Chapter 10

Waste Management, Processing, and Detoxification

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Main Messages

Human and ecosystem health can be adversely affected by all forms of waste, from its generation to its disposal. Over the years, wastes and waste management responses such as policies, legal, financial, and institutional instruments; cradle-to-cradle or cradle-to-grave technological options; and sociocultural practices have impacted on ecosystem health and human well-being. Examples are evident in all countries.

International participation and leadership in waste management and processing is essential. Waste is so diverse in its origin and forms and so pervasive in its impacts, through terrestrial, aquatic, and atmospheric ecosystems, that it has the potential to adversely affect both the inhabited and uninhabited parts of the world. These parts necessarily include the wide range of wetlands relevant to the Ramsar Convention; the species and their land and ocean habitats included in the Convention on Biological Diversity; sites important to migratory species; and grasslands, forests, and wetlands that must be protected to minimize the potential for further desertification. Without the involvement and commitment of the leaders of countries and industries, a global approach to waste management will not be achieved.

Waste management and processing involve one or more of the following processes: reduction, reuse, recovery, or disposal of waste, with practices and technologies differing according to different economic and social circumstances. The desired long-term objective of human responses should be "Avoidance of Waste." The sale of products from waste, whether by simple reuse, recycling and recovery, or by more complex technological processing, has helped to create jobs appropriate to the socioeconomic conditions of the locality or country.

Environmental awareness and educational programs have been successful in allowing consumers and resource users to make informed choices for minimizing waste in their purchasing decisions. Employers have introduced programs to encourage and recognize initiatives by the community to reduce waste. In Japan and other industrial countries, "industry clusters" have been planned, where the waste of one industry is the resource of another—an example of copying nature, or bio-mimicry.

The combined impact of these practices has been to enhance ecosystem services, improve aesthetic conditions, restore habitats for human use and for biodiversity, increase public health and well-being, create jobs, and reduce poverty. Processes for human societies to avoid waste in all its forms are not available.

Industries and governments should select indicators and standardize methods to monitor the sources, types and amounts of all wastes produced. The full costs of each type of waste produced from any proposed new product or process should also be assessed. Leaders of industry and government know that they must have precise details of waste generation, composition and characteristics, and reuse or disposal practices to manage waste, locally or internationally. Currently, the practice of transparent, participatory, and accountable decision-making for ecosystem sustainability and human well-being is lacking in many countries. Although there are gaps in the structure of waste accounting, the countries involved in State of the Environment reporting, such as Canada, The Netherlands, New Zealand, and Australia, are moving to internal standardization. The next step is to develop international standards of waste accounting to allow objective comparison of waste management.

All industries, all communities, and all countries must ensure compliance with waste management laws and regulations, and acceptance of, or changes in, such laws and regulations. Communities have shown willingness to comply with laws and regulations if there is clear understanding of the benefits of such measures, particularly if all stakeholders are involved in the formulation of such laws. Waste cannot always be confined within one locality or area of jurisdiction. Some forms of waste (particularly those associated with acid rain, greenhouse gases, and air quality in general) are transmitted in the atmosphere, which respects no political, terrestrial, or aquatic boundaries.

The rapid advances in technologies, including biotechnology, provide new opportunities for improvement in waste management. The adoption of some of these technologies may require revision of existing laws and regulations.

The dumping of waste in remote places such as deserts and oceans, and across national boundaries, is not acceptable. Moves to have the practice forbidden by international conventions should be supported by enforceable national legislation. Remote-location dumping of wastes is a classic example of the historic "out of sight, out of mind" mentality, now rejected by all internationally responsible organizations and industries. However, the challenge of safe disposal of waste often requires interim storage while new technologies are developed. Remote areas, deserts, and oceans should not be seen as convenient locations for such "interim" storage. Such international arrangements as the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal, the Kyoto Protocol on the Protection of the Ozone Layer, and the London Convention on the Prevention of Marine Pollution by Dumping of Wastes, have yielded some positive results in creating awareness among communities and adoption of alternate technologies and compliance by industries.

The essential role of water in life processes should be valued. Wastewater is a resource in many countries and the practice of safe reuse of water should be encouraged. Water, whether freshwater or marine, is both essential to life processes and a carrier and transporter of soluble and insoluble waste, solid, liquid, and gaseous.

The challenges to removing the different types of waste from waters are diverse. Modern technologies such as bioremediation, membrane filters, trickling filters, activated sludge process, vascular aquatic vegetation, and anaerobic digestion can now be used to remove all contaminants from polluted waters. Special care should be taken in the use of different types of "gray" water and effluents for human needs, to be supported with appropriate community education programs.

10.1 Introduction

Each individual living species and each type of process or operation will have by-products in its activities, processes, or operations. In nature, diverse ecosystems (notably rainforests and coral reefs) have achieved sustainability by the coexistence of a wide range of different species, whereby the waste of one species has become the resource of another, and there is an apparent balance in the system. If for any reason one species becomes dominant, the sustainability of the system is challenged, and "nature" responds to that imbalance.

At the global scale, humans have become dominant in the ecosystem, both by their numbers and by their ability to modify systems and to extract and transform natural materials, and fabricate, use, and transport the new materials. However, humans have been slower to respond than nature can, and only in recent decades they have acknowledged the need to copy the examples of nature (bio-mimicry) to avoid accumulation of waste and address the challenge of waste management holistically.

Waste and waste management are significant components of many chapters in the Millennium Ecosystem Assessment, and specific aspects of waste generation and/or management are found in relevant chapters in this and other MA volumes. The general principles of the Responses in this chapter relate to all waste but are more specifically related to *MA Current State and Trends,* Chapter 15. However, because urban and rural wastes are issues that affect everyone, there is a further concentration of specific examples dealing with responses to urban and rural waste.

Continuously increasing quality of life and high rates of resource consumption have had an unintended and negative impact on the urban environment—by way of the generation of wastes far beyond the handling and treatment capacities of urban governments and agencies. Cities are now facing serious problems of high volumes of waste, characterized by inadequate disposal technologies/methodologies, rising costs of management, and the adverse impact of wastes on the environment. These problems, however, also have provided opportunities for cities to find solutions that involve the community and the private sector, including innovative technologies, disposal methods, behavior changes, and awareness raising. Rural areas and rural communities have been affected in many ways, including the unexpected consequences of excess use of N and P fertilizers, pesticides and herbicides, soil contaminants, and soil salinization. Chapter 9 examined the selection of responses for management of excess nutrients, mainly those from fertilizers based on N and P.

The generation of wastes and their management have attracted significant attention by local, national, sub-regional, regional, and international communities. Waste has significant impact on ecosystems, and poses threats to human health and well-being. Waste also threatens the integrity of habitats that are essential to biological diversity.

The challenge is to develop responses to waste issues that can be applied in both developing and industrial countries and that will improve the quality of human life and of the biodiversity of our lands, our seas, and our skies.

10.1.1 Waste Typology and the Main Issues

The MA volume *Current State and Trends* lists the major categories of wastes and contaminants by source and the processes involved in waste processing and detoxification (see MA *Current State and Trends,* Tables 15.1 and 15.2).

Wastes exhibit multiple impacts depending on the ecosystems, ranging from small- to medium-, and ultimately long-term scales. Responses developed must acknowledge those categories and processes and be able to deal with:

- nutrient runoff from excess fertilizers, which constitute significant pollution of terrestrial (Olson 1987) and aquatic ecosystems (Howarth et al. 1999; Ikem et al. 2002; Melillo et al. 2003);
- chemicals and their residues from agro-allied industries, which remain persistent in soils, sediments, water, and the atmosphere after their planned use (Howarth et al. 2000);
- chemical toxins and their metabolic products, and their impact on terrestrial and aquatic ecosystems (Anderson 1994; Chandler et al. 1996; WRI 1992);
- nitrogen and its oxides, which contribute to acid rain (Vitousek and Hooper 1993);
- a vast array of synthetic chemicals—widely used since the 1950s for diverse functions such as the control of pest animals and plants, fuel additives, personal hygiene, etc.—many of which remained persistent in the environment (Adesiyan 1992);
- oils and oily wastes on land and water (Burger and Peakall 1995; Chokor 1996; Colwell et al. 1978; Hay et al. 1996);
- exhaust gases from combustion engines, which have changed air quality and contributed to the enhanced greenhouse effect (UNEP 2002);
- mixed streams of N and P wastes that transform from solid to liquid and to gas, and end up in freshwater and marine ecosystems and the atmosphere (Howarth et al. 1999, 2000); and
- residual materials arising from daily living, tourism, recreation, and communal activities (UNEP 2002).

All living species generate waste. Table 10.1 summarizes the diverse sources of waste and wide range of impact and effect. The focus of this assessment, however, is predominantly on wastes generated by human activities, particularly the ubiquitous urban and rural wastes, which have been described as "a monster" (Onibokun and Kumuyi 1999) and "a nightmare" (Asomani-Boateng 2002).

Although wastes produce goods and services that affect a wide variety of ecosystems (atmospheric, aquatic, and terrestrial), and in the process, confer a negative impact on human well-being,

Table 10.1. Waste Typology, Sources, and Policy Responses

Waste Type	Sources	Policy Responses
Urban solid wastes, putrescible and non-putrescible solids, semi-solids and liquids (residential, commercial, institutional)	human activities	reduce, reuse, recycle, dispose
Inorganic nutrient runoffs	fertilizers	reduce, recycle
Demolition waste, quarry rejects	construction sites, quarries	reuse, recycle, dispose
Oils and oily wastes	industries, mining	reduce, recycle
Hazardous (including clinical) expired drugs, by-products of metabolism, chemical toxins, fecal pellets in benthos, contaminated sludge, incineration ash, leachates, ignitable, corrosive, reactive, or toxic	industries, healthcare facilities, household hazardous wastes, waste disposal facilities	reduce, dispose
Radioactive waste	spent fuel from reactors, tailings from the mining/refining of uranium, medical/academic	reduce, reuse, dispose
E-waste	cell phones, computers, etc.	reduce, recycle
Ammonia and its oxidative products	industries, fertilizers	reduce, recycle
Mixed wastes (containing N and P) from livestock	livestock	recycle
Synthetic chemical wastes	pesticides, biocides, fuel additives, cosmetics, etc.	reduce, dispose
Waste products from combustion (greenhouse gases)	vehicle engines, sea craft, energy production	reduce, alternate fuel use

their appropriate management enhances the benefits that people obtain from ecosystems—improving the provisioning services such as food and fiber production; improving the water quality; protecting biodiversity; improving human well-being, and improving aesthetics for the promotion of recreation and tourism.

The main long-term issues in waste management relate to how humanity deals with the two extremes: ''no waste'' in, and the ''waste-induced pollution'' of, the environment. This is particularly so since waste is an inevitable product of nature (organismal existence). The ''no waste'' end (best-case scenario) of the spectrum is, of course, a daunting challenge to achieve, while the ''pollution'' end (worst-case scenario) is, equally, overwhelming in proffering solutions to the problems it poses. The practical challenge relates to minimizing the adverse impacts of waste and, if possible, transforming waste into a useful product or process. Ideally, one would characterize all the components of waste and assess the threat they pose, singly and in combination with other waste components, to humans and to the ecosystem.

Realistically, we should identify policy response options, seeking a socially acceptable, economically viable, and environmentally sustainable strategy of reducing the predominantly negative impact both on human well-being (including the factors of poverty reduction, quality of life, sound health, cordial social interactions, security of people and property, and personal liberty within the limits imposed by democratic practices and societal values) and on biological diversity (biodiversity) and its habitat.

