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6

Human and Nonhuman Mortality[1]

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Hazards are threats to humans and what they value: life, well-being, material goods, and environment. Today hazards originating in both nature and technology are a major concern in developing and industrial nations alike. Coping with hazards involves a wide range of adjustments--from learning to live with hazard, to sharing the burden of hazard, to controlling and preventing death, injury, property loss, and damage to human and natural environments.

In chapters 2-5, descriptions of causal structure, management, classification, and perception together provide a qualitative framework for hazard analysis. In this chapter we begin to quantify the burden of hazard consequences by estimating the extent of human and nonhuman mortality associated with technological hazards. The approach taken is "global," and rather than relying on hazard-specific data, depends on broad scale accounting and correlational analysis. We begin with a basic distinction.

Natural and Technological Hazards

For the majority of the world's people, living in rural portions of the developing nations, the hazards which most concern them are ancient ones and are predominantly rooted in nature. These natural hazards arise most often in connection with agriculture, food supply, or settlement, and they constitute a major burden. For example, the losses from geophysical hazards (floods, droughts, earthquakes, and tropical cyclones) each year in the developing world involve an average of 250,000 deaths and $15 billion in damage and costs of prevention and mitigation (Burton, Kates, and White 1978). This is equivalent to 2 to 3 percent of the gross national product (GNP) of the affected countries. Losses from vermin, pests, and crop disease are widely regarded as a larger problem (Porter 1976) and involve destruction of as much as 50 percent of food crops (Pimentel 1978). And infectious disease, though declining, typically accounts for 10 to 25 percent of human mortality, concentrated among the very young (World Health Organization 1976).

In contrast, for industrialized nations, natural hazards are relatively a much smaller problem. Thus, for the United States, geophysical hazards produce less than one thousand fatalities per year, and property damage and costs of prevention and mitigation are on the order of 1 percent of GNP. Vermin, pests, and crop disease, while leading to serious losses, are kept in bounds by pesticides and other techniques, and infectious disease accounts for less than 5 percent of human mortality. While controlling natural hazards to this extent, however, the industrialized nations have not escaped unscathed.

Taking the place of the ancient hazards of flood, pestilence, and disease are new and often unexpected hazards, predominantly rooted in technology. As Table 1 shows, these hazards now have an impact as large or larger than the natural hazards they have replaced (Kates 1978).

For example, in 1975 the United States spent $40.6 billion, or 2.1 percent of GNP, on air, land, and water pollution (Council on Environmental Quality 1978); and in the same year the cost of auto accidents was estimated as $37 billion, or 1.9 percent of GNP (Faigin 1976). In our estimate (see below) the death toll associated with technological hazards involves 20-30 percent of male and 10-20 percent of all female mortality. Overall, expenditures on hazard management in the private and public sectors, when added to value of direct losses, are estimated by Tuller to be in the range $179-283 billion (7.8-12.4 percent of GNP) for 1979 (see chapter 7).

Technological hazards are thus a big business, comparable in scope to such major sectors of the national effort as social welfare programs, transportation, and national defense. And the impacts of technological hazards go well beyond mortality. Table 2 details the various groups, sectors, and environments affected, along with the dimensions of the consequences considered in our work on the assessment and management of technological hazards.

How can the full scope of technological hazards be evaluated? Only by determining the sum of all of the impacts and consequences outlined in Table 2. This is a formidable task, one which no group,

TABLE 1
Comparative hazard sources in U.S. and developing countries

	PRINCIPAL CAUSAL AGENT[a]			
	NATURAL[b]		TECHNOLOGICAL[c]	
	Social cost[d] (% of GNP)	Mortality (% of total)	Social cost[d] (% of GNP)	Mortality (% of total)
United States	2-4	3-5	5-15	15-25
Developing countries	15-40[e]	10-25	n.a.[f]	n.a.[f]

[a] Nature and technology are both implicated in most hazards. The division that is made here is made by the principal causal agent, which, particularly for natural hazards, can usually be identified unambiguously.

[b] Consists of geophysical events (floods, drought, tropical cyclones, earthquakes and soil erosion): organisms that attack crops, forests, livestock; and bacteria and viruses which infect humans. In the U.S. the social cost of each of these sources is roughly equal.

[c] Based on a broad definition of technological causation, as discussed in the text.

[d] Social costs include property damage, losses of productivity from illness or death, and the costs of control adjustments for preventing damage, mitigating consequences, or sharing losses.

[e] Excludes estimates of productivity loss by illness, disablement, or death.

[f] No systematic study of technological hazards in developing countries is known to us, but we expect them to approach or exceed U.S. levels in heavily urbanized areas.

TABLE 2
Impacts of technological hazards

HAZARD EXPOSURE RECEPTORS	DIMENSIONS OF CONSEQUENCES
HUMAN POPULATIONS: individuals, groups, cohorts	well-being (diminution, loss) morbidity (acute, chronic, transgenerational) mortality (acute, chronic, transgenerational)
ECONOMY: activities, institutions, production	individual and collective loss cost of control adjustment cost of mitigation
SOCIETY: activities, institutions, values	activity disruption institutional breakdown value erosion
ENVIRONMENTS:	
natural	landscape transformation air and water quality loss recreational opportunities lost
built	community loss architectural deterioration
ECOSYSTEMS: population, species, communities	species extinction productivity reduction resistance/resilience diminution
natural	landscape transformation air and water quality loss recreational opportunities lost
built	community loss architectural deterioration

to our knowledge, has accomplished, or even attempted. In this chapter, we concentrate on human mortality and ecosystem impacts (particularly impacts on biological species and communities). Human mortality is based on well-defined data and, of all impacts, is most susceptible to quantification; the ecosystem impacts are at best difficult to judge and nearly impossible to quantify. These two impacts thus delimit the range of current scientific understanding within which other impacts and consequences fall.

Measuring Technological Hazard

Human death is the best defined of all hazard consequences. Even many impoverished societies keep reasonable mortality records and, for a large number of countries, including the United States, mortality statistics grouped according to "causes of death" are extensively tabulated by age, sex, and even race (World Health Organization 1976;National Center for Health Statistics 1978). It would seem, therefore, that there is a direct and obvious answer to the question, "How much death is due to technological hazard?"--that it is simply necessary to add the contribution of each "cause of death" and note the relative magnitude of the sum.

Unfortunately, once we have added the toll of transportation and occupational accidents and the impact of violence, this approach ends in a quagmire of uncertainty for at least three reasons: (1) death rarely has a single cause and, in most cases technology is at best a contributing factor; (2) when chronic disease, such as cancer and heart disease, is given as "cause of death," one can deduce little directly about the role of technology, since the root causes of chronic disease are known in only a small percentage of cases; (3) much death is not accurately classified according to "cause," even in some cases of accidents and violence. Mortality statistics are further clouded, because in many developing countries as much as 50 percent of all mortality is classified as of "unknown orgin," and even for developed countries practices in assigning causes vary widely (Preston 1976).

