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Chapter 1

Environmental Pollution

The pictures from the Apollo flights proved that not only was the earth round; it was a very finite blob. Somehow the sight of this lonely spaceship, floating friendless in the blackness of space, brought home the fact that the earth and its natural resources are indeed all we have, and that we best start worrying about the future of the earth.

It's not possible to assess what effect this view from outer space had on it, but we have seen in the past decade the formation of a new philosophical force—the environmental ethic, which questions many of our "accepted" ground rules, such as the sanctity of growth and expansion, and the freedom to exploit resources.

This ethic is closely tied to the science of environmental pollution control, for only by defining, analyzing and solving the problems of waste production can the ethic be translated to constructive action.

Before embarking on the nuts and bolts of environmental pollution control, it might be well to discuss just what is meant by environmental pollution, and to suggest the reason why it suddenly has become a critical factor in our struggle for survival.

WHAT IS ENVIRONMENTAL POLLUTION?

> "We believe all citizens have an inherent right to the enjoyment of pure and uncontaminated air and water and soil; that this right should be regarded as belonging to the whole community; and that no one should be allowed to trespass upon it by his carelessness or his avarice or even his ignorance."

This resolution, adopted in 1869 by the Massachusetts Board of Health, is the ideal of pollution control. Over a hundred years ago, therefore, pollution was already recognized as evil, and this resolution was an attempt to define the problem. Unfortunately, this definition *is* only an ideal, since total elimination of pollution would effectively require the elimination of modern civilization. The definition of pollution must therefore be more realistic if it is to be of practical value.

It is important to understand that pollution can be defined in many ways, and the specific definition used in a specific case can be important. For example, if an industry spewing forth contaminants to water and air can convince the public and the regulatory agencies that by their definition they are not polluting, pressure to force them to clean up might never materialize, even though the results of the inadequate waste disposal are obvious. Many professions are directly involved in environmental pollution, and all have defined pollution to fit the specific need. It may be instructive to review a few of these definitions, and to comment on the rationale employed.

The ecologist, trained to perceive life through a wide-angle lens, looks at pollution as something which upsets the equilibrium of a system. Typically, water pollution is defined as "anything which brings about a reduction in the diversity of aquatic life and eventually destroys the balance of life," or "any influence on the stream brought about by the introduction of materials to it which adversely affect the organisms living in the stream." These definitions have value to ecologists since ecologists are more concerned with the effect of outside forces (people) on a stream or lake than with the direct benefits the watercourse might have to man. This is not to in any way belittle this approach since, in the long run, if we cannot adjust our civilzation to be compatible with the ecosystem, we will undoubtedly lose the conflict.

In contrast to the ecologists who consider to be pollution any manmade addition which is not ecologically compatible to the existing environment, the engineers consider these additions as pollution only if and when they precipitate an immediate adverse effect. Engineers pride themselves on being realists, able to analyze problems and present clean and neat solutions. Engineers have thus proposed definitions of pollution which are, to them, more rational than the "clean as possible" approach suggested in the first paragraph or the "no change" thinking of many ecologists. All of the engineering definitions have as a core the well-being (economic, physical, social) of humans.

For example, some engineers suggest that since pollution control costs money, the benefits derived from a clean stream (or atmosphere) must be weighed against the benefits derived by spending the money on hospitals, roads, etc. The implication is that pollution is not bad in the absolute, but that as long as we don't start killing more people by cholera, typhoid, emphysema, etc. than we do on the highways, it is logical and prudent to build better highways and neglect pollution control.

Other engineers define pollution as "an impairment of the suitability of water (or air) for any of its beneficial uses, actual or potential, by man-caused changed in quality." Again the benefits to humans are emphasized, and pollution control is dependent on a favorable benefit/cost ratio.[1]

The Engineers Joint Council (composed of representatives from the various professional engineering association) has defined air pollution as "the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odor, smoke or vapor, in quantities or characteristics, and of duration such as to be injurious to human, plant or animal life or to property, or which unreasonably interferes with the comfortable enjoyment of life and property." Although this long-winded definition seems to cover all bases, it avoids classifying emissions from remotely located power plants as pollution, since the smoke is not apparently harmful and certainly having the power to run the air conditioners and electric can openers enhances man's comfort. What is missing is an admission that air is not a wastebasket, and that a defense of such emissions is untenable, regardless of their unmeasurable acute effect on plant or animal physiology.

