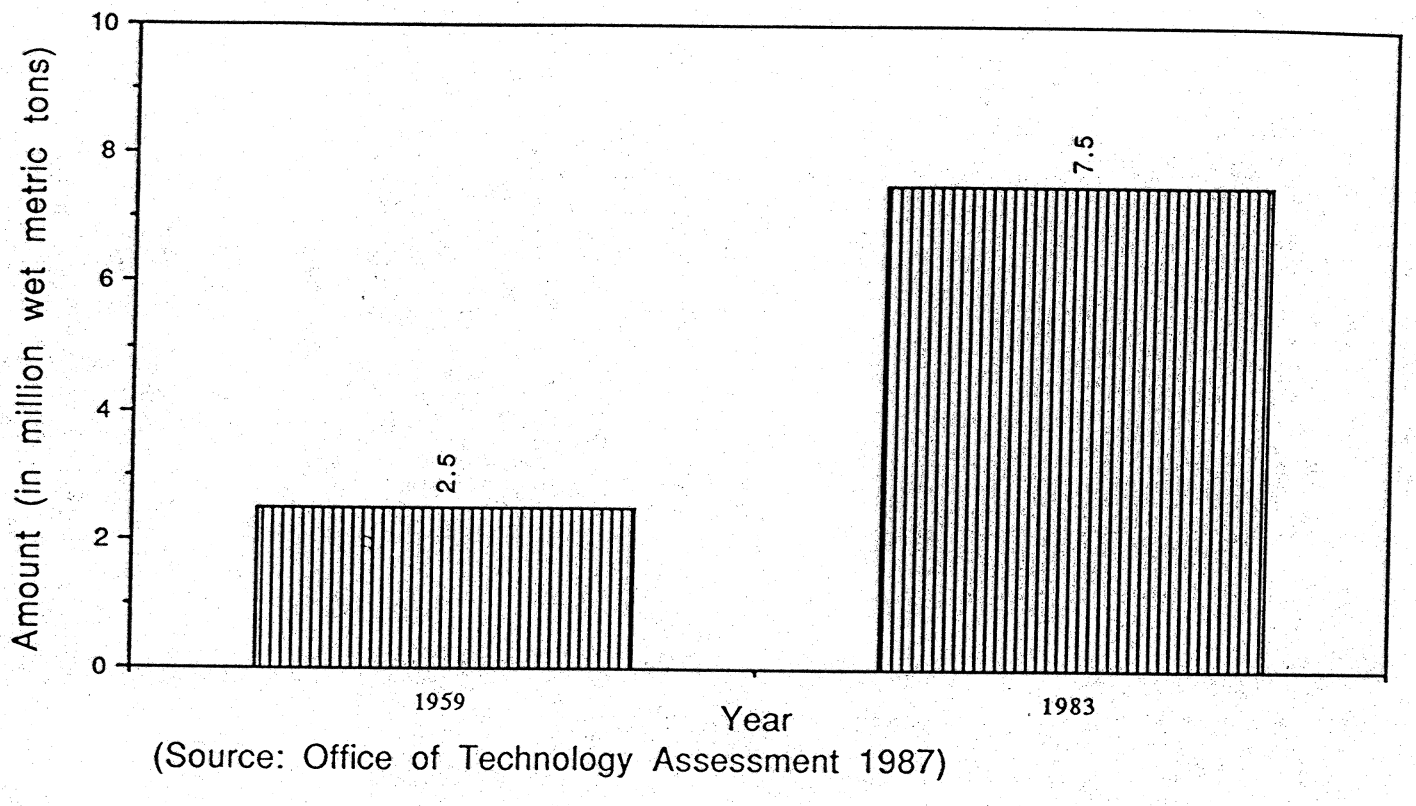
The amount of sludge that is dumped into marine waters by the United States has increased steadily, from over 2.5 million wet metric tons in 1959 to about 7.5 million wet metric tons in 1983 (Figure 10). The amounts dumped between 1984 and 1990 averaged between 7 and 8 million metric tons per year. This is equal to about 7 to 10% of all sludge generated in the

Figure 3. Marine and land disposal of sewage sludge in the U.S. in mid-1980s



marine disposal of sewage sludge
land disposal of sewage sludge
(Source: Office of Technology Assessment 1987)

Fig. 9. Marine and Land Disposal of Sewage Sludge in the U.S. in Mid-1980s.



(Source: Office of Technology Assessment 1987)

Fig. 10. Marine and Land Disposal of Sewage Sludge in the U.S. in Mid-1980s.