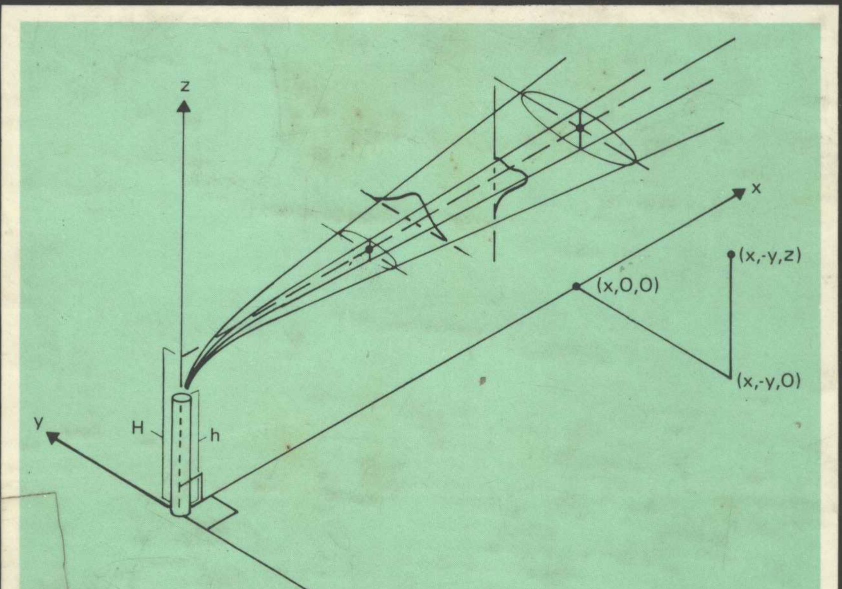
POLLUTION ENGINEERING AND TECHNOLOGY/13

Chemicals in the Environment

Distribution • Transport • Fate • Analysis



W. Brock Neely

CHEMICALS IN THE ENVIRONMENT

DISTRIBUTION • TRANSPORT FATE • ANALYSIS

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PREFACE

During the period of time marked by the creation of the Environmental Protection Agency in the United States (1970) and the final passage of the Toxic Substance Control Act of 1976, it became obvious that the chemical industry was entering into a new era of being a highly regulated industry. This era will be marked by a gradual transfer of decision making from the private sector to a situation where all major decisions on new or existing chemicals will be made in the full glare of the public arena. The citizens, through their elected representatives, have collectively said that they want to know what the consequences of any planned activity will be before the event is implemented. To accomplish this transfer of decision making in an orderly fashion, we as representatives of the scientific community must become more adept at predicting what will occur in the environment as a result of some planned activity. Of equal importance, we must also become adept at translating our information into a language that is easily comprehended by all professions.

It is my belief that only by knowing how chemicals move and distribute themselves in the various parts of the ecosystem can we make such predictions. Once we have some knowledge of the expected concentration, we can match these concentrations with the toxicological properties and then begin to make statements regarding the environmental impact.

As soon as this concept was fully recognized, I quickly became aware of shortcomings in my own background. By training I am a biochemist and felt inadequate in such fields as physical chemistry, inorganic chemistry, and mathematics. Environmental science is truly an interdisciplinary field, and without all disciplines being represented attack on the many problems will be inadequate.

This book is a beginning effort to bring these disciplines together. As such it is a general description of the tools rather than an in-depth analysis of each area. For more in-depth study, books that are more specialized must be examined.

Without the constant interaction with my colleagues representing other disciplines I would never have been able to accomplish this writing. I would especially like to thank Drs. G. Blau and R. Alfrey for their patience in helping me grasp a basic understanding of the mathematics. Drs. W. Dilling and R. Bailey were most helpful in the sections dealing with photodegradation and biodegradation, respectively. Drs. R. Moolenaar, C. Goring, and F. Hoeger offered valuable criticism in the preparation of the manuscript. Finally, a special thanks to Dr. D. Branson for many enjoyable conversations on various topics, with special emphasis on bioconcentration.

W. Brock Neely

CONTENTS

Chapter One

THE BASIS FOR CONCERN

> *Knowledge will forever govern ignorance, and a people that mean to be their own governors must arm themselves with the power that knowledge brings.* James Madison

1.1 PUBLIC AWARENESS

With the publication in 1962 of *Silent Spring* by Rachel Carson [1] the public became aware of the environment and the potential harm that could follow from the massive application of pesticides. In the intervening years scientists have uncovered other environmental problems which have increased this concern. Incidents such as the mercury contamination of fresh water [2], the widespread distribution of the industrial chemical polychlorinated biphenyl [3,4], and more recently the alleged destruction of the ozone layer in the stratosphere due to the release of aerosol propellants (chlorofluorocarbons) [5,6] have become household subjects. All through this time period there were many books written warning of the impending dangers if society did not mend its ways [7-10]. Congress and the president of the United States, after much debate, responded to public pressure with the creation of the Environmental Protection Agency (EPA) in 1970, followed almost immediately by the passage of some 30 laws designed to put the nation on a course of cleaning up the environment and minimizing any future damage. Similar legislative action has also occurred in the other industrialized countries of the world.