Probably the most widely accepted of the engineering definitions of pollution is "unreasonable interference with other beneficial uses." By this definition, if the greatest beneficial use of a water course is waste discharge, then the use of the stream for swimming and fishing might be "unreasonable." Value judgments are therefore required as to what uses a stream, lake, or air over a city might have. If reasonable men decide that it is reasonable to use a lake as a septic tank and air as a wastebasket, then we are doomed to such a "reasonable" existence.

In all fairness, however, it must be noted that this type of thinking is changing. Engineers are becoming more aware of their social responsibilities, and very few will still espouse the use of a stream as

[1]The benefits and costs are both estimated in dollars, and the ratio calculated. If the B/C ratio is greater than one, the benefits exceed the costs and the project should be undertaken. On the other hand, if $B/C < 1$, the project should be abandoned.

an open sewer even if this might be the most economically sound beneficial use.

The World Health Organization (WHO) thinks of air pollution as anything "harmful to humans, animals. plants or property." The WHO mosquito control programs using DDT sprayed from airplanes would qualify as air pollution under this definition.

Others argue that pollution occurs when an additional user of a scarce resource "will cause others to have to incur additional costs or suffer disutilities associated with congestion." Although economically sound in the classic sense, this concept views air quality, for example, as being acceptable until some detrimental effect is noted, an argument which presupposes that all effects of pollution are known, a blatantly false supposition. Further, the blotting out of a sunset with smoke cannot be calculated in dollars and cents.

We could go on quoting definitions of environmental pollution, but the point has been made. Not everyone views environmental pollution in the same light, and not everyone agrees on the short- as well as long-term effects. It should be clear, therefore, why some people feel that the pollution problem is not taken seriously enough, and why at the same time others feel that governmental agencies have become too strict with regard to the control of industrial and municipal discharges. Perhaps we cannot define pollution to everyone's satisfaction, and probably there is no need to do that, as long as we remember that there are many definitions (and hence opinions) of environmental pollution.

THE ROOTS OF ENVIRONMENTAL POLLUTION

Early man spent his entire existence surviving. The procurement of food and shelter for the family took all of his time.

When farming and hunting advanced to the point where not all of the available time was devoted to the necessities, man had time to specialize. Some people became carpenters, or potters, or politicians.

With increased specialization, man began to better his life style. This had two effects; the population and the per capita consumption of goods both increased.

Until the 16th century, man was still not very proficient in producing food or controlling disease, and famines and plagues held the population within bounds. But with the industrial revolution and the birth of modern medicine, the world population began to climb wildly (Figure 1.1). The earth is now crowded with people, and all of them consume resources, and create waste. The waste must be returned to the earth in some form, and often this process destroys or alters the ecology.