In this study of technological hazards, we have sought to circumvent these problems by what amounts to an "end run." Instead of obtaining percentage of mortality resulting from technology by direct calculation and summing, we make an indirect estimate through a two-step process. First, we estimate the percentage of mortality that is preventable in principle or, equivalently, involves external or nongenetic causes. In the literature, this is often called exogenously caused mortality.[2] Second, we estimate the percentage of technologically preventable mortality. In doing so, we recognize that externally caused or exogenous mortality sets an upper limit on technologically caused mortality, but that exogenous mortality can result from social, cultural ("life style"), and environmental factors as well as technological ones. This division of exogenous mortality (illustrated in Table 3) is not a clear-cut one. In an interrelated and mutually dependent society such as ours, most deaths have multiple causes.

TABLE 3
Classification of morbidity and mortality

CAUSE	EXAMPLES
ENDOGENOUS: causes reside predominantly within the individual	Aging; genetic defects arising from inherited genetic load.
EXOGENOUS: causes reside predominantly outside the individual	
Natural Environmental	Infection; background radiation-induced cancer; latitudinal skin cancer effects; natural catastrophes.
Social and Cultural	Diet-based disease such as cancer from betel nuts, cirrhosis of liver from alcohol, heart disease from overweight; smoking-related disease, some urban-related mortality, some violence, war death.
Technological	
diffuse effects	Pollution-related disease; some urban-related mortality.
specific technology	Transportation accidents; cancers from specific industrial chemicals such as benzene, asbestos, and vinyl chloride; gun accidents.

Exogenous Mortality

What fraction of mortality is exogenous, that is, preventable at least in principle? To answer this question, we first divide all of mortality into acute and chronic causes of death (Tables 4 and 5). Among acute causes of death, we include all those cases in which death is sudden and not preceded by a long period of illness. Among chronic causes of death, we include all those cases where death results from a long period of prior illness due to deterioration of one or more body functions. The division into acute and chronic causes is made because the analysis of the two cases is fundamentally different.

Acute Causes of Death. Except for congenital malformations leading to sudden death, a small percentage of infectious disease, and a percentage of accidents, suicides, and homicides associated with inherited deficiencies and psychotic illness, all acute causes of death are prima facie exogenous. Assignment of the exogenous percentage is therefore made at or near unity in most cases, as shown in Table 6.

TABLE 4
Acute mortality in the United States, 1972

CAUSE OF DEATH	MORTALITY DEATHS/100,000		MORTALITY (PERCENT OF TOTAL)	
	male	female	male	female
Infectious Disease	45.7	35.3	4.2	4.3
influenza	2.4	2.4		
pneumonia	31.9	23.7		
infection of the kidney	3.0	3.6		
enteritis	1.0	1.1		
infectious hepatitis	0.3	0.4		
other	4.4	3.4		
Deaths in Early Infancy	27.2	19.6	2.5	2.4
diseases of early childhood	19.5	13.2		
congenital abnormalities	7.7	6.4		
Transportation Accidents	43.1	15.7	4.0	1.9
automobile	39.6	15.1		
other	3.5	0.6		
Other Accidents	38.9	19.3	3.5	2.4
poisoning	3.7	1.6		
falls	8.4	7.7		
fire	4.0	2.5		
drowning	5.0	1.0		
firearms	2.1	0.3		
industrial machinery	5.1	0.5		
others	7.2	4.1		
Violence	32.9	10.5	3.0	1.2
suicide	17.5	6.8		
homicide	15.4	3.7		
Other Acute Causes	11.8	9.0	1.0	1.0
TOTAL ACUTE CAUSES	199.6	109.4	18.4	13.5
MALE-FEMALE AVERAGE			16.3	

Source: World Health Organization (1976).

TABLE 5
Mortality from chronic disease in the United States, 1972

CAUSE OF DEATH	MORTALITY DEATHS/100,000		MORTALITY (PERCENT OF TOTAL)	
	male	female	male	female
Cardiovascular Disease	554.5	459.3	51.3	56.5
hypertension	9.5	10.9		
ischemic heart disease	382.4	277.6		
cerebrovascular disease	94.0	110.5		
arteriosclerosis	29.2	26.7		
other cardiovascular	39.5	33.6		
Cancer	188.1	149.6	17.4	18.4
lung, trachea, bronchia	56.8	14.0		
colon	17.4	18.8		
breast	0.3	29.2		
lymphatic tissues	10.5	8.4		
prostate	18.0	——		
stomach	9.2	5.8		
leukemia	8.1	5.8		
uterus	——	6.0		
rectum	5.6	4.2		
mouth-pharynx	5.3	2.0		
other	56.9	55.4		
Chronic Liver Disease	37.7	31.8	3.5	3.9
diabetes	15.6	21.4		
cirrhosis	21.1	10.4		
Chronic Respiratory Disease	25.8	7.6	2.4	0.9
tuberculosis	2.5	0.9		
bronchitis, emphysema, asthma	23.3	6.7		
Other Chronic Disease	74.6	55.1	6.8	6.8
TOTAL CHRONIC DISEASE	880.7	703.4	81.6	86.5
MALE-FEMALE AVERAGE			83.7	

Source: World Health Organization (1976).

TABLE 6
Estimated exogenous and technologically involved deaths in the United States

CAUSE OF DEATH	ESTIMATED U.S. EXOGENOUS PERCENTAGE OF MORTALITY (percent)		ESTIMATED U.S. TECHNOLOGICAL COMPONENT OF MORTALITY (percent)		(annual deaths in thousands)	
	male	female	male	female	male	female
ACUTE MORTALITY						
Infectious disease[a]	90	90	0	0	0	0
Deaths in infancy[b]	50	50	5	5	1	1
Transportation accidents[c]	100	100	90	90	39	15
Other accidents[d]	100	100	70	50	28	11
Violence[e]	100	100	30	30	10	3
Other acute deaths[f]	100	100	70	50	8	5
CHRONIC MORTALITY						
Cardiovascular disease[g]	80	60	0-40	0-40	0-217	0-132
Cancer[h]	60	45	40	25	82	35
Chronic liver disease[i]	80		0	0	0	0
Chronic respiratory disease[j]	60	10	0-20	0-5	0-5	0
Other chronic disease[k]	70	70	25	25	19	15
ALL MORTALITY			17-30	11-21	182-318	85-167

[a] Exogenous percentage of 90 percent is based on the hypothesis that this amount of infectious disease is in principle preventable before genetic factors become dominant. Supportive of the hypothesis is the fact that the decline trend of infectious disease mortality is steep. The technological fraction of zero is based on the fact that infectious disease is usually prevented by technology, not enhanced.

