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THE BURDEN OF TECHNOLOGICAL HAZARDS

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Hazards are threats to humans and what they value: threats to life, to wellbeing, to material goods and to environment. Today, hazards originating in both nature and technology are of 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.

Particularly in the industrialized countries, major efforts are being made on two complementary fronts: risk assessment and hazard management. Risk assessment involves the identification of hazard, the allocation of cause, the estimation of the probability that harm will be experienced and the balancing of harm with benefit. Hazard management involves the choice of options to be used in control and reduction of hazardous occurrences. As practised in the industrialized world, hazard management also involves an immense and growing bureaucracy, a series of seemingly irresolvable political battles, and an interplay between science and values that often confounds rational discussion. A key question in this discussion is, "how safe is safe enough?"

Risk assessment and hazard management inevitably involve a combination of scientific understanding and social judgement as to which risks to accept, which to reduce (and by how much), and when to forego or limit the use of a technology or natural location. In practice, we marshal our science and make our judgements one at a time, addressing a specific hazard or class of hazards.

To offer needed perspective, this article provides an interim report on our best estimates of the scope of the technological hazard burden in the United States of America.

Natural and Technological Hazards

For the majority of the world's people, living in the rural areas of developing countries, the hazards of greatest concern are ancient ones, and are predominantly rooted in nature. These natural hazards most often threaten agriculture, food-supply and settlement, and constitute a major burden. For example, geophysical hazards (floods, drought, earthquakes and tropical cyclones) each year in the developing world account for an average of 250,000 deaths and $15 thousand million in damage and costs for prevention and mitigation. (Burton *et al.*, 1978). This is equivalent to 2-3 per cent 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). They can amount to as much as 50 per cent of food crops (Pimentel, private communication). And infectious disease, though declining, typically accounts for 10-25 per cent of human mortality, mostly among the very young (WHO, 1976).

By contrast, for industrialized nations, natural hazards are a much smaller problem. In the United States, geophysical hazards cause less than 1000 fatalities per year, and property damage and costs for prevention and mitigation, of the order of 1 per cent of the GNP. Vermin, pests and crop disease while occasioning serious losses, are kept in bounds by pesticides and other techniques, and infectious disease accounts for less than 5 per cent of human mortality. However, in controlling natural hazards to this extent, the industrialized nations have not escaped unscathed.

In the place of the ancient hazards of flood, pestilence and disease, new and often unexpected hazards, predominantly rooted in technology, have grown. These hazards, in our estimation are now as large or larger in impact than the natural hazards that they have replaced. We illustrate this point in Table 1 (Kates, 1978). As concrete examples of the large cost of technological hazards and their management, consider that the United States currently spends $40.6 thousand million per year or 2.1 per cent of its GNP on cleaning up air, land and water pollution (Council on Environmental Quality, 1978); that the cost of automobile accidents is estimated to be $37 thousand million, or 1.9 per cent of the GNP (Faigin, 1976); and that the toll of death alone from technological hazards involves in our estimate (see below) 20-30 per cent of male and 10-20 per cent of female mortality, and a value of medical costs and lost productivity of $50-75 thousand million, or 2.5-3.7 per cent of the GNP. Overall, expenditure and losses on technological hazards may be as high as $200-300 thousand million, or 10-15 per cent of the GNP (Tuller, 1978).

Technological hazards are thus big business, which in its scope is comparable to only a few sectors of national effort, such as social welfare programmes, transportation and national defence. And the impacts of technological hazards go well beyond mortality. To illustrate, we show in Table 2 the various groups, sectors, and environments affected, along with the dimensions of consequences that we consider in our work on technological hazard assessment and management.

TABLE 1

Comparative Hazard Sources in the U.S. and Developing Countries

	Principal Causal Agent(*a*)			
	Natural(*b*)		Technological(*c*)	
	Social cost(*d*) (% of GNP)	Mortality (% of total)	Social Cost (% of GNP)	Mortality (% of total)
United States	2-4	3-5	5-15	15-25
Developing countries	15-40(*e*)	10-25	? (*f*)	? (*f*)

(*a*)Nature and technology are both implicated in most hazards. The division that is made here is 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 costs of each of these three sources are 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 studies of technological hazards in developing countries are known to us, but we expect them to approach or exceed U.S. levels in heavily urbanized areas.

TABLE 2

Technological Hazard Impacts

HAZARD EXPOSURE RECEPTORS	DIMENSIONS OF CONSEQUENCES
1. HUMAN POPULATIONS Individuals, groups, cohorts	well-being (diminution, loss); morbidity (acute, chronic, transgenerational); mortality (acute, chronic, transgenerational);
2. ECONOMY Activities, institutions, production	individual and collective loss; cost of control adjustment; cost of mitigation.
3. SOCIETY Activities, institutions values	activity disruption; institutional breakdown; value erosion.
4. ECOSYSTEMS a. Biological	species extinction; productivity reduction; resistance/resilience diminution.
b. Environments (Natural)	landscape transformation; air and water quality deterioration; recreational opportunities lost.
c. Environments (Built)	community loss; architectural deterioration.

How may the full scope of technological hazards be evaluated? To answer this question involves the full sum of impacts and consequences as outlined in Table 2. This is a formidable job which no group has to our knowledge accomplished, or even attempted. In our work so far we have concentrated on human mortality and on ecosystems, particularly biological species and communities. The first is based on well defined data, and of all impacts, is most susceptible to quantification; the second is at best difficult to judge, and nearly impossible to quantify. They thus provide the range of current scientific understanding within which other impacts and consequences fall.

Human Mortality as a Measure of Technological Hazard

Human death is the best defined of all hazard consequences. Even many impoverished societies keep reasonable records, and for a large number of countries, including the U.S.A. (where the National Center for Health Statistics publishes vital statistics annually), mortality statistics, grouped according to "causes of death" are extensively tabulated by age, sex and even race (WHO, 1976). It would, therefore, seem that there should be a direct and obvious answer to the question, "how much death is due to technological hazard?" It seems simply necessary to add up the contributions 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 or heart disease is given as "cause of death," we 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," and this is true even of some cases involving accidents and violence.