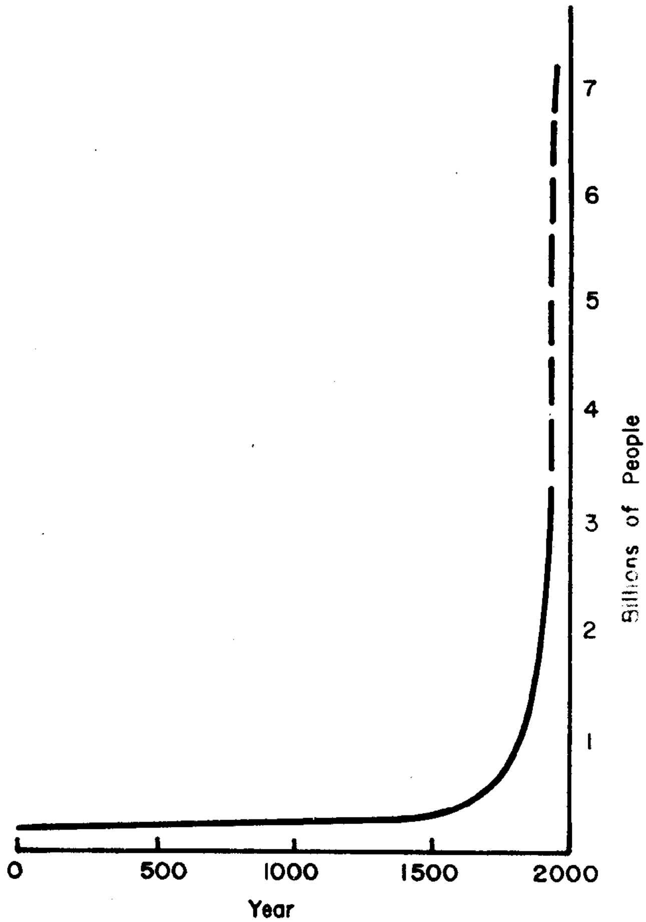

Figure 1.1. The world's population.

Overpopulation is not, however, the only danger. In economically developed countries, consumption of both manufactured and natural resources has increased tremendously within the last few decades. In fact, the problem with pollution in many countries today is mainly that of over-consumption, while population growth is responsible for only about one tenth of the increase in the use of natural resources (and the related pollution).

The consumption spiral seems to have no end, except when we finally run out of resources. This is clearly unacceptable. One solution is to drastically alter our habits as consumers.

As long as there is no tax on the use of natural resources (there is in fact a reward for using some, such as the oil depletion allowance), the education of consumers is a reasonable alternative. Unfortunately, this runs counter to human nature, and the prognostication is not good.

It is safe to state that the root of our environmental pollution problems is the tremendous leap in human population, accompanied by an even greater increase in per capita consumption of raw materials.

CONCLUSION

Although environmental pollution is difficult to define, we do know that we are perilously close to permanently spoiling our home. We must immediately control population growth and strive either to limit consumption or develop better means of recycling our resources.

We can only hope that people of the world will soon embrace the environmental ethic, before we permanently foul up our spaceship.

PROBLEMS

1.1 Choose any consumer product on the market today and write either a 15-second radio spot or design a ½-page magazine advertisement for the product, using some ecological or environmental themes inappropriately. You are, in short, to create your own "eco-pornography."

1.2 Suppose you are peacefully and comfortably sitting in front of the tube watching your favorite show and your mother/wife/girlfriend yells at you to take the garbage out. Now you have several options:

a) Jump up and do as she says
b) Procrastinate until she forgets about it
c) Tell her to do it herself

There are a number of considerations you weigh in your mind in order to make the correct decision

1. She might get mad
2. The garbage smells
3. The show is too good to miss
4. It's raining outside
5. You plan to ask her for a favor

Give these 5 considerations numerical values from 0 to 3 and calculate the Benefit/Cost ratio for the proposed project. For example, if you feel that risking her wrath is not very important, you can rate it as 1, and use this in the cost side of the ratio. Using this technique, make a decision about the garbage.

1.3 "A polluted stream is simply one that kills fish and plant life." (Mill & Factory, Nov. 1966). Do you agree with this definition of pollution?

1.4 Using a dictionary and/or thesaurus, list synonyms for "pollution." Do you agree they are all synonymous?

1.5 Find an example of "eco-pornography" in a current magazine, cut it out, paste it on a sheet of paper, and on that paper explain why you feel it is an example of "eco-pornography."

SUGGESTED READING

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Chapter 2
Water Pollution

Although people intuitively relate filth with disease, the fact that pathogenic organisms can be transmitted by polluted water was not recognized until the middle of the nineteenth century. Probably the most dramatic demonstration that water can indeed transmit disease was the Broad Street pump handle incident.

A public health worker named John Snow, assigned to attempt to control a cholera epidemic, realized that there seemed to be an extremely curious concentration of cholera cases in one part of London. Almost all of the people affected drew their drinking water from a community pump in the middle of Broad Street. Even more curious was the fact that the people who worked and lived in an adjacent brewery were not afflicted. Although this seemed to demonstrate the health benefits of beer, welcome news to most students, Snow recognized that absence of cholera in the brewery might be because the brewery obtained its water from a private well and not the Broad Street pump.