[b] Currently the U.S. ranks 13th in the infant mortality and, even in the lowest nations, infant mortality is still declining. The estimate for the exogenous percentage is meant to reflect these facts qualitatively. The technological percentage is low because infant deaths are caused largely by disease.

[c] Transportation accidents are prima facie 100 percent externally caused. The technological percentage given includes all deaths except those that are estimated to be predominantly homicidal and suicidal.

[d] Other accidents include numerous categories, as shown in Table 4. All are by definition externally caused. Some, like drowning and falls, are primarily rooted in culture and society, not technology, and hence these are excluded in estimating the technological percentage.

[e] Although nearly all violence is committed with the help of technological devices, and this suggests 100 percent exogenous causation, there is little evidence that violence is prevented by modification of technology. Rather, violence is rooted in culture and society. The assignment of a modest technological percentage reflects this fact.

[f] Other acute deaths involve many causes but relatively small numbers. The values given represent the average behavior of other acute deaths.

[g] The exogenous percentage is based on 36-nation comparisons as illustrated in Figure 1. The technological percentage is uncertain, yielding 40 percent based on cross-national plots similar to Figure 2, the difference between the U.S. rate and some theoretical rate without technology (0 percent), yet yielding near zero based on state-by-state comparison within the U.S. similar to Figure 3. Since much of cardiovascular epidemiology points toward diet and stress, we are inclined to believe the lower technological percentage.

[h] The exogenous fraction is based on Figure 1, the technological fraction on Figure 2 and the support given this by Figure 3 as well as the available literature on cancer epidemiology.

[i] The exogenous percentage is based on data similar to Figure 1. The low technological percentage is based on the predominant role of diet and alcohol in liver disease epidemiology.

[j] The exogenous percentage is based on analysis similar to Figure 1. The technological fraction is based on the literature describing the urban-rural difference in epidemiological studies of smoking-related disease.

[k] Other chronic diseases involve a large variety of causes, but rather small total mortality. Percentages assigned here are guesses based on the average behavior of the chronic diseases which we have analyzed.

Chronic Causes of Death. For chronic causes of death we obtain the exogenous percentage by a comparison of the mortality statistics reported by thirty-six nations to the World Health Organization (1976). The nations selected are believed to have sufficiently reliable statistics for our purposes; all have mortality rates for "unknown causes" amounting to less than 10 percent of total mortality. From the thirty-six nation data, the lowest age-specific mortality rate was chosen and used as the "base case." Exogenous mortality for each nation was then defined operationally as the excess mortality observed in each relative to base-case mortality.

Several problems with this definition make it necessary to regard it as only an approximate estimate of true exogenous mortality. Thus, use of the definition implicitly assumes that the genetic disposition toward mortality of various populations is identical. This is not always the case. Some cancers, for example, appear to have a genetic basis. On the other hand, when populations migrate, they usually take on the mortality patterns of their new home, thus indicating the predominance of external factors.

In addition, our method for obtaining the exogenous mortality rate is critically dependent on the validity of the base case. Our definition will tend to underestimate true exogenous mortality if some base-case mortality is preventable in principle; and it will tend to overestimate true exogenous mortality if the base case involves serious under-recording of certain chronic causes of death. Fortunately these latter effects, both of which are surely present, will at least partially cancel each other out.

Figure 1 illustrates the kind of data used: age-specific cardiovascular and cancer mortality for males and females in selected countries, including the lowest and highest mortality cases. Male and female exogenous percentages deduced from this data were 80 and 60 percent for cardiovascular disease, and 60 and 45 percent for cancer, respectively. Exogenous percentages for all causes of death are summarized in Table 6.

Technological Mortality

What percentage of exogenous mortality is associated primarily with technology, rather than with environment and culture? This is a much more difficult question, with a considerably more uncertain answer than in the case of exogenous mortality per se. There is no simple argument that allows approximate separation of the technological percentage. Our present best estimate must therefore be something of a guess, though, we hope, a good one. In order to make this guess, we again treat acute and chronic causes of death separately.

Acute Mortality. Infectious disease, though influenced by the level of technology, is largely environmental and cultural in origin. To the extent that technology is involved, it usually leads to a reduction of disease rather than increased hazard. In contrast, accidents, homicide, and suicide are highly associated with technology and culture and only marginally with the natural environment. Our estimate of the technologically involved percentage of acute mortality thus ranges from zero percent in the case of infectious disease to 90 percent in the case of transportation accidents (see Table 6). For cancer, similar results have been obtained by other