Mortality statistics are further clouded by the fact that in many developing countries, as much as 50 per cent of all mortality is classified as of "unknown origin," and even in developed countries the practices in assigning cause vary widely (Preston, 1976).

In our study of technological hazards we circumvent these problems by using an indirect approach. Instead of estimating the percentage of mortality involved with technology by direct calculation and summing, we use a two-step process.

First we estimate the fraction of mortality that is preventable in principle, or equivalently involves external or non-genetic causes. In the literature this is often called exogenous mortality.[1]

Second, we estimate the percentage of technically preventable mortality that is involved with technology. In doing so, we recognize that externally caused or exogenous mortality sets an upper limit for technological causes of mortality, and in general contains social, cultural (sometimes referred to as life-style), and natural environmental components as well. The classification of exogenous

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[1]The Latin "exogenous" means "of external origin." "Exogenous mortality" as used in our discussion should not be taken to deny all genetic involvement – it refers rather to that fraction of mortality which in a purely statistical sense can be altered by altering external conditions. Genetic factors, including inherited susceptibility to a particular disease, are by no means excluded. One need only regard disease in an individual case as a combination of genetic predisposition and external factors.

mortality (illustrated in Table 3) is not clear-cut. In an interrelated and mutually dependent society such as ours, most deaths have multiple causes.

TABLE 3

Classification of Morbidity and Mortality

Cause	Examples
1. Endogenous: causes reside predominantly within the individual	Ageing: genetic defects arising from inherited genetic load.
2. Exogenous: causes reside predominantly outside the individual	
a. Natural environmental	Infection; background-radiation induced cancer; latitudinal skin cancer effects; natural catastrophes
b. Social and Cultural	Diet-based disease such as cancer from betel nuts, cirrhosis of liver from alcohol, heart disease from overweight; smoking related diseases; some urban related mortality; some violence; war-deaths.
c. Technological	
1. diffuse effects	pollution related diseases; some urban related mortality
2. 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 in principle? To answer this question, we first divide all of mortality into acute and chronic causes of death, shown in Tables 4 and 5. Among acute causes of death we include all those cases for which death is sudden and not preceded by a long period of illness. Among chronic causes of death we include all cases for which death results from a long period of prior morbidity or illness due to deterioration of one or more body functions. The division into acute and chronic causes is made because the analysis in the two cases is fundamentally different.

Acute Causes of Death Except for congenital malformations leading to sudden death, a small percentage of infectious disease, 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 100 per cent in most cases, as shown in Table 6.

Chronic Causes of Death For chronic causes of death we obtain the exogenous pecentage by a comparison of the mortality statistics reported by 36 nations to the World Health Organization (WHO, 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 per cent of total mortality. From the 36-nation data, the lowest age-specific mortality rate was chosen, and taken 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.

There are several problems with this definition, all of which lead us to regard it as only an approximate estimate of true exogenous mortality. For example, the definition implicitly assumes that the genetic disposition of various populations toward mortality is identical. This is not always so. Some cancers, for instance, 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 depends critically on the validity of the "base case" as representative of near zero exogenous mortality. Our definition would tend to underestimate true exogenous mortality if some "base case" mortality is preventable in principle; and would tend to overestimate true exogenous mortality if the "base case" involves serious under-recording of certain chronic causes of death. Fortunately those latter effects, both of which are surely present, will at least partially cancel each other out.

To illustrate the kind of data that we have used, we show in Figure 1 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 are 80 and 60 per cent for cardiovascular disease, and 60 and 45 per cent for cancer, respectively. Exogenous percentages for all causes of death are summarized in Table 6.

TABLE 4

Acute Mortality in the United States in 1972 (WHO, 1976)

CAUSE OF DEATH	Mortality deaths/100,000		Mortality % of total (acute + chronic)	
	male	female	male	female
INFECTIOUS DISEASE	*43.0*	*34.6*	4.0	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		

TABLE 4 (Contd)

CAUSE OF DEATH	Mortality deaths/100,000		Mortality % of total (acute + chronic)	
	male	female	male	female
OTHER ACCIDENTS	35.5	17.7	3.3	2.2
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	3.1	1.3
suicide	17.5	6.8		
homicide	15.4	3.7		
OTHER ACUTE CAUSES	11.8	9.0	1.1	1.1
TOTAL ACUTE CAUSES	193.5	107.1	18.0	13.2
MALE-FEMALE AVERAGE			15.6	

TABLE 5

Chronic Mortality in the United States in 1972 (WHO 1976)

CAUSE OF DEATH	Mortality deaths/100,000		Mortality % of total (acute + chronic)	
	male	female	male	female
CARDIOVASCULAR DISEASE	<u>554.7</u>	<u>459.3</u>	51.7	56.7
Hypertension	9.5	10.9		
Ischaemic heart disease	382.4	277.6		
Cerebrovascular disease	94.0	110.5		
Arteriosclerosis	29.2	26.7		
other cardiovascular	39.6	33.6		
CANCER	<u>188.1</u>	<u>149.6</u>	17.5	18.5
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		

TABLE 5 (Contd)

CAUSE OF DEATH	Mortality deaths/100,000		Mortality % of total (acute + chronic)	
	male	female	male	female
CHRONIC LIVER DISEASE	36.7	31.8	3.4	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	7.0	6.6
TOTAL CHRONIC DISEASE	879.9	703.4	82.0	86.8
MALE-FEMALE AVERAGE			84.4	

TABLE 6

Estimated Exogenous and Technologically Involved Deaths in the U.S.A.

CAUSE OF DEATH	Estimated exogenous component of mortality		Estimated technological component of mortality			
	%		%		(annual deaths in thousands)	
	male	female	male	female	male	female
ACUTE MORTALITY						
Infectious disease*(a)*	90	90	0	0	0	0
Deaths of infancy*(b)*	50	50	5	5	1	1
Transportation accidents*(c)*	100	100	90	90	90	39
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			18-30	11-21	193-322	88-170

TABLE 6 (Contd)

(*a*)Exogenous percentage of 90 per cent based on the hypothesis that this amount of infectious disease is in principle preventable before genetic factors become dominant. Supportive of the hypothesis is that the declining trend of infectious disease mortality is steep. The technological percentage of zero is based on the fact that infectious disease is usually prevented by technology, not enhanced.