The practical response to the challenges presented by different types of waste may differ on the basis of socioeconomic and cultural priorities of different countries. The successful high-technology solutions are, currently, generally confined to the richest of the industrial countries. Knowledge should be shared to increase the capabilities and commitment of various developing and developed countries.

The best solution to the problem would be to avoid waste in the first place, but we currently lack the knowledge, the whole-of-society commitment, or the technologies for that. The next objective is to reduce the waste and its adverse impact as far as is practicable. Methods for this reduction will vary according to whether the waste is solid, liquid, or gas, biodegradable/non-biodegradable, hazardous or non-hazardous.

Solid-waste management has traditionally been viewed as a technical (engineering) problem requiring a technical solution by the civil engineering community (Goddard 1995). But now there is a clear need to move away from *waste disposal* toward *waste processing* and *waste recycling* (aiming for eventual *waste reduction*). Some of the defining criteria for future waste minimization and waste avoidance programs will include increased community participation, improved understanding the economic benefits/recovery of waste, focus on life-cycles rather than end-of-pipe solutions, decentralized administration of waste, emphasis on minimizing adverse environmental impacts, and alignment of investment costs and long-term goals.

10.1.2 Wastes in Relation to Ecosystems and Human Well-being

The essential aspects of the generation and management of wastes are depicted in Figure 10.1, which illustrates that the goal is human well-being, which is achievable through the production of multiple *services* (such as food, fiber, water, energy) in the ''niche'' provided by specific *ecosystems*. These ecosystems include terrestrial (that is, cultivated/agricultural land, natural and introduced forests), aquatic (for example, freshwater and marine/coastal waters), and specialized (such as mountain, polar, and island) landscapes. There is a strong relationship between the health of the ecosystem and the health of the human system. Waste generation is moderated by drivers that can be manipulated through a wide variety of *responses* by policy actors and decision-makers to ensure the mitigation of negative impacts of wastes and the adoption/adaptation measures. The type, peculiarity, description, and characterization of wastes generated, and the goods and services provided, are detailed in the next section.

The response policies address the specific aspects of planning and implementation of chosen alternative strategies (Jacobs and Sadler 1990; Soesilo and Wilson 1995), both as they relate to actual management practices and in such ways and manners that are environment-friendly, cost-effective, and socially acceptable. Prominent among these are waste reduction at source (minimization) (Baker 1999); waste recycling (Sridhar et al. 1992; Odeyemi and Onibokun 1997); ecological impact attenuation by conversion practices, for example, wastewater treatment and composting (Asomani-Boateng 2002; Dreschel et al. 2002; Dushenkov et al. 1995; Guterstam et al. 1998; Jana 1998; Rotimi 1995; Robinson et al. 1995; Sridhar and Arinola 1991; Sridhar and Adeoye 2003); waste stream linkages (synergies and antagonisms) (Mitsch et al. 2001; Peterson et al. 2001); transportation and related technologies (Adedipe and Onibokun 1997; Onibokun et al. 2000); and the establishment of institutional partnerships (ISWA 2002) involving the public sector, the private sector, and the community through governance and social property rights linkages (Adedipe 2002; Nsirimovu 1995).

Other management considerations include legal mechanisms, financial instruments, and economic incentives (Burges et al. 1988; Chambers 2003; Costanza and Principe 1995; Reyer et al. 1990; Miranda and Aldy 1996; Onibokun et al. 2000; Panayotou 1990).

10.1.3 Key Drivers of Change in Ecosystems and Services

The major drivers of change in ecosystems services are biophysical, demographic, economic, sociopolitical, technological, social, cultural, and religious. The drivers vary by levels of socioeconomic development. Those for developing countries include:

- *demographic change*: high population size exacerbated by high growth rate of up to 3.5% coupled with rapid urbanization, as in some West African (Onibokun and Kumuyi 1999), Latin American (Onibokun 1999), and Southeast Asian (Zurbrugg 2002) countries;
- *globalization* (adverse effect as raw material producers with minimal value-added) leading to complex and disadvantaged trade relations with industrial countries;
- *frequent changes in government,* resulting in lack of continuity in commitment to waste management and to environmental pollution policy, laws, and guidelines;
- *lack of focus* on the concept of ''resource recognition,'' that is, treating waste as an unused resource;
- *following a ''hard'' rather than a ''soft'' approach,* that is, considering waste management as a responsibility of municipal bodies than helping community-based initiatives and informal mechanisms attain recognition;
- *lack of funds and staff* to handle the ever-increasing problem of solid waste;
- *ineffective management policies and instruments*;
- *poor technology* for the collection, transfer, disposal, and processing of wastes;
- *mass illiteracy,* occasioning indifference to the environment by not adequately linking waste with deprived human well-being;

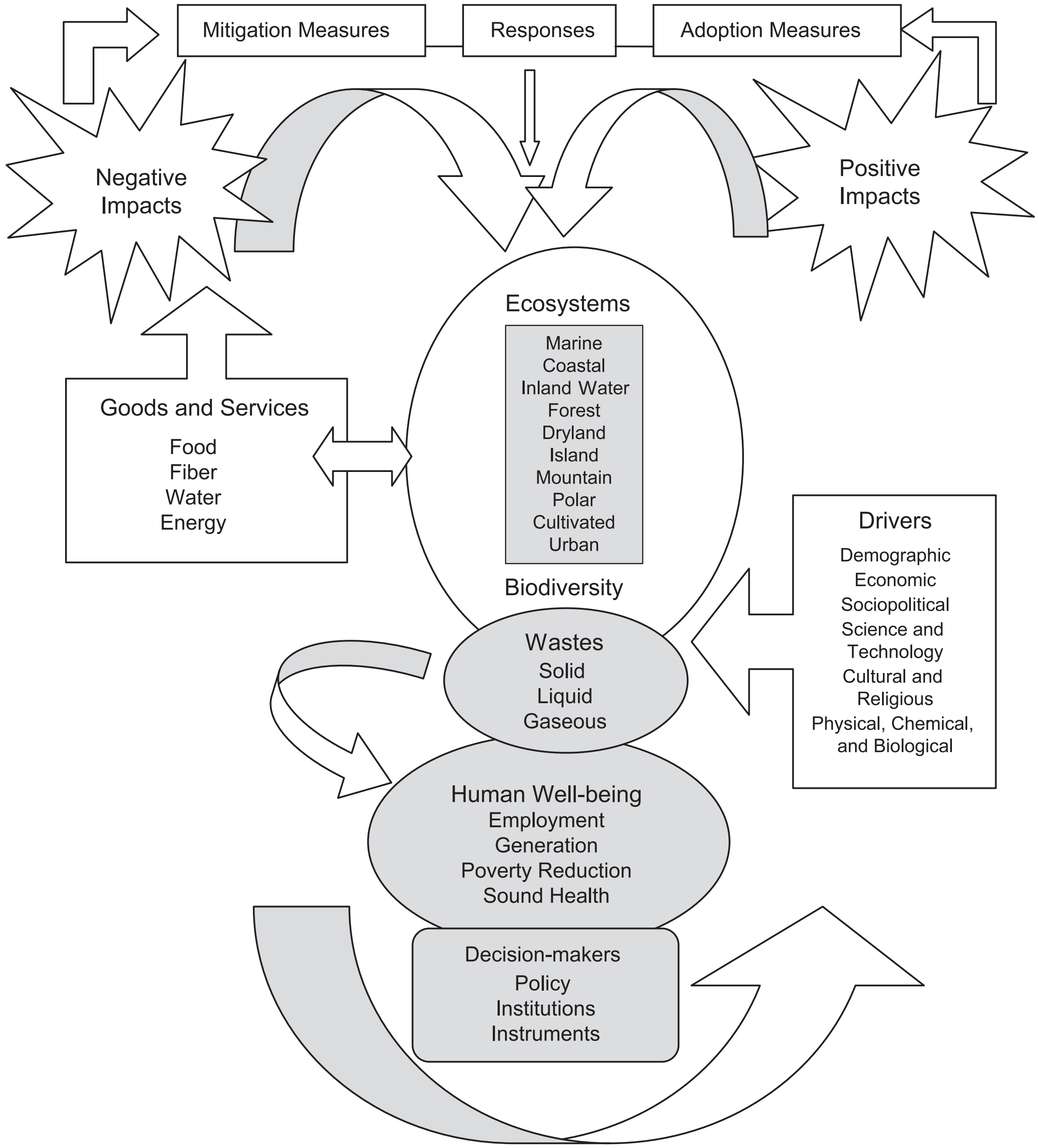

Figure 10.1. Wastes in Relation to Ecosystems and Human Well-being

- *failure to recognize, support, and integrate informal waste recyclers* into municipal solid waste systems in African cities;
- *continued use of old technologies* that continue to generate pollutants; and
- *pervasive poverty and mismanagement of public funds.*

The drivers in industrial countries include the following:

- *emphasis on wealth creation and high consumption* based on technology, industrialization, and self-created favorable international trade balance;
- *a ''use and throw away'' society* that puts little emphasis on concepts of ''reducing'' or ''reusing'';
- *regarding waste management as an ''engineering problem''*; and
- *stable political governance* characterized by transparency and accountability.

In both developing and industrial countries, national waste management policy should involve the following stages:

- waste reduction, which recognizes the costs and benefits of reducing waste;
- the optimal balance between landfill, incineration, and recycling. In developing countries, this choice will tend to be one of balancing recycling (including composting) and landfill in such a manner that recycling efforts do not use up more resources than they save;
- management of uncollected waste, an issue of some importance in developing countries but not of major significance in industrial countries; and
- the choice of regulatory measures to secure waste reduction and optimal disposal.

Around the world, developing and industrial countries have responded to the various drivers of change in ecosystems and services with a range of coping strategies, policies, and practices. These take the form of legal provisioning, improving technologies, fiscal and financial instruments, and institutionalizing waste management. "Zero waste" seems to be a difficult but not impossible task. If various options for waste management can be integrated and applied over long periods, waste minimization can be addressed effectively and sustainably.

10.2 Background and Selection of Responses

This section looks at five categories of responses: legal, technological, economic, institutional, and sociocultural. In the selection of responses, six criteria were used: historical dominance and contemporary relevance, political interest, evidence of positive impact, evidence of damaging impact, integrated design, and cutting-edge innovations.

10.2.1 Legal Responses

For the developed world, although there are copious laws dating back more than a century, there is no uniform effective enforcement (Garbutt 1995; Lieberman 1994); in the developing countries, the major problem is also that of enforcing compliance (Ajomo 1992; Adewale 1996; Onibokun et al. 2000).

The various stakeholders and actors should be involved in designing regulations and guidelines. This is because participation ensures and promotes understanding and acceptance, which helps compliance. More cooperation at the national and the international levels is also desirable to ensure that international agreements are honored. They are frequently not so honored, principally for political national interests, including the national economy, as has been the experience with the Basel Convention and the Kyoto Protocol.

A recent study of four West African countries (Gambia, Ghana, Nigeria, and Sierra Leone) identified conflicts in constitutional provisions in relation to human resource requirements and financial resource allocations, compounded by the weak revenue base of local (municipal) governments, as a major stumbling block to effective waste management and pollution abatement (Onibokun et al. 2000). The response option for developing countries lies in continuing public sector responsibility, as in the Latin American countries, or a change to privatization, particularly in mid/high-income neighborhoods. However, in low-income/high-density residential neighborhoods where waste collection and disposal is problematic, waste management has been a failure. Whatever overall policy framework is adopted, and laws are enacted, there must, in all cases, be continual processes of legal reforms to provide the underpinning for institutional and governance structures. This is to be buttressed with linkages that would promote transparent, participatory, and accountable environment-friendly decision-making for ecosystem sustainability.