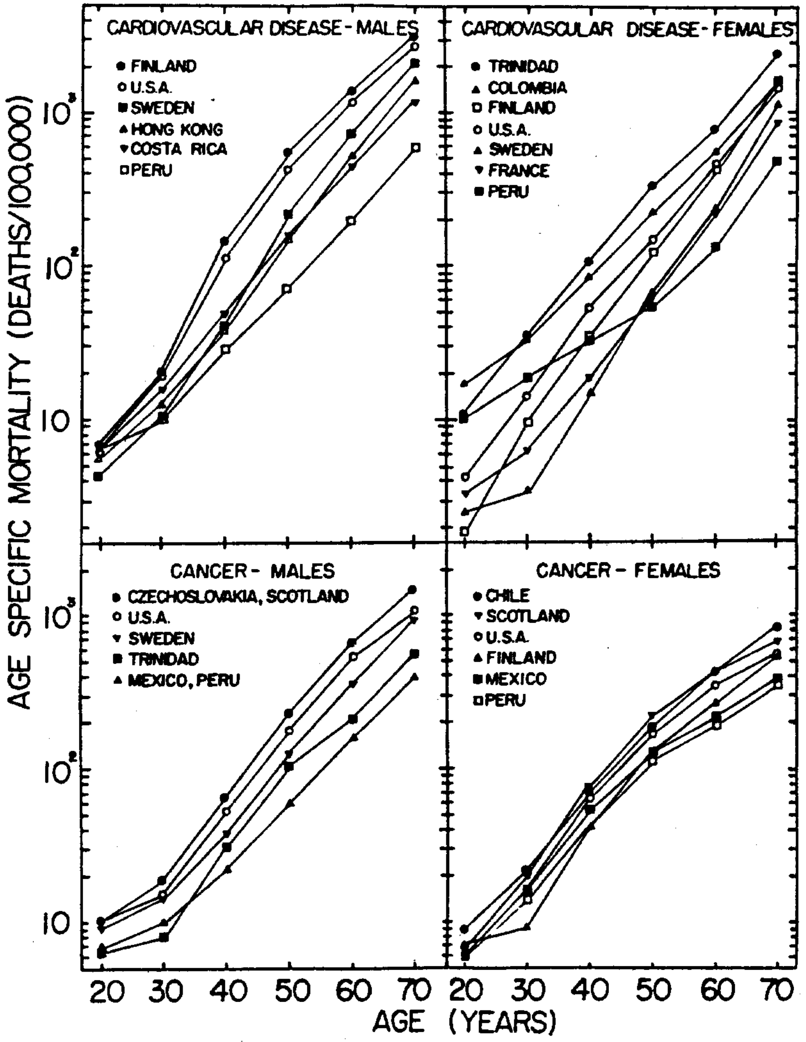

Figure 1. Age-specific cancer and heart disease mortality in selected countries for males and females for 1972-1973. The countries were selected because they are believed to have reliable statistics and because they represent the full range of recorded mortality, from lowest to highest. The difference between the lowest and U.S. mortality was used to estimate the exogenous fraction of mortality for the U.S., as indicated in Table 6. Note that the plots shown here utilize a logarithmic scale for mortality. This is a convenient device for numbers that vary over a very large range and has the effect of giving equal intervals to each factor of ten. The source for the data is the World Health Organization (1976).

researchers (Higginson 1976;Epstein 1976;Council on Environmental Quality 1977).

Chronic Mortality. We have already noted in our discussion of exogenous mortality that direct assignment of cause in the case of chronic disease is usually not possible. For estimating the technological component of exogenous mortality we again use an indirect method, based on national and international comparisons. Our approach is to look for correlations of chronic disease mortality with certain indicators of technology, such as per capita GNP, per capita energy consumption, and percent of labor in manufacturing. If chronic disease increases with level of technology, this analysis yields the equivalent of a "dose-effect" relation: it permits the determination of the change in mortality occasioned by a given change in level of technology. Unlike high quality dose-effect relations in the field of toxic substance epidemiology, the exposed populations in this case are poorly controlled for factors other than level of technology. Hence, one must expect a certain amount of scatter in mortality at a given level of technology.

The Case of Cancer. The incidence of cancer can be used as an illustration of this type of analysis. International "dose-effect" relations for men and women are shown in Figure 2; equivalent relations for the United States, for both blacks and whites, are shown in Figure 3. In each case, the mortality in 1972-1973 is plotted against percent of the labor force in manufacturing in 1940, thus allowing for the latency of cancer. Our interpretations of the observed relations are as follows:

- Internationally, cancer in males varies widely and shows an average increase of a factor of 2.7 and 1.7 for males and females as the level of technology varies from lowest to highest. Particularly for males, the scatter is very large, indicating that there are many other causes at work.
- For whites within the United States, the international pattern is repeated, though with smaller increases and less scatter. Thus mortality increases by an average factor of 1.5 and 1.4 for males and females as the level of technology rises from lowest to highest.
- For blacks within the United States, the pattern is significantly different. For black males, the increase in mortality is an average factor of 2.0 as technology varies from lowest to highest. This is a significantly greater increase than that for whites. For black females, on the other hand, no significant effect is seen, though scatter is large and average values are higher than for white females.

Thus, although there are some puzzles, a reasonably consistent picture emerges. Cancer mortality, as one would expect from the epidemiological literature (Fraumeni 1975), has an appreciable technological component. Using the international data shown in Figure 2, we estimate the difference between the U.S. rate and some theoretical rate without technology (zero percent in manufacturing). This gives a conservative estimate of the technological component of at least 40 percent for men and 25 percent for women in the United

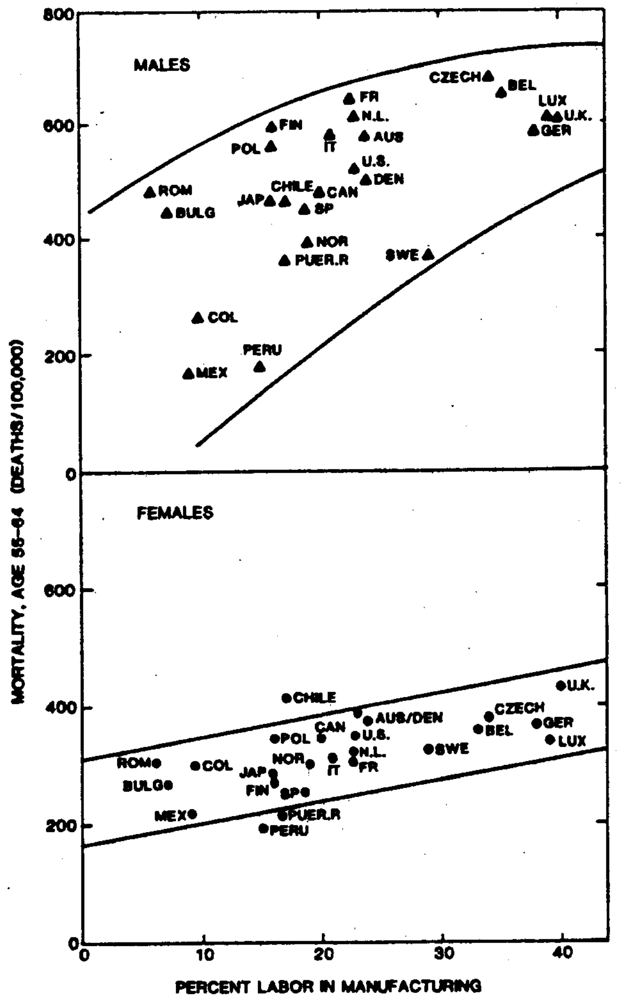

Figure 2. Correlation between age-specific 1972-1973 cancer mortality and percent labor in manufacturing in 1940 for nations believed to have reliable mortality statistics. Though the data exhibit wide scatter, both males (top) and females (bottom) show increasing cancer mortality with increasing industrialization. The scatter indicates causes for cancer other than industrialization. The consistent increase of cancer mortality probably implicates industrialization as one of the causes of cancer. The choice of 1940 allows for the known, approximately 30-year lag between exposure to carcinogens and the occurrence of cancer. Note that, consistent with their greater participation in industry, males show a bigger increase than females. These data were used to estimate the fraction of technologically involved mortality given in Table 6. Source of the mortality data: World Health Organization (1976); source of the percent labor in manufacturing: Woytinsky and Woytinsky (1953).