Unable to convince his superiors to ban the obviously polluted water supply, Snow simply removed the pump handle and thus prevented the people from using the water. The source of infection was stopped, the epidemic subsided, and a new era of public health awareness related to water supplies began.

The concern with water pollution was, until recently, a concern about health effects. In many countries it still is. In the United States and other developed countries, however, water treatment and distribution methods have for the most part eradicated the transmission of bacterial waterborne disease.[1] We now think of water pollution not

[1]There is some question of viral and chemical poison transmission, however, and some knowledgeable people suggest that there may in fact be a potentially serious public health problem.

in terms of health, but rather in terms of conservation, aesthetics, and the preservation of natural beauty and resources. Man has an inexplicable affinity for water, and the fouling of lakes, rivers and oceans is intrinsically unacceptable to the concerned citizen.

SOURCES OF WATER POLLUTION

The United States has more than 40,000 factories that use water, and their industrial wastes are probably the greatest single water pollution problem.

Organic wastes from industrial plants, at present-day treatment levels, are equal in polluting potential to the *untreated* raw sewage of the entire population of the United States. In most cases the organic wastes, as potent as they might be, are at least treatable, in or out of the plant. Inorganic industrial wastes are much trickier to control, and potentially more hazardous. Chromium from metal-plating plants is an old source of trouble, while mercury discharges have only recently received their due attention.

As important as these and other well known "heavy metals" might be, many scientists are much more concerned with the unknown chemicals. Industry is creating a fantastic array of new chemicals each year, all of which eventually find their way to the water. For most of these, not even the chemical formulas are known, much less their acute, chronic or genetic toxicity.

Another industrial waste is heat. Heated discharges can drastically alter the ecology of a stream or lake. This alteration is sometimes called beneficial perhaps because of better fishing or an ice-free docking area. The deleterious effects of heat, in addition to promoting modifications of ecological systems, include a lessening of dissolved oxygen solubility and increases in metabolic activity. Dissolved oxygen is vital to healthy aquatic communities, and the warmer the water the more difficult it is to get oxygen into solution. Simultaneously, the metabolic activity of aerobic (oxygen-using) aquatic species increases, thus demanding more oxygen. It is a small wonder, therefore, that the vast majority of fish kills due to oxygen depletion occur in the summer.

Municipal waste is a source of water pollution second in importance only to industrial wastes. Around the turn of the century, most discharges from municipalities received no treatment whatsoever. In the United States, sewage from 24 million people was flowing directly into our watercourses. Since that time, the population has increased, and so has the contribution from municipal discharges. It is estimated that presently the population equivalent[2] of municipal discharges to watercourses is about 100 million. Even with the billions of dollars spent on building wastewater treatment plants, the contribution of municipal pollution is still climbing. We seem to be falling behind instead of gaining in the control of municipal discharges.

One problem, especially in the older cities on the East Coast of the United States, is the sewerage systems. When the cities were first built, the engineers realized that sewers were necessary for both stormwater and sanitary wastes, and they saw no reason why both stormwater and sanitary wastes should not flow in the same pipelines. After all, they both ended up in the same river or lake. Such sewers are now known as "combined sewers."

As years passed and populations increased, the need for the treatment of sanitary wastes became obvious, and two sewer systems were built, one to carry stormwater and the other, sanitary wastes. Such systems are known as "separate sewers."

Almost all of the cities with combined sewers have built treatment plants which can treat the "dry weather flow," or in other words, sanitary wastes. As long as it doesn't rain, they can provide sufficient treatment. When the rains come, however, the flows swell to many times the dry weather flow and most of it must be by-passed directly into a river or lake. This overflow contains sewage as well as stormwater, and has a high polluting capacity. All attempts to capture this excess flow for subsequent treatment, such as storage in underground caverns and rubber balloons, are expensive. However, the alternative solution, separating the sewers, is estimated at a staggering $60 billion for the major cities in the United States.

In addition to industrial and municipal wastes, water pollution emanates from many other sources.