10.2.2 Technological Responses

A variety of technological responses have been developed, some local and some specific to particular types of waste. In industrial countries, waste collection services often depend on prior household or workplace sorting of domestic waste into organic material, paper and cardboard, metal containers, recyclable plastics, and glass containers, placed in separate collection bins, to facilitate reprocessing and recycling, subsequent to commercial collection. The technologies extend to the design of special collection vehicles for these bins.

Whereas the concept of waste management requires a global approach, many specific waste management technologies are financially and operationally costly and thus not affordable for many developing countries. Additionally, most industrial-country technologies transferred to developing countries without expert technical and maintenance support result in failure. Examples include packaged wastewater treatment facilities for municipalities and industries, heavy-duty waste transportation equipment, and large-scale composting plants.

For the developing countries, short-term and medium-term solutions lie in the use of relevant and appropriate technologies such as biogas plants, constructed wetlands, waste stabilization ponds, appropriate solid-waste cartage and disposal machinery (Adedipe 2002 Onibokun et al. 2000), and relevant composting schemes (Zurbrugg 2004). Governments are often tempted to choose inappropriate technologies due to social pressures. One option is for developing countries to mass-produce small-scale equipment that is amenable to community access. With improvement in access over time resulting from enhanced road networks, medium and large scales of equipment characteristic of the developed economies would be justifiable. India and China are evolving ecological engineering for solid waste, sewage sludge, and wastewater. For the developed world, the issue of energy savings and operational cost-effectiveness are the response options for long-term solutions. These response options demand appropriate policy reforms toward ecosystem sustainability promotion for, and by, decision-makers. Whatever options are considered must recognize the scale and location of operations as well as the distance between the site operations and the end-users.

In situ operations are often economic and thus widely adopted (Sridhar and Adeoye 2003); see Boxes 10.1 and 10.2 for industrial-country and developing-country examples.

Certain technological or management innovations have proved beneficial in mitigating the damage to the environment. Wastewater management, with percolating filters/trickling filters, and the activated-sludge method of treatment, improved the environment many times over since 1914 (Edgar et al. 1998; Krogman et al. 2001). The advances were more pronounced during World Wars I and II, and continued during the subsequent industrial development of various European countries, the United States, Australia, and others. The cleaning up of the Thames and Rhine rivers and various lakes in the Nordic countries is a remarkable example of innovative governmental commitment.

Relatively cheap technology innovations using oxidation ponds/waste stabilization ponds, floating vascular aquatic vegetation, including gray water reuse and duckweed ponds, reed-bed or root-zone technology, and constructed wetlands have considerably helped the poorer developing countries (Aluko et al. 2003; Jana 1998; Urban Agriculture Magazine 2002). Such waste treatment systems can actually have a measurable impact on poverty. The duckweed ponds in Mirzapur, Bangladesh, or the gray water systems in Jordan, for example, reduced poverty by 10% in the homes with such systems (Faruqui and Al-Jayyousi 2002).

Development of synthetic polymers, used to make plastics such as polyethylene, polypropylenes, polyesters, and polyamides (including nylon), has revolutionized the types of containers for products, the types of material for packaging, and the materials used for carry-bags. However, most of these polymers are not biodegradable and, once used and discarded, become major waste management challenges. In cities like Cairo, Manila, Kolkata, Mumbai, Hong Kong, Beijing, Accra, Lagos, and others, the management of plastic waste has become a nightmare for city authorities. In other cities, such as in Australia, non-biodegradable plastic carry-bags are being phased out in retail stores by 2008. The introduction of biodegradable plastics is a welcome environment-friendly development. (See Box 10.3 for steps being taken in the European Union.)

BOX 10.1

Australian Strategy for Zero Solid Waste Management (www.nowaste.act.gov.au)

In December 1996, the government of the Australian Capital Territory (ACT) initiated the *No Waste By 2010—Waste Management Strategy for Canberra* for the nation's capital, with a population of 320,000. The objective is to achieve, by 2010, a society where no waste is sent to landfill.

The strategy was developed after an extensive community consultation process and reflects the views and expectations expressed by the community. It aims to build on the community's willingness to *avoid purchases* with excessive packaging, *recycle* materials, and *improve* environmental outcomes by treating all materials as potential *resources.* It is being implemented in phases. The first step involved developing an inventory of wastes, establishing recovery infrastructure, and introducing appropriate charges to provide monetary incentives. The second step was to identify current series activities. Further programs are being developed for implementation between 2003 and 2010.

ACT No Waste, a business unit in the Department of Urban Services, provides a number of services to the community and supports businesses with reuse initiatives, notably:

- curbside recycling collection,
- free drop-off services for green wastes,
- regional drop-off centers for recyclable materials,
- concrete, masonry, and steel processing facilities,
- reprocessing of old paint to an as-new product,
- community recycling of unwanted household items through "Second-hand Sunday,"
- metal and oil recovery facilities at the two landfills,
- landfill salvage operations at the landfills, where reusable goods are sold to the public, and
- a Resource Recovery Estate, which provides sites for inventive business ideas for recycling and resource recovery.

Education has been found to be a critical factor in achieving the strategy goals, given the free flow of information in the community participation process. In the first six years, significant progress was made in increasing resource recovery, which rose from 22% in 1993/94 to 64% in 2001/02. The strategy has sparked worldwide interest, with more areas and more governments setting similar goals.

BOX 10.2

Nigerian Waste-to-Wealth Scheme of Waste Conversion to Organo-mineral Fertilizer (Sridhar and Adeoye 2003)

Nigeria (population 120 million) is a federation of 36 states and the Federal Capital Territory of Abuja. Ibadan, the capital of Oyo State, is the largest city in West Africa and the third largest in Africa; it has a population of 2.5 million. Under its Environmental Planning and Management Program initiated in 1994, various stakeholders (federal, state, and local governments; the private sector; and communities) evolved a model initiative for waste management for Ibadan.

A major traditional market, *Bodija,* was selected for the collection of organic wastes. Traders in the market, local and state government representatives, professionals from the city's tertiary institutions (The University of Ibadan, The Polytechnic, Ibadan), and community leaders were constituted into the Waste Management Working Group that mapped out a strategy and action plans, all aimed at converting waste to fertilizer, creating a decent environment, promoting good health, producing goods and services, generating employment, and thereby reducing poverty.

By July 1998, an organized system of waste collection and a 25-ton per day capacity organo-mineral fertilizer facility were established. The state government provided funds, while other stakeholders contributed essential inputs. The indigenous technology was simple, employing 25 persons. The program stimulated the traders positively toward segregation of waste to feed the fertilizer plant, achieving a 90% enhancement within a year of commencement. The plant produced 10,000 kilogram and steady revenue of $20,000 per month.

The value of the project having been demonstrated, the Oyo state government has decided to increase the number of plants to ten, to serve a number of agricultural communities. The second one has been commissioned at the community level. Five other states (Akwa-Ibom, Kaduna, Kano, Lagos, and Ondo) have also shown interest in adopting the project for their capital cities. Cow dung, hitherto a nuisance, has become marketable, with a high level of patronage by small-scale peri-urban farmers, who value its good soil properties, consequently reducing the demand for chemical fertilizers in these communities.

BOX 10.3

European Union Limits Organic Waste in Landfills (Heermann 2003)

All waste sent to landfill must be treated, unless it is inert or treatment does not reduce the quantity of the waste or hazards to human health or the environment.

The Directive sets the following targets for reducing the biodegradable municipal waste added to landfills, compared to that produced in 1995:

- by 2006, reduce to 75%
- by 2009, reduce to 50%
- by 2016, reduce to 35%.

Composting has long been viewed as environmentally beneficial, particularly in tropical developing countries. Proper facility design and operation can mitigate or overcome adverse environmental impacts arising from ammonia, nitrate, phosphorus, heavy metals, and pathogen components, simultaneously reducing discharge of nutrient chemicals into the environment. However, in the industrialized countries compost is becoming unpopular because of the toxic chemicals in the waste streams (Zurbrugg et al. 2004).

10.2.3 Financial and Economic Responses

To be effective, a waste management system requires a sustainable revenue base to cover the capital (site, equipment, and facilities), maintenance, and personnel costs. The major problem in this regard involves cost-sharing among the interacting agencies either at the national and state levels (as in most developing countries of Africa and Asia) or at the unit levels of municipal (local) waste management (prevalent in industrial countries and some South American nations, notably Bolivia, Colombia, Guatemala, and Haiti). The issues include the specific roles of private-sector dominance (in the North) and public-sector prevalence (in the South) and the extent to which cost recovery (user, disposal, and refund-deposit charges) can improve waste management.

For developing countries in particular, waste management may contribute to societal well-being through poverty reduction using waste-to-wealth activities (which produce goods and services), but what are the social costs in terms of health hazards? Another important issue is the need for full-cost accounting. Where the cost estimates cover only waste management service costs and not the social and environmental costs, the selected waste management services might be harmful to the environment and human well-being in the long term. For example, in India, Nigeria, and Thailand, the open dumpsites, which produce goods and services through material recovery and recycling, make the waste-pickers vulnerable to physical injury, communicable diseases, poisoning, and zoonotic infections (Adedipe 2002). The specific economic instruments used, particularly in developing countries, must also recognize the level of poverty in relation to national income and distribution and political sensitivity, by way of infusing humanistic responses, as Panayotou (1990) has highlighted. As far as is practicable, the burden and cost of pollution must be borne by the polluter (NRC 2000).

The financial and economic responses would be more effective if we could answer the question "what is the economic nature of solid waste?" Solid wastes are consumption and production residuals. Production and consumption are driven primarily by economic variables, particularly price and incomes, although population size and concentration are also important factors (Reyer et al. 1990). If a problem is economic, it means specifically that it is characterized by scarcity and governed by choice. It follows then that solid-waste management is an important economic problem. Importantly, in our economic system, achievement of a cost-effective balance will require careful use of the market and price system to achieve waste management objectives. These objectives can be attained cost-effectively only by instituting rules that allow maximum flexibility (substitution possibilities, to the economist) in consumption and production decisions, subject to the constraint that all of the costs are paid.

The entire production and consumption cycle involves solid-waste generation and management (Goddard 1995). Governments in both developed and developing countries for the most part have relied on regulatory instruments in their efforts to mitigate the problems of solid-waste generation, collection, and disposal. But there is growing interest in some countries in the application of economic instruments in order to improve the efficiency of the waste management process.

In industrial countries, and some developing countries (for example, Nigeria) (FRN 1991), the following economic instruments have at one time or another been under consideration, or have been implemented as part of a waste management strategy: ambient standards; effluent standards; emission standards; performance standards; product standards; process standards; land use regulations; shoreline exclusion or restrictions; local ordinances; permits; protected area designations; pollution tax; product charge; administrative charge; tax incentives; subsidies; enforcement incentives; noncompliance fee; property rights; environmental assessment; need-based environmental communication and public participation programs; recycling credit (to stimulate increased recycling activity); landfill disposal levy (to reduce the amount of waste put in landfills); product charge (for example, packaging tax, to discourage overpackaging); tax concessions (to stimulate reuse/recycling or other activities); deposit refund systems (to increase the recycling of selected items such as batteries, or encourage returnable container systems); levy/tax on virgin raw materials (to influence the relative prices of primary and secondary recycled materials); and user charges (for example, household waste charges, to discourage the throwaway ethic and encourage reuse/recycling).