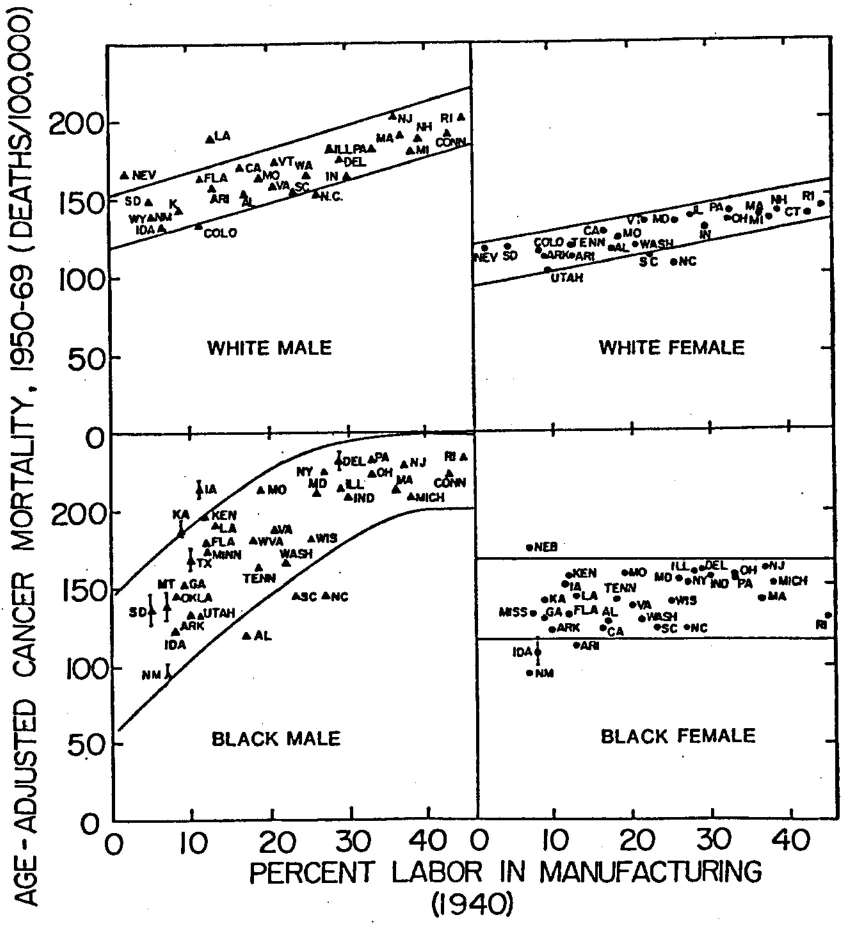

Figure 3. Correlation between average 1950-1969 age-adjusted cancer mortality and percent labor in manufacturing in 1940 for states within the United States. As might be expected from the greater homogeneity of the United States, the scatter is considerably reduced relative to international data shown in Figure 2. At the same time, the pattern of increasing mortality with increasing industrial exposure is repeated. Again men show a more pronounced increase than women and, in addition, black men show a bigger increase than white men. The only surprising aspect of the data is that black females show no apparent increase. Source: U.S. Cancer Mortality by County, 1950-69 (U.S. National Cancer Institute 1974).

States. Thus, very roughly speaking, about half of exogenous cancer mortality is the result of technology, the rest of social and cultural causes. Similar results are obtained if the per capita energy consumption is used as an indicator of technological development.

We do not wish to claim that energy consumption or industrial employment causes cancer per se. Correlations such as those shown in Figures 2 and 3 are too weak a tool for this purpose. When correlations with mortality exist for several indicators across a wide range of populations and cultures, however, it is likely that the results are not accidental but are evidence of a number of factors that form links in the causal chains leading directly or indirectly to observed chronic disease mortality. Sometimes these links are fairly simple and well-established; for example, coal mining leads to deposit of fine coal dust in deep lung cavities and, through obstruction of these, reduces lung function (black lung disease). In other cases the links are highly complex, such as the incompletely understood connections between diet and heart disease. It is the task of medical science, particularly epidemiology, to identify and describe these specific links, and it is the task of hazard management to control them. Our purpose here is to explore the magnitude of the problem and for this our correlations of disease with general indicators of technology are adequate and appropriate.

Using a method similar to that employed in the cancer illustration above, we have estimated for other chronic disease the percentage of mortality that is technologically related (Table 6). It is necessary to stress that by technologically related percentage we mean mortality, which is in principle preventable by adjustments in technology. This does not exclude the involvement of other causative factors such as genetics, cultural milieu, life-style, and natural environmental conditions as contributing causes. To compensate, and to be conservative, we exclude smoking and diet as technological causes, even though technologies have figured highly in the consumption of cigarettes (as opposed to the less hazardous tobacco forms) or in the availability of low-cost meat and dairy products (implicated in cardiovascular disease).

The Cost of Technological Mortality

Estimates of mortality and morbidity costs for various causes of death are available in the literature (Rice, Feldman, and White 1976). These estimates indicate the dollar value of medical costs and of the cost of lost productivity. Such estimates do not place any dollar value on life and suffering as such, since this necessarily depends on diverse personal and societal ethical judgments that are widely held to be beyond economic valuation. However, such estimates are important because they define the magnitude of the economic problem of lost life and illness and in this way serve to indicate the savings that can be realized if mortality and illness are prevented.

Using the percentages of technologically involved deaths given in Table 6 and the estimated values of life shortening applicable to each cause of death, we find that the total annual loss due to technological hazard mortality is approximately seven to ten million person-years, about two-thirds of which occurs in males. Using the methodology developed by Rice, Feldman, and White (1976) for translating this into medical and lost productivity costs, we find that an annual loss of $50 to $75 billion (1975 dollars) is due to technologically involved mortality and related morbidity. Interestingly, accidents and violence, though they constitute only 10 and 6 percent of male and female mortality, respectively, account for 40 to 60 percent of the costs. This is because of the relatively higher technological percentages and larger life-shortening effects in the case of accidents and violence.

Technological Impacts on Ecosystems

In contrast to human mortality, the ecosystem impacts on biological communities, while perhaps the most important of the dimensions of technological hazard in the long run, are also the most difficult to quantify. Here there are no world-wide, nearly all-inclusive accounting systems such as death certificates. And instead of dealing with one dominant species, we are dealing with literally millions of species related by a complex and often fragile system of interdependence. How can the impacts of technology on this system be defined? Two possible measures of ecosystem impacts by technological hazards (recall Table 2) are species extinction and ecosystem productivity. Both of these measures are in principle quantifiable. Yet each has less specific meaning to humans and what they value than does human mortality. Each is separately considered below.

Species Extinction

Species extinction is the most drastic and inclusive form of wildlife mortality. Like human mortality this can occur naturally, independently of any technological effects. As in the case of human mortality, we are interested here in the percentage of species extinction that is of technological origin. As before, we divide the problem by asking two questions:

1. What is the rate of exogenous species extinction, that is, the percentage of cases for which the underlying causes are not of predominantly natural origin?
2. What is the rate of technologically involved extinction, that is, the percentage of exogenous extinction that is predominantly related to technological causes?