Agricultural wastes, should they all flow into a stream, would have a population equivalent of about 2 billion. Fortunately, very little of it does reach streams. The problems are intensifying, however, with the increase in the size and number of feed lots. Feed lots are cattle pens constructed for the purpose of fattening up the cattle before slaughter. These are usually close to slaughterhouses (hence cities)

[2]Population equivalent is the number of people needed to contribute a certain amount of pollution. For example, if a town has 10,000 people, and the treatment plant is 50% effective, then their discharge has a population equivalent of 5,000 people. Similarly, if an industry discharges 1,000 lb of solids per day, and if each person contributes 0.2 lb per day into domestic wastewater, the industrial waste can be expressed as being the equivalent of $1000/0.2 = 5000$ people.

and a large number of animals are packed in a small space. Drainage from these lots has an extremely high pollutional strength.

Sediment from land erosion can also be classified as a pollutant. Sediment consists of mostly inorganic material washed into a stream as a result of farming, construction or mining operations. The detrimental effects of sediment include interference with the spawning of fish by covering gravel beds, interference with light penetration thus making food more difficult to find, and direct damage to gill structures. In the long run, sediment could well be one of our most harmful pollutants.

The concern with pollution from petroleum compounds is relatively new, starting to a large extent with the Torrey Canyon disaster in 1967. Ignoring maps showing submerged rocks, the huge tanker, loaded with crude oil, plowed into a reef in the English Channel. Almost immediately, oil began seeping out, and both the French and British became concerned. Rescue efforts failed and the Royal Air Force attempted to set it on fire, with little success. Almost all of the oil eventually leaked out and splashed on the beaches of France and England. The French started the back-breaking chore of spreading straw on the beaches, allowing the straw to adsorb the oil, and then collecting and burning the oil-soaked straw. The English, being more sophisticated, used detergents to disperse the oil and then flushed the emulsion off the beaches. Time has shown the French way to be best, since the English detergents have now been shown to be potentially more harmful to coastal ecology than the oil would have been.

Although the Torrey Canyon disaster was the first big spill, many smaller ones preceded and followed it. It is estimated that there are no fewer than 10,000 serious oil spills in the United States every year. In addition, the contribution from routine operations such as flushing oil tankers may well exceed all the oil spills.

The acute effect of oil on birds, fish and microorganisms is reasonably well catalogued. What is not so well understood, and potentially more harmful, is the subtle effect on aquatic life. Salmon, for example, have been known to find their home stream by the specific smell (or taste) of the water, caused in large part by the hydrocarbons present. If man continues to pour (albeit unintentionally) hydrocarbons into salmon rivers, it is possible that the salmon will become so confused that they will refuse to enter their spawning stream.

Another form of industrial pollution, much of it willed to us by our ancestors, is acid mine drainage. The problem is caused by the leaching of sulfur-laden water from old abandoned mines (as well as some active mines). On contact with air, these compounds are soon oxidized to sulfuric acid, a deadly poison to all living matter.

It should be amply clear, therefore, that water can be polluted (made unusable?) by many types of waste products.

Other than the direct effect of toxic materials such as heavy metals and refractory organics,[3] the most serious effect of pollution is the depletion of dissolved (free) oxygen. All higher forms of aquatic life exist only in the presence of oxygen, and most desirable microbiologic life also requires oxygen. Generally, all natural streams and lakes are aerobic (containing dissolved oxygen). If a watercourse becomes anaerobic (absence of oxygen), the entire ecology changes to make the water unpleasant or unsafe.

Problems associated with pollutants which affect the dissolved oxygen levels cannot be appreciated without some understanding of the concept of biodegradation, part of the total energy transfer system of life.

BIODEGRADATION

Plant growth, or photosynthesis, can be represented by the equation

$$CO_2 + H_2O \xrightarrow[\text{\& nutrients}]{\text{sunlight}} HCOH + O_2$$

In this representation formaldehyde (HCOH) and oxygen are produced from carbon dioxide and water, with sunlight the source of energy.[4] If the formaldehyde and oxygen are combined and ignited, an explosion results. The energy which is released during such an explosion is stored in the carbon-hydrogen-oxygen bonds of formaldehyde.