(*b*)Presently, the U.S.A. ranks 17th in 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 result largely from disease.

(*c*)Transportation accidents are *prima facie* 100 per cent externally caused. The technological percentage given includes all deaths except those that are estimated to be predominantly homicidal or 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 thus suggests 100% 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 behaviour 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% based on cross-national plots similar to Figure 2, the difference between the U.S. rate and some theoretical rate without technology (0%), yet yielding near zero based on

(contd overleaf)

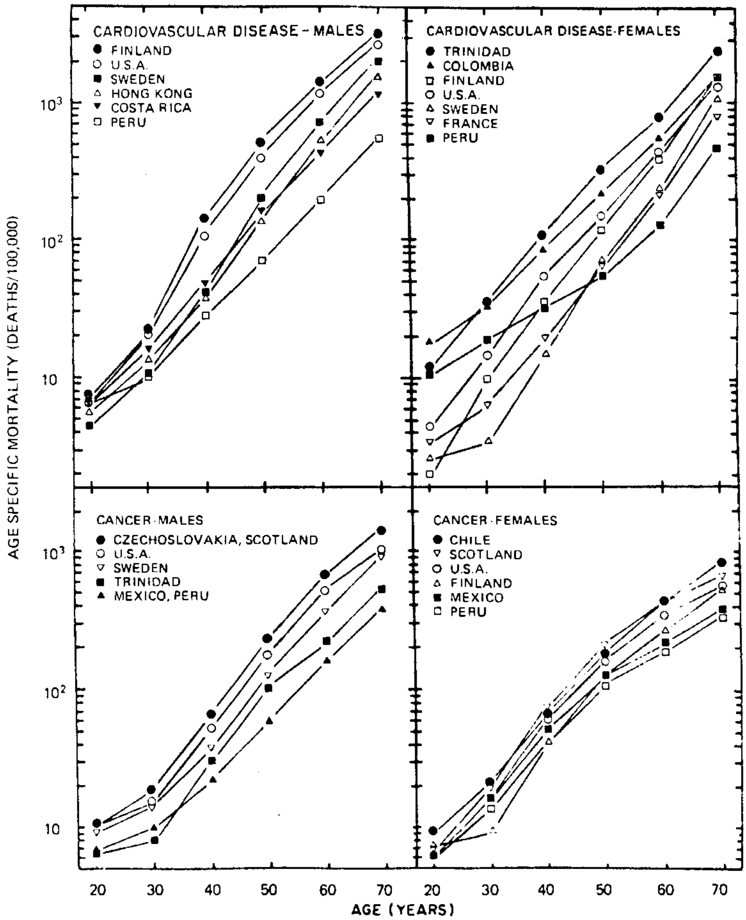

Fig. 1 Age-specific cancer and heart disease mortality in selected countries, for males and females during 1972-73. These countries were selected because they are believed to have reliable statistics and because they represent the full range of recorded mortality, from lowest to highest. The differences between the lowest and those for the U.S. were used to estimate the exogenous fraction of mortality for the U.S., as given in Table 6. Note that the plots shown here utilize a logarithmic scale. (WHO, 1976).

Technological Mortality

What percentage of exogenous mortality derives primarily from technology, as opposed to the natural environment, society or 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 is thus pretty much a guess, though hopefully a good one. To proceed with this guess, we again treat acute and chronic causes of death separtely.

Acute Mortality Infectious diseases, though influenced by the level of technology, is largely environmental and cultural in orgin. Technology usually leads to a reduction of disease, rather than increased hazard. In contrast, accidents, homicide and suicide are heavily involved with technology and culture, and marginally with the natural environment. Our estimate of the technologically involved percentage of acute mortality thus ranges from 0 per cent in the case of infectious disease to 90 per cent in the case of transportation accidents (See Table 6).

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 caput* GNP, *per caput* energy consumption, and per cent of labour in manufacturing. If chronic disease increases with level of technology, this analysis yields the equivalent of a "dose-effect" relation: i.e. it permits the determination of the change in mortality with a given change in level of technology. Unlike the 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 We illustrate our analysis for the case of cancer. International "dose-effect" relations for men and women are shown in Figure 2; equivalent relations for the U.S., for both blacks and whites, are shown in Figure 3. In each case the mortality in 1972-73 is plotted against per cent labour in manufacturing in 1940, thus allowing for the latency of cancer. Our interpretation of the observed relations are as follows:-

1) Internationally, cancer in males varies widely, and shows an average increase of a factor of 2.7 for males and 1.7 for 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.