One approach to the first question is through the historical record. As shown in Figure 4, the world-wide rate of vertebrate extinction has speeded up considerably during the last hundred years, culminating in a current rate that is at least ten times the "baseline" or evolutionary rate observed 300 years ago (Ehrlich, Ehrlich, and Holdren 1977). As shown in Table 7, one in ten species of native, higher plants in the United States is currently endangered, threatened with becoming endangered, or recently extinct; in Hawaii, nearly half of the total diversity of native vegetation is similarly involved (Council on Environmental Quality 1974;Brunnel and Brunnel 1967;Uetz and Johnson 1974;Fisher, Simon, and Vincent 1969).

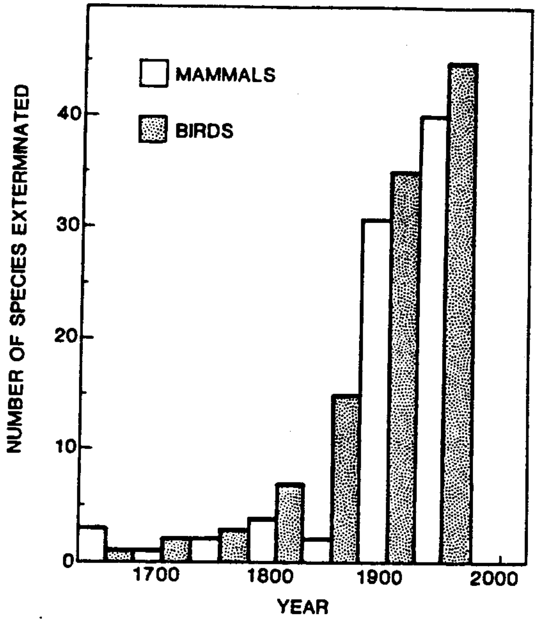

Figure 4. The number of exterminated mammal forms (white bars) and bird forms (shaded bars) eliminated over the last 300 years. Each bar represents a 50-year period. Source of the data is the National Center for Health Statistics (1978).

Another approach to estimating the rate of exogenous extinction is through direct classification of species extinction according to cause. Using available data (Fisher, Simon, and Vincent 1969) on extinction and rarity for birds and mammals since 1800, we have obtained the division into exogenous and natural causes, as shown in Table 8. Thus, for the period studied, more than two-thirds of extinction and rarity have specifically non-natural causes.

How much of exogenous extinction is of distinctly technological origin? This question is unfortunately unanswerable in terms of any well-defined analytical approach. Technology certainly plays an important role in hunting and in much of physical habitat modification, but we do not have the data for a case-by-case review of recorded extinction. In the absence of such detailed data, we conservatively estimate the technological percentage of exogenous species extinction at approximately one-half, with the remainder being largely of cultural character.

Whatever the division between technological and cultural causes may be, it is clear that the rates of exogenous extinction currently being observed are much faster than the normal evolutionary process of replacement. Nor is it possible to insure adequately against such loss in zoos, botanical gardens, and other protected environments (Ehrlich, Ehrlich, and Holdren 1977). Ecological theory, furthermore, suggests that wildlife mortality of the magnitude currently being observed can lead to significant diminution and loss

TABLE 7
Endangered, threatened and extinct species of native higher plants in the U.S.

STATUS	CONTINENTAL UNITED STATES		HAWAII	
	species, subspecies and varieties	percent	species, subspecies and varieties	percent
Total native higher plants	20,000	100.0	2,200	100.0
Endangered[a]	761	3.8	639	29.0
Threatened[b]	1,238	6.1	194	8.8
Extinct[c]	100	0.5	255	11.6
TOTAL	2,099	10.4	1,088	48.9

Source: Smithsonian Institution (1975).

[a] Endangered is defined as in danger of becoming extinct throughout all or a significant portion of their natural range.

[b] Threatened is defined as likely to become endangered in the foreseeable future.

[c] Extinct is defined as limited to recently (or possibly) extinct species only: they cannot be found after repeated searches in the localities where they were formerly observed or other likely places. Some of the latter appear to be extinct in the wild but are still preserved in cultivation.

of ecosystem productivity and resilience, with occasionally catastrophic consequences.

We wish to emphasize that counting species by itself is inadequate for defining the impact of technology on ecosystems. It is not enough to have a catalog of characters to predict the outcome of an evolutionary play. What is needed is some measure of the effectiveness with which ecosystems use energy and how well an ecosystem is able to recover from a stressed condition (resilience). Important new concepts related to ecosystem energy analysis (Odum and Odum 1976) and ecosystem resilience (Fiering and Holling 1974) are currently undergoing intensive study in the scientific community. Until these provide well-defined indicators, however, it seems prudent to use crude indicators, such as species extinction, as warning signals of potential hazard.

Ecosystem Productivity

As a second measure of ecosystem impacts we consider productivity, or the ability of ecosystems to produce organic material from inorganic substrate and sunlight. In so doing, we limit ourselves

TABLE 8
Classification of causes of extinction and rarity for birds and mammals since 1800 on a worldwide scale

CAUSE OF EXTINCTION	BIRDS (%)	MAMMALS (%)
NATURAL CAUSES	24	25
EXOGENOUS CAUSES		
Acute (hunting)	42	33
Chronic		
habitat disruption (physical)	15	19
habitat modification (biological and chemical)	19	23
TOTAL	100	100

CAUSE OF RARITY	BIRDS (%)	MAMMALS (%)
NATURAL CAUSES	32	14
EXOGENOUS CAUSES		
Acute (hunting)	24	43
Chronic		
habitat disruption (physical)	30	29
habitat modification (biological and chemical)	14	14
TOTAL	100	100

Source: Recalculated from Fisher, Simon, and Vincent (1969).

to the changing magnitude of the land biomass--that is, the organic material of biological origin found on land. Land biomass is subject to natural variability arising from such factors as weather and disease; it also responds to the expansion of timbering, agriculture, urbanization, and similar pressures from humans. The question of biomass impacts can therefore, as before, be divided into natural and exogenous effects.

Global changes in land biomass have recently been explored in connection with studies of the world carbon cycle (Bolin 1977; Woodwell et al. 1978). These studies show a net annual decline in global land biomass (albeit with great uncertainty) amounting to 0.2 to 2 percent. The causes of change are largely exogenous and, as seen in Table 9, involve decline and destruction of major land plant communities in areas of maximum population pressure. Among the communities destroyed, tropical forests are of particular concern because it is not clear that reforestation can take place in some lateritic soils. A detailed study of tropical forests estimates that 0.3 to 0.6 percent of the total is being destroyed each year (Sommer 1976).