Financing charges (user charges) have been used to facilitate the collection, processing, and storage of waste, or the restoration of old hazardous waste sites. Incentives charges (for example, product charges) on the other hand can, among other things, be used to stimulate increased reuse/recycling.

Economic instruments also have other properties, including a revenue-raising capacity. This feature will be of particular importance in developing countries that lack basic waste treatment facilities and infrastructure. Revenue raised via waste-user charge (based on collection and/or disposal costs), for example, could be "recycled" into new or improved waste collection treatment and recycling facilities in the local area. A balance will need to be struck in terms of the level of the charge that could be levied, so that a meaningful amount of finance is raised, without at the same time stimulating extensive "illegal" dumping or corrupt practices.

Other economic instruments that appear to offer some advantages in the developing-country context are recycling credits, tax concessions, and deposit refunds. The first two instruments could involve fairly modest sums of finance but still increase recycling activities.

10.2.4 Institutional Responses

Institutional responses in their generic context embrace a set of rules that are based on the social values of the people, approved by the people through wide-ranging mechanisms, and allowed to operate freely in the society. This simple definition buttresses the concept of global governance as the sum of the many ways individuals and institutions (public and private) manage issues (Commission on Global Governance 1995). In its application to waste management, it is the process by which there is a defined structure for administering effective waste management. This demands the participation of all stakeholders concerned and creates a mechanism for transparency, accountability, and public pressure-driven commitment of government to effective and sustainable waste management operations and practices.

In industrial countries, the assumption is that there is an existing private sector to which certain public-sector functions may be transferred. But in developing countries, a viable private sector does not exist or exists in an embryonic (formative) stage. Proponents of privatization argue that it improves the efficiency and effectiveness of services previously delivered by the public sector. However, there is evidence that more often than not new inequities and ineffectiveness arise from privatization. There are therefore complexities in the transformation from public to private sector. In waste management, a shared responsibility through public-private sector partnership seems to be the answer, with the public sector providing capital equipment, promulgating laws, and conducting research, and the private sector taking responsibility for management operations, including health risk reduction and the promotion of overall human well-being (Sappington and Stiglitz 1987). Community-based organizations should be involved in this process as stakeholders, in accord with the proposal of Nsirimovu (1995) that human rights and participatory governance should be focused on the individual as the prime subject of all developments, including urban waste management.

Stakeholder participation can be encouraged by including waste prevention and resource recovery explicitly, by encouraging the analysis of interactions with other urban systems, and by promoting an integration of different habitat scales like city, neighborhood, and household (Klundert 2000).

Some of the institutional linkages that would be needed to sufficiently manage waste do not exist or are confused in developing countries. The local (municipal) governments, which are constitutionally charged with the responsibility, invariably lack the equipment base and skilled human resources. The policy response that has to be considered is the establishment of viable units of municipal governance for routine operations, while the state/provincial governments should be responsible for major cost-intensive facilities such as sanitary landfills, incinerators, and wastewater treatment plants. Consequently, state governments should work out partnerships with the national governments. Where there is need, regional/global collaboration should be encouraged. For the industrial countries, more stringent governance reforms are the response option. For example, in the United States, the *Toxic Release Inventory* has led to dramatic decreases in corporate emissions. Among developing countries, Nigeria's recent *Inventory of Hazardous Wastes* has been a tremendous response option, contributing to waste and ecosystem management (Osibanjo 2002).

At the global level, the protocols, conventions, and treaties need to be implemented with strict adherence to agreed commitments and prescribed sanctions, including diplomatic interventions. For a start, the local (municipal) and state (provisional, district, prefecture, as the case may be) governance structures should be reviewed for better compliance inculcation.

10.2.5 Sociocultural Responses

Waste management problems are closely associated with society, its beliefs, and its attitudes. The flow of waste from the place of origin to the site of disposal has human dimensions besides the application of technology, given the concept of a city or region functioning as an anthroposphere. Effective resource management must be prescribed to closely fit particular societal norms and values, since governance is in constant flux and operates in an ''established milieu'' even in epistemic societies, with the ultimate aim of exercising power in the management of a country's economic and social resources for development. Human rights and individual liberty, within the limits imposed by democratic principles, must also be respected (Nsirimovu 1995).

Knowledge and attitudes govern the practices. There is need to motivate change toward more environmentally sound attitudes at various levels, for example, home, school, and workplace. Education plays a key role. When developing educational programs to motivate changes in behavior, it is important for their success to include stakeholder input and to understand in-depth behavioral aspects (Okpala 1996). Obviously, the methodology options will differ with sociocultural value content of each community and nation. Generally, but particularly in developing countries, there are two sets of options for educating about waste clearance: formal and informal, these being the incorporation of waste management into the curriculum on environment and sustainable development (for the formal) and the establishment of environment and conservation clubs (for the informal) (Okpala 1996).

There is need for a shift from a single-purpose focus on ecological aspects to a more multifaceted approach that routinely considers social and risk analysis, implications, and management. The ultimate aim entails analyzing aggregate environmental degradation costs, establishing systems of national resource accounting that reflect environmental damages and losses, correcting market prices to reflect full costs (and benefits), and offering incentives such as rebates for industries adopting anti-pollution measures as well as disincentives such as taxes (Panayoutu 1990, Reyer et al. 1990).

Although sociocultural response options are theoretically sound, their practical application has not been as rewarding as globally expected; in developing countries, they have yet to be adopted as part of socioeconomic policy response regimes (Chokor 1996).

10.2.6 The Need for Integrated and Sustainable Waste Management

Responses when applied individually have been able to handle the issue of waste management only partially. Thus it becomes imperative to integrate efforts in a planned manner. Integrated waste management implies that decisions on waste handling should take into account economic (including technical in relation to its costs), environmental, social, and institutional dimensions. Economic aspects may include the costs and benefits of implementation, the available municipal budgets for waste management, and spin-off effects for other sectors in the economy in terms of investments. The environmental dimension may consist of local problems (increased risk of epidemics and groundwater pollution), regional problems (resource depletion and acid rain), and global problems (global warming and ozone depletion). Social aspects include employment effects for both the formal and the informal sectors, impact on human health, and ethical issues such as the use of child labor. Finally, the institutional dimension of integrated waste management aims at developing a system that effectively involves the main stakeholders.

''Integrated'' refers to the integration of:

- different aspects of sustainability (technical, environmental/public health, financial, etc.);
- different collection and treatment options at different habitat scales, that is, household, neighborhood, and city level (operational interaction);
- different stakeholders, including governmental or nongovernmental, formal or informal, profit- or nonprofit-oriented (cooperation, linkages, alliances, economic and social interaction); and
- the waste management system and other urban systems (such as drainage, energy, urban agriculture, etc.).

10.3 Some Aspects of Responses to Waste

As identified in MA *Current State and Trends* (Chapter 15), the sources of waste and contaminants, and their impacts, are numerous and continue to grow. Society must be alert to address the challenges that new wastes present. Not every human response has been successful, and there are lessons to be learned from the past. This section considers some examples of past activities and highlights the need for holistic approaches to satisfactory responses to waste.

10.3.1 Historical Considerations

The history of waste and waste management, in general, is intricately bound with the history of solid waste, given its ubiquitous nature and visibility. It is also inevitably tied to civilization. For most of the last two million years humans generated little ''garbage''; what was produced was easily disposed of through biodegradation, which was a simple ecosystem service. The rate of garbage accumulation in the ancient city of Troy was calculated to be 1.4 million tons per century (Rathje 1990).

Sanitary sewers were found in the ruins of the prehistoric cities of Crete and the ancient Assyrian cities. Storm-water sewers built by the Romans are still in service today. Although the primary function of these was drainage, the Roman practice of dumping refuse in the streets caused significant quantities of organic matter to be carried along with the rainwater runoff. Toward the end of the Middle Ages, below-ground privy vaults and, later, cesspools were developed. When these containers became full, sanitation workers removed the deposit at the owner's expense and the deposits were used as fertilizer at nearby farms or were dumped into watercourses or onto vacant land. A few centuries later, there was renewed construction of storm sewers, mostly in the form of open channels or street gutters. At first, disposing of any waste in these sewers was forbidden, but by the nineteenth century it was recognized that community health could be improved by discharging human waste into the storm sewers for rapid removal. By 1910, there were about 25,000 miles (40,225 kilometers) of sewer lines in the United States which have increased manifold today. U.S. marine waters are estimated to receive over 45 million metric tons of wastes per year (UNEP 2002).

Accumulation of waste prompted New York City to introduce incineration as a response (Breen 1990). Following this seeming success, as many as 700 cities adopted the use of incineration, further popularizing incineration as a viable societal response. Given that incineration response also created air pollution, a second phase of response necessitated the use of sanitary landfill.

While incineration was a nightmare in the early part of the last century, more advanced technologies using high temperatures have yielded wider acceptance by people and policy-makers, as modern incinerators produce less emissions and most of the toxic substances are further oxidized. This has become a very handy tool for managing industrial and infectious hazardous wastes (Tchobanoglous et al. 1993). In some cases, incineration is still not the method of choice and it has been replaced with irradiation techniques. But the latter are not affordable in the developing countries.

Legal response in the United States was later provided by the enactment of the U.S. Solid Waste Disposal Act of 1965 and the Resource Conservation and Recovery Act of 1976. This Act also established what later became the ''cradle-to-grave'' system of hazardous waste management (Soesilo and Wilson 1995). In developing countries, however, from the 1930s to date, their own response to the need to manage wastes has been by the use of ''open dump sites,'' as in Africa (Onibokun et al. 1995), Asia (Hoornweg 1999; Zurbrugg 2002), and elsewhere (Lardinois and van de Klundert 1995; Klundert 2000). The point must be made, however, that the effectiveness of open dumping differs from country to country. Garbage mountains point up an important truth: ''Efficient disposal is not always completely compatible with other desirable social ends—due process, human dignity, and economic modernization'' (Rathje 1990, pp. 32–39).

In terms of liquid wastes, perhaps the first alarm on unsanitary conditions and their relation to health and disease is credited to Sir Edwin Chadwick of Britain, who in 1842 wrote the classic report on ''Sanitary Conditions of the Labouring Population of Great Britain.'' The cholera epidemics of 1849 and 1853 created the need for a response when society demanded the ''removal of dirt.'' John Simon in 1848 developed the famous British Public Health System, which was accepted by the United States and some parts of Europe (Dubos et al. 1980), and later by other countries as well.

The history of other forms of wastes is not as richly detailed as that of liquid and solid wastes. Only recently have scientific studies conclusively shown that wetlands contribute substantially to comprehensive human health and welfare (Hemond and Benoit 1988; Queen and Stanley 1995) and that such positive ecosystem functions are threatened by chemical pollution (Mitsch and Gosselink 1986). These developments were further strengthened through comprehensive and standardized analytical techniques during the 1970s (USEPA 1979), with applications to different ecosystems, notably freshwater, wetlands, forests, arid and semiarid lands, and soils (Linthurst et al. 1995).