Plants, generally speaking, use inorganic chemicals as nutrients and with sunlight as a source of energy build high-energy molecules (Figure 2.1). Animals eat these high-energy molecules and during their digestion process some of this energy is released and used by the animal. The release of this energy is quite rapid and the end products of digestion (excrement) consist of partially stable com-

[3]Refractory organics are man-made organic materials such as the pesticide DDT which decompose very slowly in the environment. There are, of course, naturally-occurring refractory compounds as well.

[4]Of course, formaldehyde is not the end product of photosynthesis, but it is an organic molecule and happens to provide a simple equation.

pounds. These compounds become food for other organisms and are thus degraded further but at a slower rate. After several such steps, very low energy compounds are formed which can no longer be used by microorganisms for food. Plants then use these compounds to build more high energy molecules, and the process starts all over again.

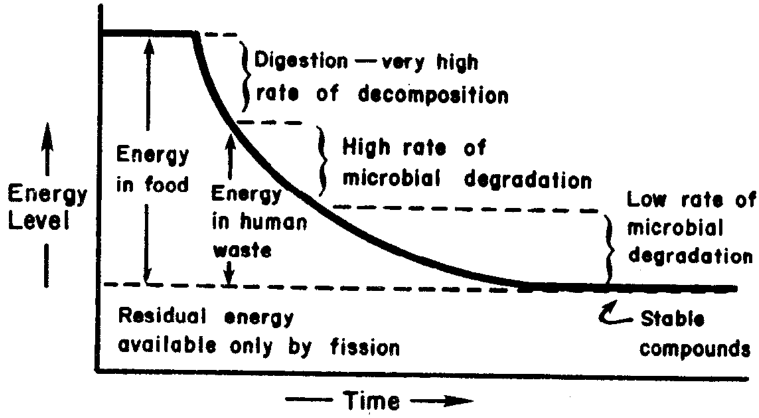

Figure 2.1. Energy loss in biodegradation.

It is important to realize that many of the organic materials responsible for water pollution enter watercourses at a high energy level. It is the biodegradation, or the gradual use of this energy, by a chain of organisms which causes many of the water pollution problems.

AEROBIC AND ANAEROBIC DECOMPOSITION

Decomposition, or biodegradation, can take place in one of two distinctly different ways: aerobic (using free oxygen) or anaerobic (in the absence of free oxygen).

The basic equation of aerobic decomposition is

$$\text{Complex Organics} + O_2 \rightarrow CO_2 + H_2O + \text{Stable Products}$$

Carbon dioxide and water are always two of the end products of aerobic decomposition. Both are stable, low in energy, and are used by plants in the process of photosynthesis. If sulfur compounds are involved in the reaction, the most stable end product is $SO_4^{=}$, the sulfate ion. Similarly, phosphorus ends up as $PO_4^{\equiv}$, orthophosphate. Nitrogen goes through a series of increasingly stable compounds, finally ending up as nitrate. The progression is

$$\text{Organic Nitrogen} \rightarrow NH_3 \text{ (ammonia)} \rightarrow NO_2^- \text{ (nitrite)}$$
$$\rightarrow NO_3^- \text{ (nitrate)}$$

Because of this distinct progression, nitrogen has been in the past and to some extent is still used as an indicator of pollution.

A schematic representation of the aerobic cycle for carbon, sulfur, and nitrogen compounds is shown as Figure 2.2. This figure illustrates only the basic facts, and is a gross simplification of the actual steps and mechanisms involved.