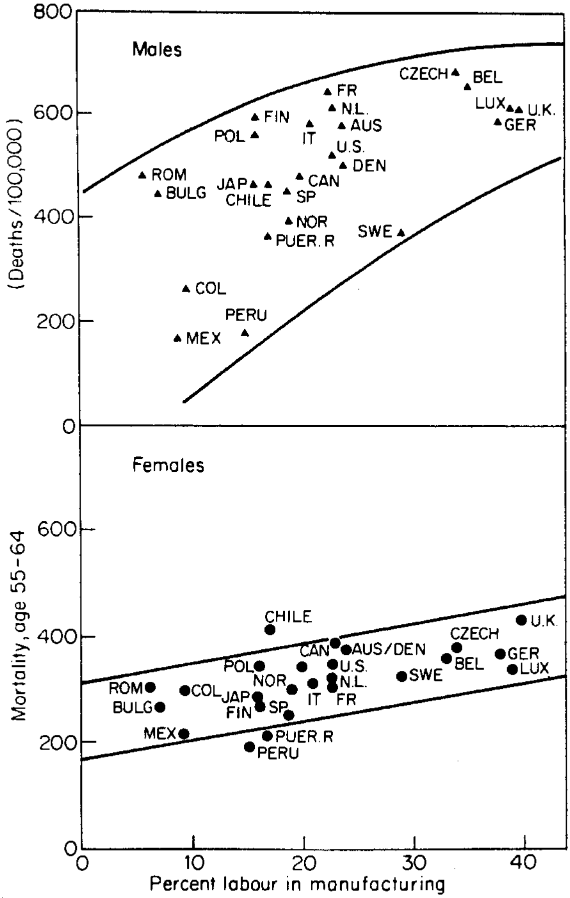

Fig. 2 Correlation between age-specific 1972-73 cancer mortality (WHO, 1976) and per cent of labour in manufacturing in 1940 (Woytinsky and Woytinsky, 1953) for nations believed to have reliable mortality statistics. Though the data exhibit wide scatter among nations, both males and females show increasing cancer mortality with increasing industrialization. The scatter indicates that there are causes other than industrialization. The consistent increase of cancer mortality with industrialization indicates that the latter is probably one of the causes of cancer (see footnote[2] p.121 on cause and correlation). The choice of 1940 to measure the level of industrialization allows for the known lag of approximately 30 years 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.

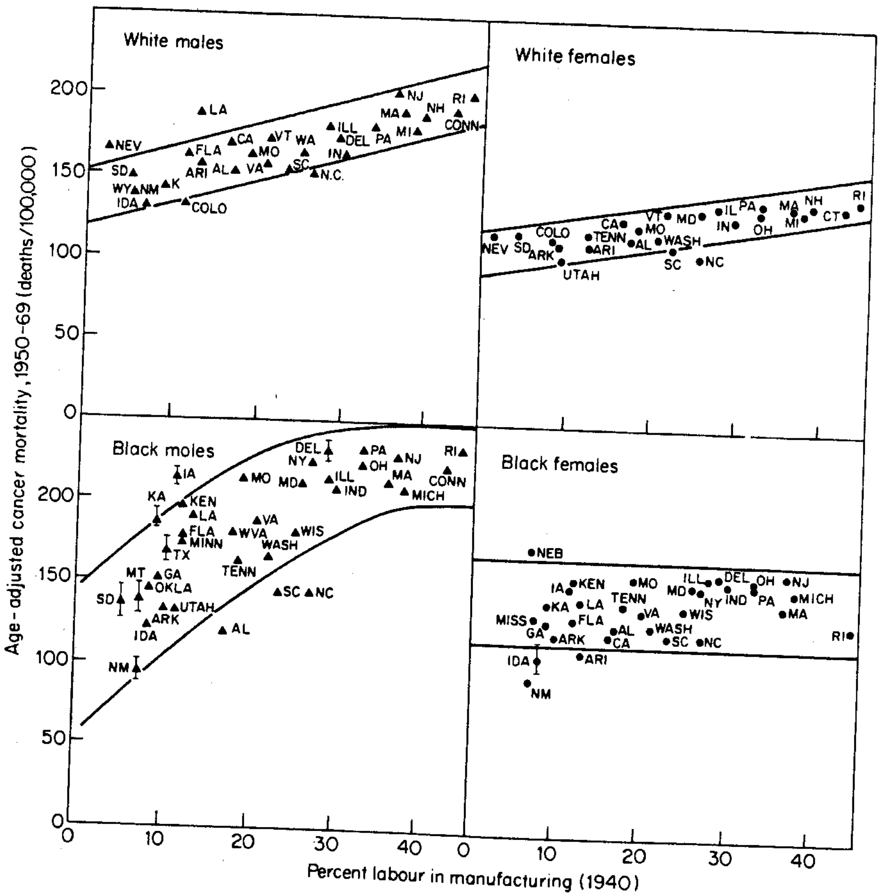

Fig. 3 Correlation between average 1950-1969 age adjusted cancer mortality and per cent of labour in manufacturing in 1940 for states within the United States. As might be expected from the greater homogeneity of the U.S., the scatter is considerably smaller than that for the international data shown in Figure 2. 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. (National Institute of Health, 1970).

2) Within the U.S. for whites, the international pattern is repeated, though with smaller increases, and less scatter. Thus mortality increases by an average factor of 1.5 for males and 1.4 for females as

level of technology ranges from lowest to highest.
3) Within the U.S. for blacks, the pattern is significantly different. For males the increase in mortality is on average a factor of 2.0, as technology varies from lowest to highest. Compared with whites, this is a distinctly larger effect. For females, on the other hand, no distinct effect is seen, though scatter is large, and average values are higher than those for white females.

Thus, although there are some puzzles, a reasonably consistent picture emerges. Cancer, as one would expect from the epidemiological literature, (Fraumeni, 1975) has an appreciable technologically involved component of mortality. Using the international data shown in Figure 2, we estimate the difference between the U.S. rate and some theoretical rate without technology (0 per cent labour in manufacturing). This gives a conservative estimate of at least 40 per cent for men and 25 per cent for women in the U.S. Thus, very roughly speaking, about half of exogenous cancer mortality is involved with technology, the rest with social and cultural causes. Similar results are obtained if *per caput* energy consumption is used as an indicator of technology.

Does Technology Cause Cancer? We do not wish to claim that energy consumption or industrial employment causes cancer *per se*. Correlations such as shown in Figures 2 and 3 are too weak a tool for this purpose [2] However, when correlations with mortality emerge for

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[2] To observe a correlation is not to establish a cause. A correlation is simply the regular change in one variable *associated* with a corresponding change in another variable. On a graph, cause and correlation look the same. How can they be distinguished? The best answer seems to be that to establish cause one tries to establish as close a link as possible, using when available, generally established theory and/or experimental evidence. To illustrate, consider three examples:

1) To-day most scientists are willing to agree that the force of gravity *causes* the earth to orbit around the sun, the tree to fall in the forest, and the tide to flow and ebb. Yet not so long ago, before an adequate universal theory of gravitation was formulated and applied, these three events were viewed as disparate phenomena, each understandable only in terms of a series of *ad hoc* assumptions, most of which turned out to be incorrect.