TABLE 9
Estimates of current net loss of major land plant biomass, as reflected by the release of carbon into the atmosphere

PLANT COMMUNITY	CARBON RELEASED (BILLION TONS/YR) Average	Range
Tropical forests	3.5	1-7
Temperate forests	1.4	0.5-3
Boreal forests	0.8	0-2
Other vegetation	0.2	0-1
Detritus and humus	2.0	0.5-5

Source: Modified from data in Woodwell et al. (1978).

In addition to direct losses in ecosystem productivity from deforestation, indirect impacts on drainage basins, resulting from major changes in hydrologic and chemical cycles, can also diminish long-term productivity of the total ecosystem. For example, replacing biomass and nutrients lost in harvesting northern hardwoods may take sixty to eighty years (Likens et al. 1978).

As with the case of species extinction, exogenous decline of land biomass is of specifically technological as well as cultural origin. Because the bulk of the large changes now being seen, particularly in tropical forests, involves the application of high technology, we believe the technological component of biomass decline to be as high as 75 percent of the total.

Technological Hazards in Historical Perspective

Our discussion so far has focused on present technological hazard impacts. Except in the case of species extinction, we have made no effort to look at the historical record. Industrial development in the West is now 300 to 400 years old, and much of what has occurred in the past fifty years has been termed "post-industrial." Historical experience with technology is therefore extensive, and it is thus interesting to ask whether the problem of technological hazards is getting worse.

Human Mortality

In regard to human mortality, the benefits of technology appear to have been large and dramatic. As already noted, they include the near elimination of the worst of natural hazards--infectious disease. This development is largely responsible for the fact that, since 1850, when the United States had a highly dispersed agricultural population, life expectancy has shown a near doubling at birth, a 30 to 50 percent increase at midlife, and a modest increase at age sixty. Technology has also led to a food supply system that

is so productive that few in the industrialized world need fear even slight deprivation in relation to this basic need.

In addition, hazards of technology were undoubtedly higher in earlier, less fully managed stages of industrial development. Thus occupational mortality, at least of the acute variety, has shown a continuing and steady decline, as shown in Figure 5; and large technological disasters apparently peaked during 1900-1925 (National Safety Council 1977). If evidence from literature is desired, one needs only recall the novels of Charles Dickens and D.H. Lawrence, which contain accounts of environmental pollution and human exploitation in an industrial setting that find few parallels in the modern age.

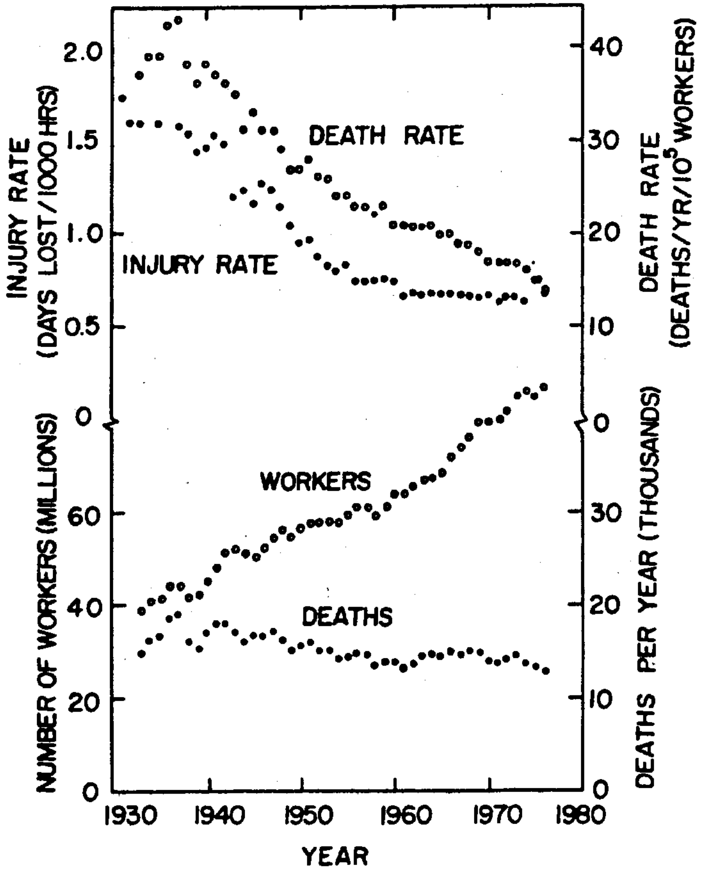

Figure 5. Historical variation of occupational death and injury rates in the United States for 1930-1976. Due to varying recording practices, injury data are considered to be only roughly correct. Source of the data is the National Safety Council (1977).

Thus, at worst the present problem may be that the positive effects of technology have for some time now reached their maximum effect on human mortality, whereas the hazards of technology continue partially unchecked, affecting particularly the chronic causes of death that currently account for 85 percent of mortality in the United States. Supportive of this view is the fact that male life expectancy has not increased since 1950 and has even shown a slight decline.

But this view may be too pessimistic. Even the apparent increase in chronic disease, which forms the principal evidence for unchecked technological hazard mortality, may be erroneously interpreted. Thus, as shown in Figure 6, along with most other causes of death, the age-adjusted mortality from heart disease is declining; and increasing cancer mortality can in large part be explained by the delayed effect of earlier increases in smoking. In addition, there is indirect evidence (Preston 1976) that certain chronic diseases were seriously under-reported in earlier parts of this century. Therefore, the actual cancer and heart disease mortality rates shown from 1900-1940 were probably higher and the overall increase since 1900 lower than shown in Figure 6.