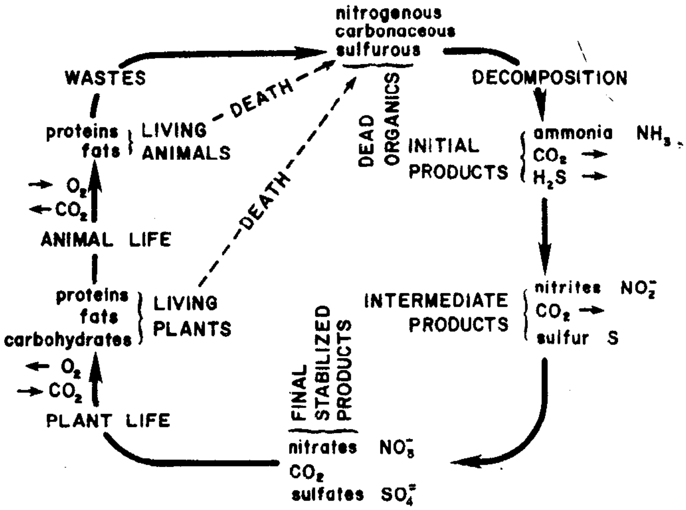

Figure 2.2. Aerobic nitrogen, carbon and sulfur cycle.

The second type of biodegradation is anaerobic, performed by a completely different set of microorganisms, to which oxygen is in fact toxic. The basic equation of anaerobic decomposition is

$$\text{Complex Organics} \rightarrow CO_2 + CH_4 + \text{other partially stable compounds}$$

Note that many of the end products shown are biologically unstable. CH_4, for example, is methane, a high energy gas commonly called marsh gas, physically stable but still able to be decomposed biologically. Nitrogen compounds stabilize only to ammonia, NH_3, and sulfur ends up as evil-smelling hydrogen sulfide (H_2S) gas. Figure 2.3 is a schematic representation of anaerobic decomposition. Note that the left half of the cycle, the photosynthesis by plants, is identical to the aerobic cycle in Figure 2.2.

Biologists often speak about various compounds as "hydrogen acceptors." The hydrogen atoms, torn from high energy organic molecules, must be attached to various compounds. In aerobic decompo-

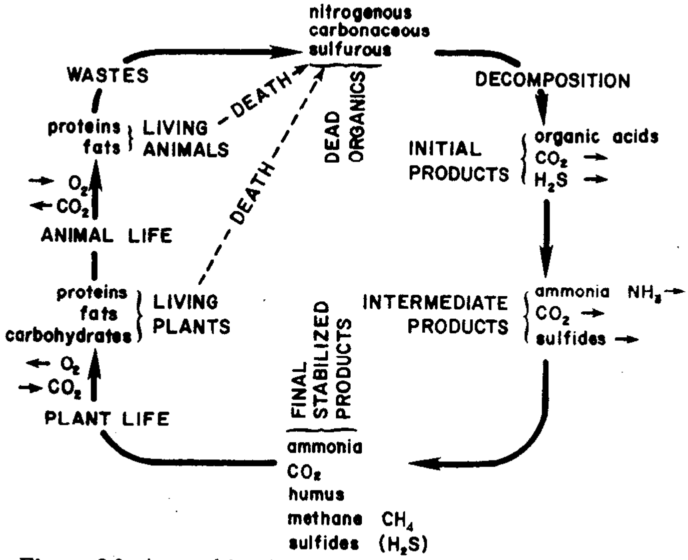

Figure 2.3. Anaerobic nitrogen, carbon and sulfur cycles.

sition oxygen serves this purpose and is thus known as the hydrogen acceptor. It accepts the hydrogen atoms to form water.

In anaerobic decomposition free oxygen is not available, and the next preferred hydrogen acceptor is nitrogen, thus forming ammonia, NH_3. If free oxygen is not available, ammonia cannot be converted to nitrites or nitrates. If nitrogen is not available, the next preferred hydrogen acceptor is sulfur, thus forming hydrogen sulfide, H_2S, the chemical responsible for the notorious rotten egg smell.

THE EFFECT OF POLLUTION ON STREAMS

When a high energy organic such as raw sewage is discharged to a stream, a number of changes occur downstream from the point of discharge. As the organics are decomposed, oxygen is used at a greater rate than before the pollution occurred, and the dissolved oxygen (D.O.) level drops. The rate of reaeration, or solution of oxygen from the air, also increases, but this is often not great enough to prevent a total depletion of oxygen in the stream. When this happens, the stream is said to become anaerobic. Often, however, the D.O. does not drop to zero, and the stream recovers without experiencing a period of anaerobiasis. Both of these situations are de-