2) A more difficult case is the correlation between cigarette smoking and lung cancer. Though many scientists are now willing to say "smoking causes lung cancer," this was for a long time a disputed case because no general theory of cancer was and is available. Recently however, many of the substances in cigarettes and cigarette smoke have been isolated and used separately to expose animals experimentally, with the result that lung cancer developed.

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several indicators across a wide range of populations and cultures, it is likely that the results are not accidental, but are evidence of a number of factors that form links in the causal chains directly or indirectly leading to observed chronic disease mortality. Sometimes these links are fairly simple and well-established: e.g. coal mining leads to a 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 very 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 possible 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 the case of cancer, illustrated above, we have estimated the technologically involved percentage of mortality for other chronic disease as summarized in Table 6. We stress that by technologically involved percentage we mean mortality which is in principle preventable by adjustments in technology. This does not exclude other causative factors in this component of mortality, 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 or in the availability of low-cost meat and dairy products.

The Cost of Technological Hazard Mortality

Estimates of mortality and morbidity costs for various causes of

(footnote contd)

3) With cancer of the colon there is a strong correlation with *per caput* meat consumption. Here the causal situation is highly ambiguous. The "cause" may be the meat itself; but it may also be the absence of high grain consumption which is normally present in cases of low meat consumption; and finally, it may be neither meat nor grain *per se*, but the way the meat is cooked or some other unrecognized factor. One must conclude, therefore, that here, turning correlation into cause is in its very early stages, and that by taking action one runs a fairly high risk of pursuing an irrelevant goal.

The specific links that buttress the involvement of technology with chronic disease span the full range of "strong" to "weak" causation illustrated by the above three examples. The overall correlation of chronic disease with technological indicators is itself closer to the weak end of the spectrum, but is probably the best that can be done at the present time.

death are available in the literature (Rice *et al.*, 1976). These indicate the dollar value of medical care and the cost of lost productivity. Such estimates do not place a dollar value on life and suffering *per se*, since this depends necessarily on many personal and societal ethical judgements that are widely held to be beyond economic valuation. At the same time, 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 may be realized if mortality and illness are avoided and prevented.

With the values for technology-connected 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 mortality from technological hazards is approximately 0.7-1.0 million person-years, about two-thirds of which applies to males. Using the methodology developed by Rice, Feldman and White (1976) to translate this into medical costs and costs for lost productivity, we find an annual loss of $50-75 thousand million due to technology-connected mortality and related morbidity. (Details of our analysis can be found in Goble *et al.*, 1978). Interestingly, accidents and violence, though they constitute only 10.5 per cent of male and 6.5 per cent of female mortality, respectively, account for 40-50 per cent of costs. This is because these cases generally have higher technological involvement and larger life-shortening effects.

Technological Impacts on Ecosystems

In contrast to human mortality, the ecosystem impacts on biological communities, while perhaps the most important of all 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 a single dominant species, we are dealing with literally millions of species related by a complex and often fragile system of interdependence. How may the impacts of technology on this system be defined? Two measures of ecosystem impacts by technological hazards (see 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 human mortality. We consider each separately below.

Species Extinction

Species extinction is the most drastic and inclusive form of wildlife mortality. Like human mortality it can occur naturally, independent of technological effects. In analogy to 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 consisting of

cases for which the underlying causes are not of predominantly natural origin?

2) What is the rate of technologically involved extinction, consisting of the percentage of exogenous extinction that is predominantly related to technological causes.

One approach to the first question is through the historical record. As seen in Figure 4, this shows that the world-wide rate of

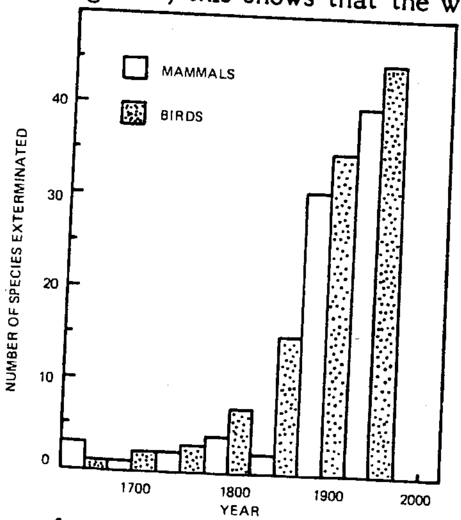

Fig. 4 The number of species of mammal and birds eliminated over the last three hundred years. Each bar represents a 50-year period. (Brunnel and Brunnel, 1976).

vertebrate extinction has considerably speeded up in the last 100 years, culminating in a current rate that is at least ten times the "baseline" or evolutionary rate observed 300 years ago (Ehrlich *et al.*, 1977). As shown in Table 7, in the U.S.A., one in ten species of native, higher plants is currently endangered, threatened with becoming endangered, or recently extinct; and in Hawaii, nearly half of the total diversity of the native vegetation is similarly involved (Brunnel and Brunnel, 1967; Fisher *et al.*, 1969; Vetz and Johnson, 1974; Council of Environmental Quality, 1975).

Another approach to estimating the exogenous extinction is through direct classification of species extinction according to cause. Using available data (Ehrlich *et al.*, 1977) on extinction and rarity of birds and mammals since 1800, we have obtained the division into exogenous and natural causes shown in Table 8. Thus for the period studied, more than two thirds of extinction and rarity has specifically non-natural causes.

How much of exogenous extinction is of distinctly technological origin? This question is unfortunately unanswerable in terms of well

TABLE 7

*Endangered, Threatened and Extinct Species of Native Higher Plants in the U.S.A.**

Status	Continental United States (including Alaska)		Hawaii	
	Species, sub-species and varieties	%	species, sub-species and varieties	%
Total native higher plants	20,000	100.0	2,200	100.0
Endangered§	761	3.8	639	29.0
Threatened¶	1,238	6.1	194	8.8
Extinct†	100	0.5	255	11.6
Total	2,099	10.4	1,088	48.9

*Source: Smithsonian Institution, (1975).