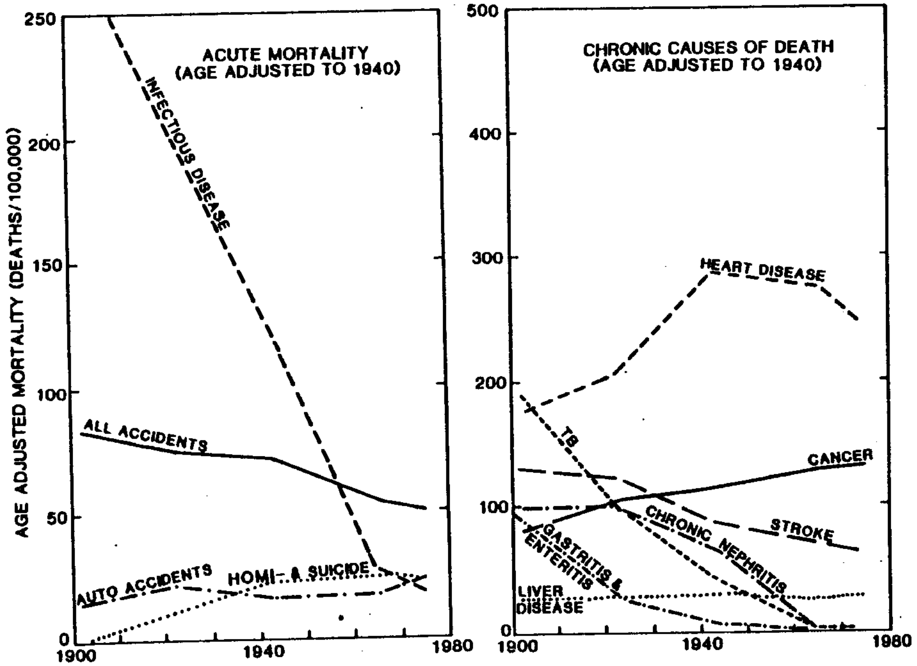

Figure 6. Historical variation of age-adjusted causes of death in the United States from 1900 to present. Among acute causes of death, note the sharp decline of infectious disease and the rise in auto-accident mortality; among chronic causes of death, note the decline of most causes except for cancer and cardiovascular disease. Even the latter shows a peaking in 1940, followed by a subsequent decline. Sources of the data is Spiegelman and Erhardt (1974).

In summary, we believe the burden of technological hazard mortality is not currently rising. Rather, it is clear that in the United States the last century has brought three things: (1) a longer life through elimination of old ways of death, which were largely acute and rooted in natural hazards, (2) an increase in chronic causes of death, which are rooted significantly in technology, providing therefore (3) a continuing burden of death, close to half of which results from accidents and violence and the remainder from various chronic diseases.

Ecosystem Impacts

Beyond species extinction and productivity decline, what are the long-term trends in technological hazard impacts on ecosystems?

On the positive side of the ledger, it is clear that massive, local releases of pollutants to the environment, as exemplified by the London killer smog, Minamata disease, and fish-killing concentrations of pesticides in rivers, are now less frequent. Trends in air and water quality indicate that, after massive investments, environmental quality in the heavily populated and industrialized areas of the United States is generally improving (Environmental Protection Agency 1977a;1977b). Thus strong control programs for particulates and sulfur dioxide have reduced emissions to the point that very few urban regions are now experiencing violations of standards for these pollutants. Fish have returned to western Connecticut's Naugatuck River, even in areas where no aquatic life could survive in the 1950s (Council on Environmental Quality 1978). Interestingly, almost all of the major ecological hazards which have been identified and brought under control share two attributes that determine the nature of the hazard management process--they originate from an easily identifiable point source, and they are amenable to control by technological fixes of the source.

On the negative side of the ledger, it is equally clear that widespread releases of pollutants in relatively low concentrations are degrading aquatic and terrestrial ecosystems at an unmitigated or even increasing rate. Calculated ratios of manmade to natural fluxes of heavy metals, for example, indicate that natural cycles of mercury, lead, antimony, and selenium are being significantly altered by human activities (Stumm 1977). The input of mercury to the global atmosphere from industrial and fossil fuel emissions exceeds the natural flux eighty-fold, and the ratio of man-made to natural flux is large for a number of other cases (Table 10). This explains, in part, why toxic metal pollution was cited by thirty-five of forty-one states that reported water quality problems to the Environment Protection Agency in 1976 (Council on Environmental Quality 1978).

Similarly, persistent pesticides consisting of chlorinated hydrocarbons, though banned for some time because of potentially harmful ecosystem impacts, are found with a 68 percent detection rate in water and sediment samples in Houston, Texas (Council on Environmental Quality 1978). And DDT, although controlled in the U.S., is increasingly being produced for global sale in developing countries (Goldberg 1976).

TABLE 10
Global average ratios between manmade and natural flux of selected heavy metals in the environment

ELEMENT	RATIO OF MANMADE TO NATURAL FLUX
Nickel	0.9
Vandium	1.3
Copper	2.3
Arsenic	3.3
Tin	3.5
Zinc	4.6
Cadmium	5.2
Selenium	14
Antimony	28
Molybdenum	29
Lead	70
Mercury	80

Source: Modified from Garrels, Mackenzie, and Hunt (1975).

Finally, acid rain, resulting from regional deterioration of air quality in areas downwind from urban centers, is having a number of effects. One of the most remarkable and potentially hazardous of these is the fact that it apparently results in a complete shift in forest floor mineral cycling processes which may eventually lead to problems with nutrient availability and metal toxicity as well as direct damage to leaf tissue (Cronan et al. 1978;Seliga and Dochinger 1978).

Thus, for ecosystems, as for human mortality, we observe a change from acute to chronic effects, from easily understood to complex causal structure. Much of what is happening in ecosystems is so incompletely understood that no clearcut directives can flow from scientific work to hazard management. All that science can currently hope to provide are warnings about what may possibly happen.

The Challenge

Hazards arising explicitly or implicitly out of technological practices have, in the industrialized world, significantly surpassed natural hazards in impact, cost, and general importance. At present in the United States, technological hazards account by our estimate for 15 to 25 percent of human mortality, with associated economic costs and losses of $50 to $75 billion annually. About half of these costs and losses are associated with accidents and violence, the remainder with various forms of chronic disease. Ecosystem impacts, though difficult to define fully, are indicated by a number of danger signals, such as significant exogenous species extinction, productivity losses, and high concentrations of man-made toxic chemicals in the environment.

Overall, the burden of risk assessment, hazard management, coping, and adjustment may be as high as $280 billion per year (1979 dollars), or 12.4 percent of GNP (chapter 7). So far, the principal result of this effort has been the elimination of numerous acute effects, such as infectious disease and point-source pollution, with little progress in stemming the tide of chronic disease and ecosystem impacts.

We conclude, therefore, that, although the problem of technological hazards is on balance not getting worse, the main success of hazard management has been with the relatively more accessible part of the problem. And, whereas this part of the problem is by no means under control, as indicated by the continuing burden of violence and accidents, the principal challenge for the future involves hazards that have indistinct causes and a broad distribution of impacts. Coping with technological hazards is and will continue to be one of the major social issues of our time.

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NOTES

1. This chapter originally appeared as "Our Hazardous Environment." Except for minor revisions appropriate to this volume, the article is reproduced with permission from Environment 20 no. 7 (September 1978):6-15,38-41, a publication of the Helen Dwight Reid Educational Foundation (HELDREF).

2. The Latin meaning of "exogenous" is "of external origin." As used in our discussion "exogenous mortality" does not necessarily exclude any genetic involvement. Rather, it refers to that fraction of mortality which, in a purely statistical sense, can be altered by changing external conditions. Genetic factors, including inherited susceptibility to a particular disease, can easily be active in this context. One needs only think of the initiation of disease in an individual case as a combination of genetic predisposition and external factors.

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