10.3.2 Political Interest in the Responses

Since 1972, there has been reasonably sustained political interest at the national, and particularly global level, of concerns arising from the reported striking effects of DDT on wildlife (Carson 1962) and occurrence of pesticide residues in various foods, including mothers' milk (UNEP 2002). With such global sensitization, but arising from continuing degradation of the environment through a multitude of agents and causes, prominently including wastes, there was a decisive turning point with the Stockholm Conference on the Human Environment in 1972, which led to the establishment of UNEP. Despite the intensive coordinating activities of UNEP, the pollution of the environment did not abate from source, nor was it effectively controlled by the polluting economic activities of nations. Given the sad state of the continually deteriorating environment, the UN enunciated Agenda 21 in 1989, which led to the UN Conference on Environment and Development (UNCED); the first Earth Summit, in Rio de Janeiro, Brazil in 1992. For the first time, the world took the bold step to map out strategies for the integration of environment concerns with all development issues aimed at improving human well-being (Adedipe 1992). Ten years later, the whole issue was revisited at the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002, given that the expected goals of Agenda 21 were yet to be substantially achieved. The WSSD came up with the Millennium Goals, which are in the continuing thrust for human well-being. (Table 10.2 summarizes the milestones in the modern history of waste management.)

10.3.3 Evidence of Positive Impacts of Responses

Waste management practices and policies over the last three decades have resulted in positive responses in terms of improvement of ecosystems. Some positive impacts of the responses identified (Hu et al. 1998; Jana 1998; Pillai et al. 1946, 1947; Smit 1996; Sommers and Smit 1996; Sridhar et al. 2002) are:

- Waste recycling activities have been found to result in improved resource conservation and reduced energy consumption as well as reduction of heavy metal contamination of water sources.
- In the Baltic Sea, the mercury levels of fish caught were reduced by 60% due to stringent pollution control measures.
- Major rivers such as the Thames have supported biodiversity, as is evident from the reappearance of salmon after rigorous pollution control measures. The ten-year ''clean river'' program initiated by the Singapore government in 1977 at a cost of US $200 million has brought life back to the Singapore River and the Kallang Basin, with increased dissolved oxygen levels ranging from 2 to 4 mg per liter (UNEP 1997).
- Phasing out of lead from gasoline has reduced lead emissions from vehicular sources.
- Wetlands have been widely reported to absorb significant amounts of anthropogenic pollutants.
- Ferti-irrigation practices have significantly improved the economic base of low- income communities in urban areas.

In the tropical countries in particular, controlled and judicious use of aquatic weeds such as water hyacinth (water hyacinth treatment plant for wastewater) and blue green algae (waste stabiliza-

Table 10.2. Milestones of Waste Management Responses

Year	Response
1972	• United Nations Conference on the Human Environment, Stockholm • UNEP established • UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage
1980	• International Water Supply and Sanitation Decade begins
1982	• United Nations Convention on the Law of the Sea
1989	• Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal
1990	• Eco-efficiency established as a goal for industry
1992	• United Nations Conference on Environment and Development (Earth Summit), Rio de Janeiro • Convention on Biological Diversity
1996	• United Nations Conference on Human Settlements (Habitat II), Istanbul • ISO 14000 created for environmental management systems in industry
1997	• Kyoto Protocol adopted • Rio + 5 Summit reviews implementation of Agenda 21
2000	• Cartagena Protocol on Biosafety adopted
2001	• Stockholm Convention on Persistent Organic Pollutants
2002	• World Summit on Sustainable Development, Johannesburg
2003	• World Water Forum, Kyoto, Japan

tion ponds) for treating small wastewater flows helped in improving environmental sanitation and the by-products provided protein and mineral needs of livestock.

10.3.4 Evidence of Damaging Impacts of Responses

Most of the established waste management practices such as landfills, incineration plants, and wastewater treatment plants have been shown to have negative impacts. Hazardous wastes are a particular case in point (Lieberman 1994; Soesilo and Wilson 1995). The types and quantities vary significantly from place to place and affect human health and well-being in terms of increased numbers of new cancers, abortions, mutagenic and teratogenic effects on the newborn, and increased morbidity and mortality (Adesiyan 1992).

Some waste management facilities have become difficult to maintain due to local policies and regulations, and some countries resorted to transboundary movement. In Nigeria, for example, hazardous waste from Italy was dumped in Koko (a small coastal town in southwestern Nigeria), generating a diplomatic furor between Italy (transporter) and Nigeria (recipient). The hazardous waste dumped eventually led to some deaths. Using the polluter-pays principle, the exporter of the waste was compelled to return it to Italy and to carry out remediation activities. Following the unfortunate incident, Nigeria created the Federal Environmental Protection Agency in 1989; since then, several decrees and regulations have been enunciated to improve the environment (Aina and Adedipe 1991).

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal aims to minimize the creation of such wastes, reduce their transboundary movement, and prohibit their shipment to countries lacking the capacity to dispose of them in an environmentally sound manner. The Convention notwithstanding, such transboundary movement keeps recurring, to the detriment of human and biodiversity well-being.

Another instance of well-documented negative impact is the practice of irrigation with wastewater. In Pakistan, for example, over-applied wastewater with insufficient drainage resulted in degradation of soil structure, visible soil salinity, and the delayed emergence of wheat and sorghum due to excessive nutrients from the ferti-irrigation practice. Further, farmers using raw wastewater for irrigation are five times more likely to be infected by hookworm than those using canal water (Scott et al. 2004). Also, irrigation with industrial wastewater has been associated with a 36% increase in enlarged livers and 100% increase in both cancer incidence and congenital malformations in China compared to areas where such practices were not adopted (Yuan 1993). Another example is in Japan, where chronic cadmium poisoning from wastewater use caused the Itai-Itai disease, a bone and kidney disorder (Osibanjo 2002; WHO 1992).

10.3.5 Integrated Design of Responses

Integrated responses—which consider the interactions and interdependencies among the regulatory, economic, technological, and institutional elements—are the beginning of a holistic approach to waste management and processing.

In a comprehensive mode of integration in the Middle East, gray water treatment and reuse in home gardens is one means of dealing with overflowing cesspits that would otherwise contaminate "wadis" and the shallow groundwater table. This response conserves fresh water by recycling it and, perhaps most importantly, helps to reduce poverty by offsetting food purchases by the poor. To be sustainable, this response must be integrated: in terms of regulations, gray water use must be made legal—it is often illegal in both developed and developing countries—and housing bylaws and standards must be changed to separate black and gray water pipes to facilitate gray water use. Second, a major appeal of the policy is economic—the poor are willing to install the gray water systems at their own cost because they know that their neighbors with installed systems are generating income as a result.

Technological aspects of the policy that must be addressed are: building the capacity of universities and research institutions to teach, train, and do research to improve gray water reuse technology, and building a cadre of plumbers who know how to install, maintain, and repair the systems. Finally, institutions such as departments of agriculture need to be reformed so that they support both traditional rural agriculture as well as peri-urban agriculture. In addition, departments of water, environment, and agriculture must develop integrated and consistent policies that facilitate gray water reuse (Faruqui and Al-Jayyousi 2002).

Ecohouses may be good models where all the wastes generated are integrated into the community for farming, livestock development and human well-being. The Australian Capital Territory's '"zero waste to landfills by 2010" strategy is another practical experiment; through a range of recycling and reuse initiatives its goal is to have very little disposable waste by 2010 (Baker 1999).

10.3.6 Cutting-edge Innovations

Certain technological or management innovations have proved beneficial in mitigating the damaging effects of waste on the environment, and in recent years, business firms and organizations have been established specifically to develop "smart ways" to deal with waste. They can include biotechnology, and may well result from smart observations of how nature itself deals with or removes waste. Bioremediation of coastal and industrial waters, where eutrophication occurs, can be affected using naturally occurring microorganisms or macroorganisms to remove the waste, and also to generate valuable and salable products.

Halogenated organic compounds (such as DDT, PCB, and the halogenated dioxins) can be degraded by a combination of bacterial, chemical, and irradiation techniques. Whereas the carbon-halogen bonds of halogenated hydrocarbons are not common in natural products from the land, they are very common natural products from the sea, and marine microbes are able to degrade many of the persistent synthetic halogenated organic substances. There is much we can learn from the sea.

Not all innovations demand high-technology input. For example, the marking of plastic containers to indicate if they can be recycled or not is a simple but essential communication idea. Also, suggestions on possible uses for containers when the original purpose is complete can stimulate the development of new implements, ornaments, or even works of art.

Innovations are simply "putting good ideas to work" and may be seen in the home, at work, or in commercial ventures. Innovations are more likely to be seen in societies that are challenged to think of better ways to overcome problems. They are often stimulated by government legislation, and can be implemented at every stage of the process from design and development to recycling and reuse. The European Union gave directions for change and different nations responded in different ways. Finland in 1998 set a target of 70% recovery of waste by 2005, with the result, there has been a large increase in recycling nation wide. The Australian Capital Territory and New Zealand targets of "zero waste to landfill" have seen the development of new industries and new uses for what was previously waste.

Sonar has been used to "remotely" determine the waste density and layering in used tanks, and remote sensing is also being investigated to detect dumping of waste in remote locations. Spectrometric fingerprinting of wastes can lead to the specific identification of the source of a particular discarded waste stream.

In the United States, the Federal Energy Technology Center performs, procures, and partners in research, development, and demonstration to advance technology for commercial waste management innovations. Other countries have similar organizations to encourage lateral thinking and application in every aspect of waste minimization.

10.4 Assessment of Selected Responses

10.4.1 Urban and Terrestrial Ecosystems

10.4.1.1 Impacts on Ecosystems and their Services

Urbanization is expanding more rapidly than any country's economy. The problem with urban waste is not only the quantity but also the change from dense and more organic to bulky and increasingly non-biodegradable. Increasing amounts of plastic, aluminum, paper, and cardboard are being discarded by households and industries (Cielap 2003), but many of these materials have been recycled in the informal sector to produce creative marketable household and novelty articles. Whereas dumpsites are typical of the developing countries, sanitary landfills and incinerators are the order in the developed world. For the developing countries, however, adoption of appropriate materials may be a long-term strategy using consensus-derived legal instruments. The primary wastes from industrial, urban, and near-urban activities, and their byproducts, the goods and services that are affected, and the nature of impacts are shown in Table 10.3.

10.4.1.2 Impacts on Human Health and Well-being

Heavy metals, mercury, cadmium, tributyl tin, and lead emanating from the waste pose serious health risks. Human activities and responses such as mining, smelting, waste dumping (including tires, used oils, electrical and electronic equipment and parts, and batteries), rubbish burning, and the addition of lead to gasoline have greatly increased the amounts of heavy metals circulating in the environment.

Mosquitoes such as *Culex quinquefasciatus, Aedes aegypti,* and others can breed in the wastewater retained in blocked drainage channels and may transmit filariasis and viral infections such as dengue and yellow fever (Cairncross and Feachem 1993). Emissions from waste burning and decomposing organic wastes may lead to gaseous emissions, thus leading to the change of pollutant status from one form to another. (See Table 10.4.)

10.4.1.3 Enabling Conditions

10.4.1.3.1 Waste reduction and recycling

With the growing unemployment, hunger, and poverty particularly in urban centers of developing countries (UNDP 2000; FAO 2003), waste may provide a short- to medium-term trade-off through reuse and recycling activities. Social conflicts in waste management are not uncommon at local, regional, and country level. To solve these problems, there is a need for economic instruments such as user charges and tax incentives for innovative practices (Heermann 2003), as discussed above. Such instruments as may be used must recognize aesthetic standards, cultural heritage, and social values.