§"Endangered" is defined as in danger of becoming extinct throughout all or significant portion of their natural range.

¶"Threatened" is defined as likely to become endangered in the foreseeable future.

†"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.

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		
1. Acute (hunting)	42	33
2. Chronic		
a. habitat disruption (physical)	15	19
b. habitat modification (biological and chemical)	19	23
TOTAL	100	100

Cause of rarity	Birds (%)	Mammals (%)
NATURAL CAUSES	32	14
EXOGENOUS CAUSES		
1. Acute (hunting)	24	43
2. Chronic		
a. habitat disruption (physical)	30	29
b. habitat modification (biological)	14	14
TOTAL	100	100

Source: Recalculated from Fisher *et al.*, (1969).

defined analytical approaches. Technology is certainly heavily involved 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 place the technological percentage of exogenous species extinction at approximately one half, with the remainder largely of cultural character.

Whatever the division between technological and cultural 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 *et al.*, 1977). Ecological theory, furthermore, suggests that wildlife mortality of the magnitude being currently observed can lead to significant diminution and loss of ecosystem productivity and resilience, with occasionally catastrophic consequences.

We wish to emphasize that counting species is inadequate by itself for defining the impact of technology on ecosystems. To predict the outcome of an evolutionary play, it is not enough to have a catalogue of characters. 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 stress 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 by the scientific community. Until these provide well-defined indicators, however, it seems prudent to use crude indicators like 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 to the changing magnitude of the land biomass – the organic material found on land. Land-biomass is subject to natural fluctuations from such factors as weather and disease; it is also affected by forestry, agriculture, urbanization, and similar pressures from humans. Biomass impacts can therefore, as before, be divided into natural and exogenous effects.

Global changes in land biomass have recently been explored in connexion with studies of the world carbon cycle (Bolin 1977; Woodwell *et al.*, 1978). These studies show, albeit with great uncertainty, a net annual decline of 0.2 - 2 per cent in global land biomass (See Table 9). The causes of change are largely exogenous, and in areas of maximum population-pressure involve decline and destruction of major land-plant communities. Among the communities destroyed, tropical forests are of particular concern because it is not clear that reforestation can take place on some lateritic soils. A detailed study of tropical forests indicates that about 0.3-0.6 per cent 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 Average	1000,000,000 tons/yr 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 given 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 hydrological 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 60 to 80 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, involve the application of high technology, we believe the technological component of biomass decline to be about 75 per cent of the total.

Technological Hazards in Historical Perspective

Our discussion so far has focussed on the impacts of present technological hazard. 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 300-400 years old, and much of what has occurred in the past 50 years has been termed "post-industrial." Historical experience with technology is therefore extensive, and it is therefore interesting to ask "is the problem of technological hazards getting worse?" We discuss human mortality and ecosystem impacts separately.

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 U.S.A. had a highly dispersed agricultural population, life expectancy has shown a near doubling at birth, a 30-50 per cent increase at midlife, and a modest increase at age 60. Technology has also led to a food supply system that is so productive that few in the industrialized world need fear even slight deprivation of 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 need only recall the novels of Charles Dickens and D.H. Lawrence, which contain accounts of industrial pollution and human exploitation in an industrial setting that find few parallels in the modern age.

Thus, at worst the present problem may be that the positive effects of technology have for some time reached their maximum effect on human mortality, while the hazards of technology continue partially unchecked, affecting particularly the chronic causes of death that currently account for 85 per cent of mortality in the U.S.A. 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, the age adjusted mortality from heart disease is declining along with most other causes of death, 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,

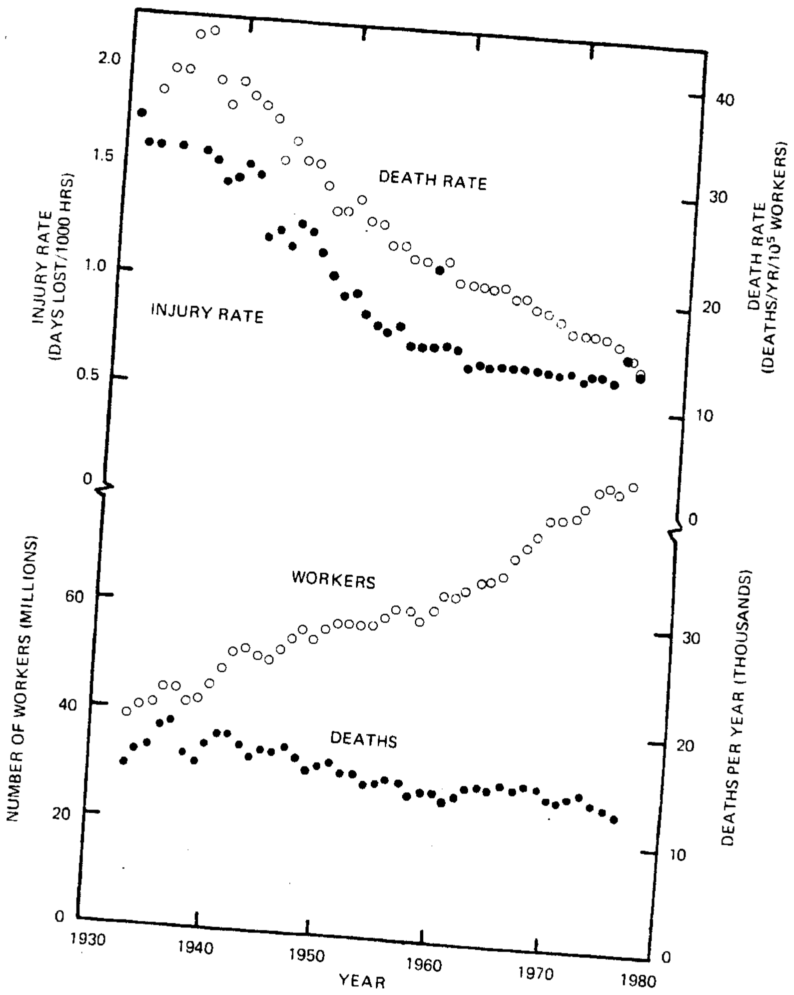

Fig. 5 Variation of occupational death and injury rates in the United States during the period 1930-76. Injury data are considered to be only approximate, since recording practices vary. (National Safety Council, 1977).

the actual mortality rates for cancer and heart disease shown from 1900-1940 were probably higher, and the overall increase since 1900 lower than shown in Figure 6.