Waste minimization is apparently the best response option for urban rejuvenation coupled with reuse and recycling of a major portion of the waste. Rising living standards and increased mass production have reduced markets for many used materials and goods in affluent countries. In most developing countries, traditional labor-intensive practices of repair, reuse, waste trading, and recycling have endured. Thus there is a large potential for waste reduction in developing countries; by contrast, the greatest potential for waste reduction currently rests with diverting biodegradable, non-biodegradable, and construction wastes. Most countries in Western Europe and North America, Australia, New Zealand, Japan, and Korea have adopted municipally sponsored source separation and collection systems. Other strategies are choice of packaging materials, packaging reduction goals in a given period of time, and mandatory separation of post-consumer materials by waste generators.

- Sensible recycling programs balance social, environmental, and commercial benefits. Paper recycling not only saves trees, it also reduces energy costs by 35 to 50% and decreases water consumption and pollution. Recycling aluminum cans brings energy savings of up to 95% and produces 95% less greenhouse gas emissions than when raw materials are used.
- Recycling also creates jobs. A "solid waste turnover sector analysis" carried out in 1994 put the British market value of solid waste at $3 billion (Jones 1995). In Britain, the recycling industry, already worth over $20 billion a year, employs 140,000 people. Getting the United Kingdom to recycle 35% of its household waste by 2010, a target under consideration by the government, will generate another 50,000 skilled and unskilled positions (Ribbans 2003).
- The motivating forces for waste recovery and recycling in the developing countries are scarcity or high cost of virgin materi-

Table 10.3. Impacts of Wastes on Urban Ecosystem Goods and Services

Urban Ecosystem	Peculiarities	Primary Wastes/Waste Byproducts Generated	Goods and Services Affected	Impacts
Urban Peri-urban Peripheral	built environment with a high human density (with human settlements of 5,000 or more)	mostly human and technology-based wastes; demolition, organic and inorganic, solid, liquid, gaseous, vehicular emissions, industrial wastes	food, biochemicals, genetic resources, climate regulation, water regulation, recreation and tourism, aesthetic, cultural heritage, spiritual and religious	population pressures rural–urban migration overuse of land environmental degradation disease burden poverty inadequate infrastructure

Table 10.4. Waste Management Responses and Health Risks

Waste Management Response	Health Risk
Collection, transportation, and disposal activities	injuries and chronic diseases due to sharps, contaminants, collapse of waste piles, cuts, infective wounds, burns, trauma, cancers, chronic respiratory infections
Mixed wastes—due to infected sharp waste, exposure to infected dust, breeding of vectors in waste-generated ponds, contaminated soil, rodents and other animals feed on waste, accidental ingestion of waste/ contaminated food, contaminated drinking water, foods grown on leachates and other waste streams	bacterial, viral, and parasitic—tetanus, staphylococcus, streptococcus, hepatitis B, AIDS, blood infections eye-related (trachoma, conjunctivitis) skin (mycosis, anthrax), respiratory infections (bacterial and viral) vector-borne (dengue, yellow fever) parasitic (malaria, filariasis, schistosomiasis) worm infestations (hookworm, ascariasis, trichuriasis) bacterial (cholera, diarrhea, typhoid) viral (dysentery) parasitic (helminthiasis, amoebiasis, giardiasis)
Toxic chemicals, leachates, and gaseous emissions from waste handling or treatment	respiratory tract infections, cancers, nuisance, particulate-induced disease conditions
Urban wastes in specific (solid wastes and their leachates, sewage, and sullage/greywater)	malaria transmitted through *Anopheles* breeding, dengue and yellow fever through *Aedes* mosquitoes, filariasis through breeding of *Culex* mosquitoes.

als, import restrictions, poverty, the availability of workers for lower wages, and the large markets for used goods and products made from recycled materials (IETC 1996).

- To solve the problems of poverty, waste recycling activities use policy and economic responses, particularly in developing countries where there is chronic unemployment. Such waste-to-wealth activities (Figure 10.2), including harnessing of nitrogen and energy from waste, need to be formalized as policy responses. However, such policies should also include presorting to protect the health of the recycling worker.

10.4.1.3.2 Urban agriculture

Urban agriculture, which was little known in the 1970s, is becoming more common (Rodrigues and Lopez-Real 1999). The number of urban farmers producing for the market is expected to double from about 200 million in the early 1990s to 400 million by 2005 (Smit 1996). Globally, more than 800 million urban dwellers are involved in this economic activity (Smit 1996; Sommers and Smit 1996; Kaspersma 2002; Redwood 2004). Many successful urban agriculture schemes are reported around the globe—from Dar es Salaam to Singapore, from Vancouver to Curitiba. Singapore is in the forefront in the development of urban aquaponics. Other examples:

- In Brazil (Saõ Paulo), urban agriculture is a planned land use activity.
- Most households in Southeast Asia and the Pacific Islands subregions practice urban agriculture.
- About 30% of the Russian Federation's food is produced on 3% of the land in suburban "dachas." In Moscow, the proportion of families engaged in agriculture grew from 20% of the city's population in 1970 to 65% in 1990.
- In Harare, when sanctions on urban agriculture were lifted temporarily in 1992, within two years the area cultivated doubled and the number of farmers more than doubled. Municipal costs for landscape maintenance and waste management were down, food prices were down, and hundreds of jobs were created.
- Urban agriculture has an important significance to global sustainability in that the production of food close to the consuming market reduces the need for transportation, thus reducing the consumption of fossil fuels and the associated emissions of CO_2. There is also a reduction in packaging, refrigeration, and the use of preserving additives (Rees 1997).
- School gardens are becoming popular and are effective learning tools to students of all ages.
- Effective wastewater use for urban agriculture cannot be implemented without creating enhanced awareness by formal and informal education, information, and awareness through a policy response (Okpala 1996; Buechler et al. 2002). In many developing countries urban agriculture is contributing to reuse of organic matter through the recycling activities. In many places, solid wastes converted to compost, and gray water emanating from open drains, are used to fertilize soils (Pillai et al. 1947; Sridhar et al. 1992; Sridhar 1995; Sridhar et al. 2002; Urban Agriculture Magazine 2002).

10.4.2 Agricultural Ecosystems

Certain agricultural products and practices are implicated in human health problems, including animal antibiotics, nitrates in

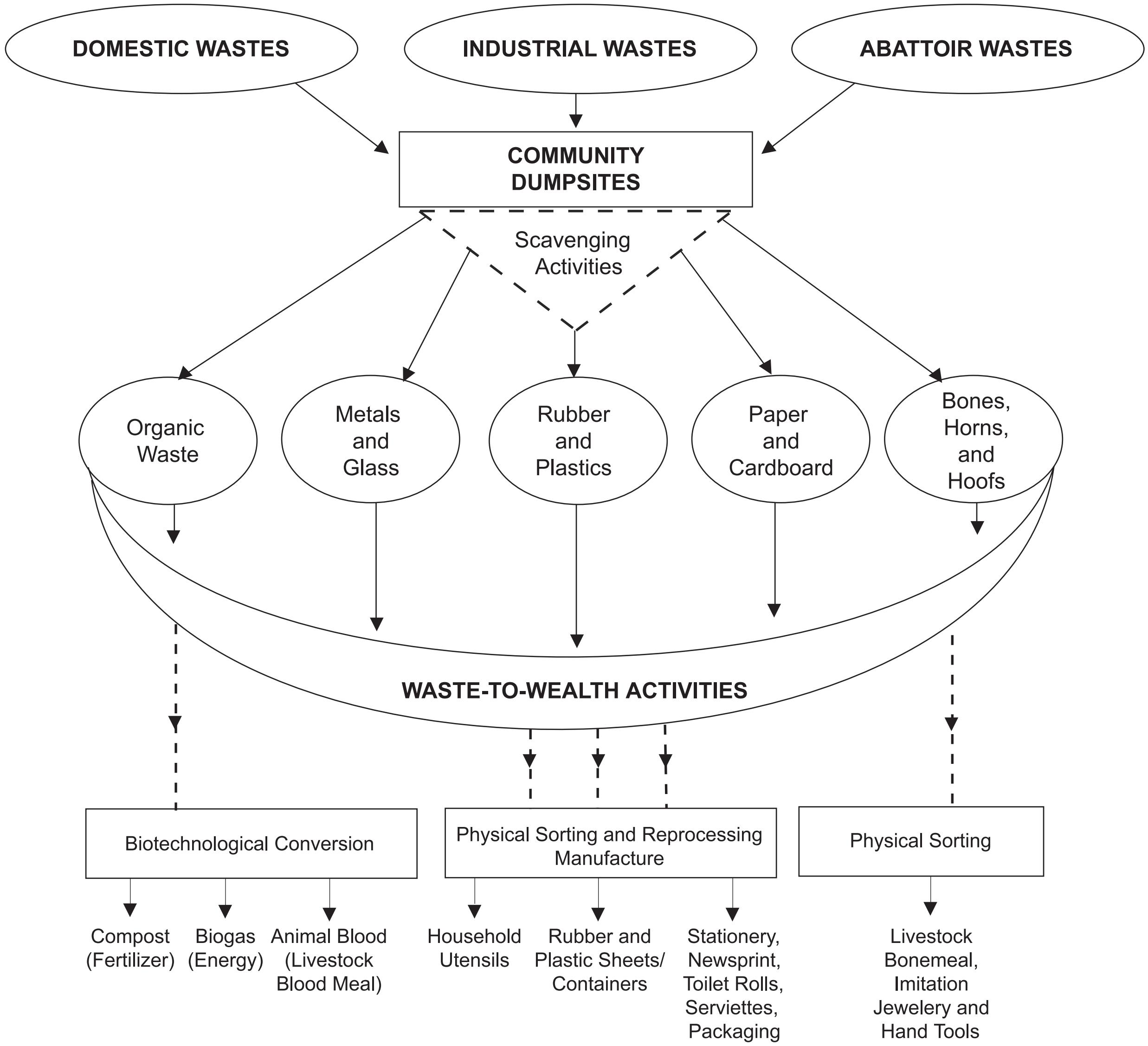

Figure 10.2. Waste-to-Wealth Activity and Processing Profiles in Developing Countries (Adedipe 2001)

groundwater, pesticide exposure in an occupational setting, pesticide residues and food additives in foods, and certain food processing techniques. (See Box 10.4.) There is some evidence to suggest that conventional soil management practices are contributing to declining nutritional value in foods (MacRae 1990).

Global Assessment of Soil Degradation estimated that about 13% or 850 million hectares of the land in the Asia and Pacific region is degraded (Olderman 1994). Improper ferti-irrigation using wastewater and poor drainage practices results in salinization and degradation of soils. Policy and technological responses should be able to offset these. Virtually every part of the globe has these problems (Pillai et al. 1946; MOAFFA 1999).

The ecosystem-positive responses to waste management lie in increased production of food and fiber, soil conservation, and/or remediation. The negative responses include soil degradation, soil erosion, weed growth, eutrophication, groundwater pollution, loss of biodiversity, and the greenhouse effects. They also include the use of agrochemicals for pest control. To this extent, as an example, the use of persistent organic pesticides is being discouraged by gradual substitution of biological pest control (Adesiyan 1992).

In Brazil, nitrogen-fixing bacteria are being used successfully to remediate nitrogen-deficient agricultural ecosystems; Doebereiner (1997) reported that Brazil has become the world leader in replacing N fertilizers by biological nitrogen fixation with large positive impacts on the production of food and biofuel crops. See Chapter 9 for a more detailed assessment of response options relative to the use of nitrogen- and phosphorus-based fertilizers in agriculture.

10.4.3 Hazardous Waste, Biosolids, and Soil Remediation

Soil contamination through waste discharges, particularly hazardous wastes, is a worldwide phenomenon. Compost is also known to remedy the contaminated soils, particularly from heavy metals and organic pollutants. Working with oil-contaminated soils, researchers showed that a combination of NPK fertilizer and straw mulch promoted natural revegetation through the restoration of soil properties, while either of them when applied singly was less effective (Odu 1972).

In industrial nations, many municipalities face the problem of disposing of increasing volumes of wastewater economically and

BOX 10.4
Agriculture-related Health Problems

- Crops irrigated with polluted water or fertilized with inadequately produced compost or animal manure may be infected with bacteria (shigella, typhoid, cholera), worms (e.g., tape- and hookworms), protozoa, enteric viruses or helminths (ascaris, trichuris); schistosomiasis is prevalent in some regions due to irrigated agriculture.
- Crops may take up heavy metals and other hazardous chemicals from soils, irrigation water, or sewage sludge polluted by industry. Crops grown close to main roads or industry, and food purchased from street vendors, may be contaminated by airborne lead and cadmium. Residues of agrochemicals may contaminate crops or drinking water (pesticides, nitrates). If waste materials are not separated at source, compost may contain heavy metals, which can be taken up by crops. Despite a 64% drop in annual global atmospheric emissions of lead since 1983, several million adults and children suffer the adverse health effects of lead poisoning, including impaired mental and physical development. In the United States alone, childhood lead poisoning is estimated to cost some $43 billion per year.
- Mosquitoes that are the vector for filariasis breed in standing water heavily polluted with organic materials. Mosquitoes that transmit dengue breed in water containers that include much solid waste, like coconut husk, rubber tires, broken bottles, water storage jars, buckets, and water butts.
- Closeness of animals and humans may lead to the occurrence of zoonotic diseases like bovine tuberculosis (cattle) and tapeworms, especially when animals are scavenging waste tips. Drinking water may get contaminated with pathogens by application of animal waste (e.g., slurries) to land. Animal products can become contaminated with pathogens due to contamination of animal feed with infected feces (salmonella, campylobacter).
- Tanneries may discharge hazardous chemicals in their wastes (tannum, chromium, aluminum).
- If fish (especially shellfish) are reared on wastewater and/or human and animal excreta, there is risk of passive transfer of pathogens (hepatitis A) and transmission of trematodes where trematodes are endemic and fish is consumed raw. Contamination of fish with human or animal fecal bacteria may occur during post-harvest operations (for example, salmonella). Poorly managed fishponds may become a breeding ground for anopheles mosquitoes. Use of antibiotics in fish feed may lead to development of antibiotic-resistant bacteria in the food chain. Fish products may be contaminated with heavy metals and agrochemicals.

in an environmentally sound manner without involving risk to human health. It is estimated that the total quantity of U.S. domestic wastewater, for example, could supply around 1.5 million tons of nitrogen alone, or about 15% of the amount currently marketed as inorganic fertilizers. But the heavy metals—zinc, lead, cadmium, and selenium—could be toxic, which is a trade-off between economic gains and health hazards (Olson 1987). Biosolids (treated residuals from wastewater treatment) are proving useful to replace wastewater residuals (formerly sewage sludge). Because of the proven fertilizer value of sewage sludge, land application of this waste material is becoming a popular and more feasible method than other alternatives (for example, incineration, landfill, ocean dumping, pyrolysis). However, sludge has the disadvantage of building up mercury levels in the soils, making it more available for plant uptake and entry into the human food chain (Cappon 1984).

A study reported from Cairo (UNCSD 1999) indicated that farmers are ready to pay for the biosolids as they are convinced of the benefits. The Greater Cairo Wastewater Project produces about 0.4 million tons of sludge or biosolids from its wastewater treatment plant and has a ready market for growing wheat, berseem clover, forage maize, and grapevines. This has reduced pressure for manures, which are scarce and more expensive to buy. India, China, and some other Asian, African and South American countries have been following this practice, though on a small scale.

Industrial waste materials are often used in fertilizers as a source of zinc and other micronutrients. Current information indicates that only a relatively small percentage of fertilizers is manufactured in United States using industrial or hazardous wastes as ingredients (National Agriculture Compliance Assistance Center 2004). The U.K. Department for Environment, Food, and Rural Affairs (DEFRA—formerly MAFF) has developed a code of practice for minimizing plant health risks through residue management. Anaerobic digestion of agricultural residues proved sound as it produces three usable products—biogas, which can be used to generate heat/electricity; fiber, which can be used as a nutrient-rich soil conditioner; and liquor, which can be used as liquid fertilizer (AGRIFOR 2004). A well-designed and cost-effective waste management system, based on resource recovery and recycling technologies as well as reuse of wastewater for irrigation or aquaculture, can produce substantial social and economic benefits that are gaining the attention of decision-makers. When total costs are considered—health, pollution, landfill, and incinerator—these options begin to make sense (World Bank 1997). Some reported successes are shown in Box 10.5.

10.4.4 Protecting Remote Ecosystems (Island, Mountain, and Polar)

There is increasing use of mountains as dumping ground for litter, hazardous and semi-hazardous wastes, and incineration ash (UNEP 2002).

The Arctic landmass is approximately 14 million square kilometers, of which the Russian Federation and Canada account for 80%. The decrease in area of glaciers in both the Arctic and the Antarctic is probably due to air pollution and lower albedo of the "dusted" glaciers' surfaces. Habitat loss, terrain modification, disturbance to wildlife, and introduction of exotic species and disease are the response impacts. There are legislative and regulatory bodies to control degradation, but implementation has been hindered by financial constraints, particularly in the Russian Federation (UNEP 2002).

10.4.5 Freshwater Ecosystems

Freshwater ecosystems are aquatic systems that contain drinkable water or water of almost no salt content. Freshwater resources include lakes and ponds, rivers and streams, reservoirs, wetlands, and groundwater. They provide drinking-water resources and water resources for agriculture, industry, sanitation, and food, including fish and shellfish. They also provide recreational opportunities and a means of transportation. Freshwater ecosystems are home to numerous organisms, for example, fish, amphibians, aquatic plants, and invertebrates. It has been estimated that 40% of

BOX 10.5

Examples of Waste Use in Agriculture (World Bank 1997)

Recycling

- Well-known examples include use of city waste in peanut-growing systems on the Kano plains of Nigeria, use of nightsoil in China, and "sewage farms" around European cities during the nineteenth century; city waste improved soils in the Netherlands.
- Urban wastewater is used in many parts of the United States, Israel, and Jordan.
- Abattoir waste is used to produce methane and compost in Senegal.
- The Kolkata sewage fisheries system is the largest single wastewater system involving aquaculture, with 4,600 hectares of sewage-fed fishponds employing 4,000 families
- In California, growers add compost to build up soil organic matter—high-quality compost is widely used in horticulture, seedling production, and general agriculture, while lower-quality material is used in city parks and to stabilize land. Sludge and compost add nutrients and organic matter to the soil, improve water retention and transmission, and improve soil structure.
- Widespread adoption of recycling technologies has been hindered by undeveloped markets, transportation costs, health and cultural issues, and inadequate regulations.
- The primary barrier is that the potential benefits are not adequately taken into account by urban planners, sanitary engineers, and farmers. Waste handling has focused on landfills and incinerators, while inorganic fertilizer and fresh water are the primary inputs used to meet the needs for soil nutrients and irrigation water.

Technology

- The current use of waste in agriculture has been mostly beneficial, but there are some potential detrimental effects, usually closely related to either the quality of the raw material, its processing, or both. The level and type of treatment varies, as does cost. Composting technologies have improved greatly in recent years and provide better quality compost with increased acceptability.

Public Health Concerns

- While disposal of municipal waste by land application is generally successful, there is evidence that irrigation with untreated municipal and industrial waste can harm crops as well as humans, either those living in the area or those who consume the products. These risks can be resolved by preventing pollutants from accumulating in the soil, taking advantage of the soil's capacity to assimilate and detoxify pollutants, and determining optimal levels of safe application. Specific attention needs to be given to the risks associated with transfer of human pathogens.

all known fish species on earth come from freshwater ecosystems (USEPA 2002).

Eutrophication leads to aquatic weed growths, prominent among them being water hyacinth (*Eichhornia crassipes*), *Salvinia molesta* and *Typha sp.* Aquatic weed growths also lead to new habitat development, particularly snails carrying schistosomiasis and mosquitoes carrying various diseases. Many tropical countries are now trying to utilize these aquatic weeds for income generation, employment, and resource utilization for energy and compost. Floating vascular aquatic weeds such as water hyacinth is a good system to treat sewage and other wastewater containing low organic content. The technology is cheap and the byproducts are easily recycled. This is a typical example of how the problem of one ecosystem can be harnessed for the benefit of other ecosystems. However, in open, uncontrolled, large bodies of water, this approach is still not practicable, given the experiences of Lake Victoria in eastern Africa, many areas of Brazil, Australia, and elsewhere.

Anthropogenic N additions to temperate ecosystems have been shown to affect a wide range of ecosystem properties and processes, especially when the inputs are large and continuous. Phosphorus is the critical limiting nutrient and the one of concern for eutrophication of freshwater systems, but evidence points to combinations of phosphorus and nitrogen. A eutrophic lake is characterized by a shift toward the dominance of phytoplankton by cyanobacteria, including noxious forms, most of which produce toxins (Anderson 1994; Chandler 1996; World Resources Institute 1992).

Increased inputs of nitrogen also manifest in relatively increased productivity but loss of biodiversity. Freshwater systems that are poorly buffered are acidified by increased deposition of nitrate and ammonia. The continuing acidification of Europe, northeastern North America, and parts of Asia is now leading to nitro-pollution rather than a sulfur pollution problem (Rabalais 2002). It is becoming increasingly apparent that the effects of eutrophication are not minor and localized, but have large-scale dimensions and are spreading rapidly (Nixon 1995). (See also Chapter 9 on this issue.)

Aquaculture, which has become a global economic venture, is also known to contribute to eutrophication. In China, polyculture of scallops, sea cucumbers, and kelp reduces eutrophication and the use of toxic antifouling compounds. Nutrients from scallop excreta are used by kelp, which used to require the addition of tons of fertilizers. Antifouling compounds and herbicides can be reduced because sea cucumbers feed on organisms which foul fishing nets and other structures. For shrimp and catfish culture, deeper ponds can be constructed to reduce weed growth to further limit herbicide use. This technique is a synergism and environment-friendly (Emerson 1999). Integration of such technologies into ecosystem restoration will bring in economic benefits.

10.4.6 Wetlands

Wetlands are among the most productive ecosystems, covering about 6% of Earth's land surface. They are characterized by marshlands, swamps, and bogs and play a vital cleansing role for the pollutants by acting as "sinks," regulating floods and providing habitat for numerous species of plants and animals. Wetlands help in water purification. Particulate matter such as suspended soil particles and associated adsorbed nutrients and pollutants settles out. Dissolved nutrients such as phosphorus and nitrogen can become adsorbed onto the particles and taken up by living organisms, or nitrogen is lost to the atmosphere. Other contaminants such as heavy metals can also be adsorbed onto sediment or organic particles. Exposure to light and atmospheric gases can break down organic pesticides or kill disease-producing organisms. The salinity of water within wetlands often increases as water levels drop, and the pollutants may become concentrated. If a lot of contaminants are flushed from the wetland by floods, they can foul the water downstream. A wetland is not a final sink for most pollutants but it may retain them for a period of days, months, or years (Australian EPA 2002).