In summary, we believe the burden of technological hazard mortality is not currently rising. Rather, it is clear that the last

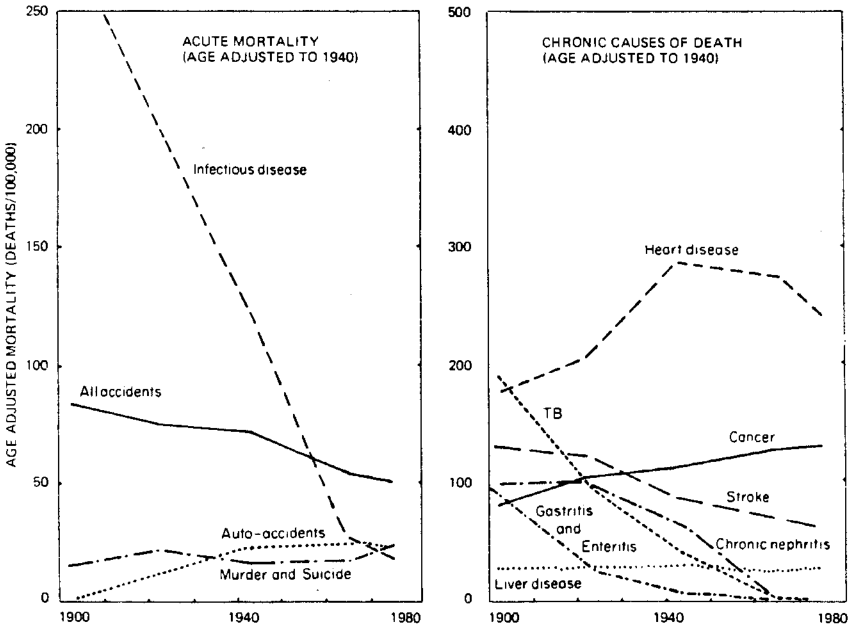

Fig. 6 Variation of age-adjusted causes of death in the United States from 1900 to the present. Among acute causes of death, note the sharp decline of infectious disease and the rise in automobile accident/mortality; among chronic causes of death, note the decline of most causes except for cancer and cardiovascular disease. Even the latter has declined since 1940. (Spiegelmann and Erhardt, 1974).

century in the U.S. has brought three things:

1) 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, rooted in part in technology; providing therefore;
3) a continuing burden of technologically related death, close to half arising 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? We restrict ourselves to a few brief observations on what amounts to an enormous topic.

On the positive side, 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 U.S. is generally improving (Environmental Protection Agency, 1977a,b). Thus strong control programmes for particulates and sulphur 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 common attributes which determine the nature of the hazard management process – they originate from an early identifiable point source and are amenable to control by technological fixes of the source.

On the negative side of the ledger, it is equally clear that widespread release of pollutants in relatively low concentrations is degrading aquatic and terrestrial ecosystems at an unabated or even increasing rate. Calculated ratios of man-made 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 80-fold, and the ratio of man-made to natural flux is also large for a number of other cases (Table 10). This explains, in part, why toxic metal pollution was cited by 35 of 41 states that reported water quality problems to the Environmental 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 per cent detection rate in water and sediment samples in Houston, Texas. (Council on Environmental Quality, 1978). And DDT, while controlled in the U.S.,

TABLE 10

Average Ratios Between Man-made and Natural Flux of Selected Heavy Metals in the Global Environment

Element	Ratio of man-made to natural flux
Nickel	0.9
Vanadium	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 Stumm (1977).

is increasingly being produced for sale in developing countries (Goldberg, 1976).

Finally, acid rain – containing sulphuric acid resulting from fossil fuel combustion in urban centres – is having a number of effects. One of the most remarkable and potentially hazardous of these is apparently a complete shift in forest-floor mineral cycling processes,

TABLE 11

Technology and Biology: A Checklist of Concerns

1. Habitat Modification

- Reduction in biological diversity: e.g. replacement of natural species by hybrids that are less resistant to environmental variation.
- Unexpected biological succession: e.g. river impoundments that produce explosive growth of exotic organisms, creating new habitats that may have harmful effects.
- Alteration of regional and global bio-geochemical cycles: e.g. carbon dioxide, nitrogen, heavy metals, etc.

2. Genetic Effects

- Development of resistance by potentially harmful organisms: e.g. resistance of bacteria to antibiotics, resistance of insects to pesticides.
- Spread of potentially harmful mutations: e.g. through experimentation with recombinant DNA.
- Reproductive failure in humans or other organisms: e.g. through exposure to sublethal amounts of certain synthetic organic compounds.

3. Spread of Disease

- Rapid world-wide spread of disease organisms: e.g. spread of new strain viruses through travel and trade by air, land and sea.
- Increases in diseases related to urban conditions: e.g. gonorrhea and lung-cancer.
- Reduction of disease defence mechanisms: e.g. through reduction in natural defence mechanisms, or through specific immunization with live vaccines.
- Emergence of new diseases: e.g. as in the case of Legionnaires Disease or the increased evidence of cancer in aquatic organisms inhabiting polluted habitats.

which may eventually lead to problems with nutrient availability and metal toxicity, as well as direct damage to leaf tissue. (Seliga and Dochinger, 1976; Cronan *et al.*, 1978).

Thus, for ecosystems as for human mortality, we observe a range from acute to chronic effects, from easily understood to complex causal structure. Much of what is happening in ecosystems is in fact so incompletely understood that no clear cut directives can flow from scientific work to hazard management. All that science can presently hope to provide are warnings of what is possible. To illustrate this point a listing of some potential hazards for the future is given in Table 11.