Many wetlands have been degraded or destroyed by human activities since European settlement, through filling, draining, flooding, and clearing, and by pollution. The Ramsar Convention with 43 member signatories, signed in 1971, has protected some 200,000 square kilometers of wetlands.

10.4.7 Marine and Coastal Ecosystems

Marine ecosystems cover over 70% of Earth's surface. The habitats range from the more productive near-shore regions to the deep ocean floor, which was once thought to be uniformly barren. More recent studies and more extensive investigations by remotely controlled unmanned submarine vessels have revealed such features as deep-sea vents, which support significant marine communities. At this stage, those remote areas appear to be buffered from the adverse impacts of human activities, but we know that "dilution is not the solution" in any waste clean-up measures, and even remote and deep areas of the oceans may in time be adversely affected from some types of waste. Deep-sea dumping of waste must be banned completely. Important marine ecosystems include: oceans, sea mounts, rocky sub-tidal (kelp beds and seagrass beds), intertidal (rocky, sandy, and muddy shores), tropical communities (mangrove forests, coral reefs, and atolls), estuaries and salt marshes, and lagoons. Marine ecosystems are home to a host of different species ranging from tiny planktonic organisms that comprise the base of the marine food web (that is, phytoplankton and zooplankton) to large marine mammals like the whales, manatees, dugong, and seals. In addition, many fish species reside in marine ecosystems including flounder, scup, sea bass, monkfish, squid, mackerel, butterfish, and spiny dogfish.

Areas such as mangroves, reefs, and seagrass beds also provide protection to coastlines by reducing wave action, and helping to prevent erosion, while areas such as salt marshes, coastal lagoons, and estuaries have acted as sediment sinks, filtering runoff from the land (USEPA 2002).

Mangroves, seagrass beds, and coral reefs have all been shown to be sensitive to different types of waste, whether they are nutrients from the land or discharges of waste or oil from ships. The Australian government to the threat posed by human activities on its bio-diverse mangroves, sea-grass beds, and coral reefs and islands of the Great Barrier Reef Region was to nominate the Great Barrier Reef Region for inscription on the World Heritage List. Such listing, achieved in 1981, requires the implementation of management plans to protect these natural areas and the life they support (Baker, personal communication).

Marine and coastal degradation is caused by increasing pressure on both terrestrial and marine natural resources, and the use of the oceans for waste deposition. Some 20 billion tons of wastes, treated or untreated, end up in the sea every year through land, runoff, and other means. The total quantity of oil spilled by tankers between 1979 and 2000 is 5,322,000 tons (Encarta Encyclopedia 2003). Most tanker spills result from operations such as loading, discharging, and bunkering. However, the largest spills occur as a result of collisions and grounding. About 90% of these wastes stay in coastal waters where, particularly in coastal lagoons or marshes, they interfere with bird and marine life, mangroves, sea-grass beds and coral reefs, as well as with fisheries, tourism, and recreation.

Seventy-five percent of the pollutants in the ocean are estimated to be from the land. Increased human activities such as overfishing, coastal development, pollution, and the introduction of exotic species have also caused significant damage and pose a serious threat to marine and coastal biodiversity. The connection to land-based pollution sources can be observed visually by 58 known "dead zones"—areas where ocean life is absent, all located along coastlines (J & D Informatics 2001; Field et al. 2002). In the Gulf of Mexico, a 7,000 square mile area from the mouth of the Mississippi to the Texas border becomes so oxygen-deficient each summer that nothing can survive, creating a massive dead zone.

Efforts toward integrated coastal zone management in Africa have not made any meaningful impact, despite serious social and economic problems (Adedipe 1992, 1996; World Bank 1996). In Nigeria, the ecosystem response has been characterized by biodiversity loss and food insecurity due to overexploration and overexploitation, particularly in the Niger Delta area. A specific policy response has been a multinational project, spearheaded by UNIDO, IUCN, and UNESCO, involving six countries in the West Africa sub-region (Coté d'Ivoire, Ghana, Togo, Benin, Nigeria, and Cameroon) in the restoration of the Guinea Current Large Marine Ecosystem (UNIDO 2002). The concern is driven by population growth, urbanization, industrialization, and tourism. In 1994, an estimated 37% of the global population lived within 60 kilometers of the coast. That percentage has risen in the last decade. Fish farming in seas (for example, large salmon farms along Norwegian and Scottish coasts) is also a source of waste.

Globally, sewage has been the largest source of contamination because of the volume and the nature of organic matter it carries. Public health problems of the 1970s have been well documented (GESAMP 2001). Modern technologies can be used to remove all solid material, nutrients, and microorganisms from sewage. In industrial countries, therefore, there is no reason why untreated sewage should be discharged to the sea. Ways should be found to have these technologies made available for sustainable implementation in developing countries as well.

Coastal marine ecosystems are experiencing high rates of habitat loss and degradation. Shoreline stabilization, the development of large ports, and the existence of densely populated coastal cities—all contributed to this loss. In these zones, high human population levels coupled with increased road and pipeline densities have increased pollution as well as sedimentation and erosion rates (USEPA 2002).

Ironically, one reported dead zone between Denmark and Sweden actually increased catches temporarily, which is a positive impact (J & D Informatics 2001). Record catches of Norway lobster were being recorded when oxygen levels were very low. The lobsters normally burrow into the sea floor, but with the low oxygen levels, they swam up higher to locate oxygen, and made themselves susceptible to trawling. Thus the deteriorated conditions made the lobster more susceptible to the catch method. The yield was unsustainable.

The phenomenon of red tides appears to be becoming more frequent. Populations of marine dinoflagellates occasionally become so large that the dying organisms color the water and are referred to as tides. Such tides may lead to the poisoning of both fish and humans. Red tides occur off the western coast of Florida and in the coastal waters of New England, southern California, Texas, Peru, eastern Australia, Chile, Hong Kong, and Japan. In 1946, such a tide killed fish, turtles, oysters, and other marine organisms in the Gulf of Mexico near Fort Myers, Florida. The blue-green alga *Trichodesmus* sometimes, in dying off, imparts a reddish color to water; the Red Sea derived its name from this phenomenon.

10.5 Toward Improving Waste Management for Overall Biodiversity and Human Well-being

10.5.1 Biodiversity Conservation

A diversity of species is generally important to the natural functioning of ecosystems, and a balanced and ''stable'' biodiversity is therefore considered an indication of the good health of an environment. Biodiversity is also valued for aesthetic enjoyment and for natural products such as foods and drugs. Global biodiversity on the earth is well known for larger organisms such as mammals (over 4,000 species). However, total biodiversity can only be estimated, because most species of insects, deep-sea invertebrates, and microorganisms have yet to be described. Estimates of total terrestrial biodiversity range from 10 million to 100 million species, most of which are insects. Natural ecological systems generally support higher biodiversity than agricultural or urban landscapes, particularly in the tropics, where natural biodiversity is greatest. The issue of conservation of biodiversity is discussed in detail in Chapter 5.

The increasing human population threatens biodiversity (Mooney et al. 1996). Some ecologists believe that more than 50% of existing species will be lost in the next hundred years, many before they have been identified. Laws have been designed to protect threatened and endangered species, but legal and biological difficulties in defining species or other groups used for measuring biodiversity make such laws controversial. Moreover, experience has shown that species' survival depends on the preservation of their habitat. Increased nitrogen in soil and water can lead to loss of species composition of plant communities. Disappearance of salmon (an indicator fish) along with other species from River Thames in Britain in the early part of the last century is a typical example of biodiversity loss, which was restored after the introduction of stringent regulations on wastewater treatment. The international conventions such as the Basel Convention on transboundary movement of hazardous wastes and their disposal, the London Convention on dumping of wastes at sea, and the establishment of toxic waste registry have considerably reduced the threats on biodiversity. Recent data on the nature of flora at waste dumpsites revealed plant species loss (Sridhar 2004 unpublished data).

10.5.2 Poverty Reduction Strategies

As indicated earlier, poverty is ''on the rampage'' in developing countries. While industrial nations continue with carefree and high-consumption patterns, the developing nations are stifled by low incomes, due to massive underemployment and unemployment. Waste recycling offers ample opportunities for poverty alleviation and job creation (for example, waste-to-wealth schemes). Such opportunities already exist in Nigeria and proved particularly successful in Rio de Janeiro, where the municipality facilitated cooperatives of aluminum can collectors. Other examples include reusing newspapers, polyethylene terphthalate (PET) bottles, and other potential wastes produced with the guidance of artisans, architects, and artists. Education for adaptation should also be considered as a viable strategy for waste reduction and reuse. In addition to such income-generating activities and ventures, other approaches include promotion of cleaner environment and the reduction of negative health impact for overall human well-being.

10.5.3 Education and Enlightenment

Education and communication are essential elements of waste management, particularly waste reduction, through formal education starting with kindergarten to elementary schools (primary institutions), high schools (secondary institutions), and colleges (tertiary institutions), as well as informal and vocational training. Extension services, NGOs, the Internet, and distant learning programs contribute immensely. Also, vocational training response should be used as a tool for capacity building of the waste generators and managers. Along these lines, various professionals, particularly in the creative arts, should be involved in programs to inculcate ''greener behavior'' in communities. In addition, there is a need for a waste management information databank.

10.5.4 Public Health Implications

In tropical African countries, the results of improperly managed solid waste are evident in public health-related disease incidence causing ill health, sometimes leading to serious morbidity and mortality (Adedipe 2002; Onibokun et al. 2000). Poorly managed waste dumpsites, untreated sludge, and wastewater are sources of proliferation of rodents, which transmit typhoid fever, rabies, and other infectious diseases. They also lead to prolific breeding of flies, cockroaches, and mosquitoes, which transmit diarrhea, gastroenteritis, malaria, yellow fever, dengue, mosquito-borne encephalitis, filariasis and helminthiasis. Smoke emissions from burning of solid wastes are known to cause upper respiratory tract infections. In some cases, the accumulated and untreated waste penetrates the soil to contaminate groundwater or, through surface runoff, to contaminate surface water, with severe consequences for human health, for which eco-health is emerging as a viable and sustainable integrated response option involving water supply, sanitation, and waste management. A strategic policy response is needed, consisting of massive public health campaigns using all possible information, education, and communication materials.

10.6 Conclusions

This assessment covers the general challenge of waste management but concentrates on human waste and urban and rural waste. It attempts to avoid overlap with other chapters and summarizes the major issues in waste management in the context of the MA. It identifies the key drivers of ecosystem services and the responses thereto for protecting the environment and thereby improving human well-being.

The assessment shows that there are significant differences in the drivers and responses between developing and industrial countries and also within developing countries. This observation needs to be considered in any follow-up action on the MA.

The assessment views the issues of waste material reuse and recycling as a positive impact of waste management. Also, the careful and controlled use of wetlands in the management of sewage sludge and wastewater is a positive impact.

The assessment draws attention to the importance of effective governance structures, integrated responses such as harmonized institutional arrangements, relevant cost-effective civil society involvement, recognition of individual human rights, the special needs of epistemic communities and social values, private sector participation, education and public enlightenment. It stresses the overall goal of suitably modified consumption scales and patterns in the developed world and poverty reduction in the developing nations through recycling and resource recovery schemes that would reduce unemployment, in line with the millennium goal of reducing poverty by 50% in the year 2015.

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