Summary and Conclusions

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 15-25 per cent of human mortality, with associated economic costs and losses of $50-75 thousand million annually. About half of these costs and losses are in connection 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 extinction of species, productivity losses and high concentrations of anthropogenic toxic chemicals in the environment. The impacts of technological hazards are clearly incomplete; serious consequences not considered in this paper, arise from threats to economy, society and environment.

Overall, the burden of risk assessment, hazard management, coping and adjustment may be as high as $200-300 thousand million per year, or 10-15 per cent of the Gross National Product. 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 tides of chronic disease and ecosystem impacts.

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

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References

Bolin, B. (1977). Changes of land biota and their importance for the carbon cycle. *Science* **196**, 613-615.

Brunnel, F., and Brunnel, P. (1967). "Extinct and Vanishing Animals." Springer Verlag, New York.

Burton, I., Kates, R.W. and White, G.F. (1978). "The Environment as Hazard." Oxford University Press, New York.

Council on Environmental Quality (1975). Environmental Quality 1974. U.S. Government Printing Office, Washington, D.C.

Council on Environmental Quality (1977). Environmental Quality 1976. U.S. Government Printing Office, Washington, D.C.

Council on Environmental Quality (1978). Environmental Quality 1977. U.S. Government Printing Office, Washington, D.C.

Cronan, C.S., Reiners, W.A., Reynolds, R.C. and Lang, G.E. (1978). Forest floor leaching: contributions from mineral, organic and carbonic acids in New Hampshire sub-alpine forests. *Science* **200**, 309-311.

Ehrlich, P.R., Ehrlich, A.H. and Holdren, J.P. (1977). "Ecoscience: Population, Resources and Environment." W.H. Freeman and Co., San Francisco, California.

Environmental Protection Agency. (1977a). National Water Quality Inventory – 1976 Report to Congress. (EPA-440/9-76-024). U.S. Government Printing Office, Washington, D.C.

Environmental Protection Agency. (1977b). National Air Quality and Emission Trends Report – 1976. (EPA-450/1-77-002). U.S. Government Printing Office, Washington, D.C.

Epstein, S.S. (1976). The political and economic basis of cancer. *Technology Review*, July-August, 35-43.

Faigin, B.M. (1976). Societal Costs of Motor Vehicle Accidents. (Report DOT-HS 802 119). U.S. Department of Transportation, Washington, D.C.

Fiering, M.B. and Holling, C.S. (1974). Management Standards for Perturbed Ecosystems. *Agro-Ecosystems* **1**, 301-321.

Fisher, J., Simon, N. and Vincent, J. (1969). "Wildlife in Danger." Viking Penguin, New York.

Fraumeni, J.F., Jr. (ed.). (1975). "Persons at High Risk of Cancer: An Approach to Cancer Etiology and Control." Academic Press, New York.

Goble, R.L., Yersel, M. and Hohenemser, C. (1978). "Estimates Direct Costs and Productivity Losses Due to Technological Hazard Mortality" (working paper). Hazard Assessment Group, Clark University, Worcester, Massachusetts.

Goldberg, E.D. (1976). "The Health of the Oceans." UNESCO Press, Paris.

Higginson, J. (1976). A hazardous society? Individual versus community responsibility in cancer prevention. *American Journal of Public Health* **66**, 359-366.

Kates, R.W. (1978). "Comparative Hazard Sources in U.S. and Developing Countries" (working paper). Hazard Assessment Group, Clark University, Worcester, Massachusetts.

Likens, G.E., Bormann, F.H., Pierce, R.S. and Reiners, W.A. (1978). Recovery of a deforested ecosystem. *Science* **199,** 492-496.

National Institute of Health (1970). U.S. Cancer Mortality by County, 1950-1969. U.S. Government Printing Office, Washington, D.C.

National Safety Council. (1977). Accident Facts. National Safety Council, Chicago, Illinois.

Odum, H.T. and Odum, C.E. (1976). "Energy Basis for Man and Nature." McGraw Hill, New York.

Porter, P.W. (1976). "Agricultural Development and Agricultural Vermin in Tanzania" (conference paper). Department of Geography, University of Minnesota, Minneapolis, Minnesota.

Preston, S.H. (1976). "Mortality Patterns in National Populations." Academic Press, New York.

Rice, D.J., Feldman, J.J. and White, K.L. (1976). "The Current Burden of Illness in the United States" (occasional paper). Institute of Medicine, National Academy of Sciences, Washington, D.C.

Seliga, T.A. and Dochinger, L.S. (eds.). (1976). "Proceedings of the First International Symposium on Acid Precipitation and the Forest Ecosystem." U.S. Department of Agriculture, Washington, D.C.

Smithsonian Institution. (1975). "Report on Endangered and Threatened Plant Species in the United States". U.S. Government Printing Office, Washington, D.C.

Sommer, A. (1976). Attempt at an assessment of the world's tropical moist forests. *Unasylva* **28,** 5-25.

Spiegelmann and Erhardt (1974). "Mortality and Morbidity in the United States." Harvard University Press, Cambridge, Massachusetts.

Stumm, W. (ed.). (1977). "Global Chemical Cycles and their Alterations by Man." Abakon Verlagsgesellschaft, Berlin.

Tuller, J. (1978). "The Scope of Hazard Management Expenditure in the U.S." (working paper). Hazard Assessment Group, Clark University, Worcester, Massachusetts.

Vetz, G. and Johnson, D.L. (1974). Breaking the web. *Environment* **16,** 31-39.

Woodwell, G.M., Whittaker, R.H., Reiners, W.A., Likens, G.E., Delwiche, C.C. and Botkin, D.B. (1978). The biota and the world carbon budget. *Science* **199,** 141-146.

World Health Organization. (1976). "World Health Statistics Annual", Vol. I. World Health Organization, Geneva, Switzerland.

Woytinsky, W.S. and Woytinsky, E.S. (1953). "World Population and Production." Twentieth Century Fund, New York.