1.2 THE NEED FOR REGULATION

While individuals are basically opposed to regulations imposed by others, subconsciously they are also aware of the need for controlled action. One of the best articles outlining the dilemma is Hardin's famous essay "The Tragedy of the Commons" [11]. In this article Hardin concluded that this dilemma has no technical solution but requires a fundamental extension or change of morality. Hardin illustrated his essay with a scenario dealing with a pasture that was open to all herders. It would be expected that each herder would keep as many animals as possible on the commons. This type of arrangement works well as long as wars, poaching, and disease keep the numbers of both humans and beasts well below the capacity of the land to support them. However, the day of triumph finally arrives when the long-awaited goal of social stability becomes a reality. At this point, as Hardin states, "the inherent logic of the commons remorselessly generates tragedy." As a rational person each herder seeks to maximize his or her gain and concludes that the only sensible action is to add more animals. However, this is the same conclusion that all herders reach. The tragedy is that the system compels each person to increase their herd without limit in a pasture that is limited. As long as belief in the freedom of the commons is retained, it will bring ruin to all. Hardin then goes on to discuss other commons such as air and water and the problems society has with pollution. Rational people (similar to the herder) find that their share of discharging waste into the common air or water is a charge borne by all people. Since this is true for everyone, society is again locked into a system that is destined to bring ruin. One solution to these types of problems has been to establish laws and regulations which in effect put fences around the commons. Through such mutual coercion society seeks to break out of the inevitable consequences of pursuing a "commons-type philosophy."

Once the reality of governmental regulation is accepted in the area of pollution, another problem is raised. Environmental science is a very young science which has not yet uncovered all the facts or solved enough problems to provide the technical guidance necessary for the many regulations that are being written. However, the regulatory section of the EPA, by law, cannot wait for the necessary data. They are required to do something now. This impasse introduces the first law of ecology [9]:

> Whenever we propose to do away with one disruption of the environment we implicitly propose a substitute disruption--or we can never do merely one thing, we can never do nothing.

The danger in the present state of affairs is that by promulgating regulations without sufficient knowledge one danger may be replaced with a greater danger.

1.3 HISTORICAL BASIS FOR THE PROBLEM

How did the situation develop in which air and water have been treated as a commons suitable for the release of excessive amounts of certain chemicals? There have been many articles dealing with the exponential increase in both population and natural resource consumption [10,12]. However, these are the results, not the causes of the problem. A plausible thesis is presented by L. White, Jr., who wrote a very thought provoking article [13] entitled "The Historical Roots of our Ecological Crisis." In this article White traces present-day problems back to the emerging Western civilization in Europe during the seventh century. One of the dominant characteristics of these people was the union of technology with science. The consequences of such a fusion are best illustrated by the example of farming cited in White's article. These early European peasants were beginning to use a plow that was the forerunner of the modern moldboard plow. Such a plow has a sharp knife that cuts the soil and a shearing action which turns over a large slice of sod. This was a sharp break with the old scratch plows that were used and are still used in many parts of the world. However, the new equipment required large teams of oxen to operate. Since no peasant owned enough oxen to pull the new plow, they had to pool their animals in order to generate sufficient power. Once again tradition was broken since it meant the distribution of land was based not on need but on the capacity to till the earth. As White says, "Man's relation to the soil was profoundly changed. Formerly man had been part of nature, now he was the exploiter of nature." The genetic characteristics leading to this course of action that was initiated so many centuries ago by these northern peasants have been passed on to the present-day heirs. The new agricultural practice based on power to cultivate rather than need has grown and expanded tremendously since the seventh century. This is especially evident in those areas of the world populated by descendants of the northern European peasants. Confirmation of this observation may be obtained by examining the statistics compiled by the United Nations world food agency [14]. Table 1.1 is an extraction of some of these data showing the percent of the work force in various countries actually working in food production. It is seen that North America, Australia, and Europe all have developed technology and power sources which require fewer and fewer people to actually till the soil.

One of the impacts from this direction has been the release of a large percentage of the work force from food raising. This has provided time for pursuit of other activities, and since we seem to be dominated by an implicit faith in perpetual progress, great success has been achieved. During the early history of the United States such a course of action could be pursued with reckless abandon because the low level of economic activity combined with the relatively small population did not tax the capacity of the environment to assimilate the resultant wastes. Consequently, air and water were considered "free goods." However, in recent years these free goods have become scarce. Nevertheless, they are still treated as free. Smog-laden air and unsightly, foul-smelling rivers are manifestations of the failure to cope successfully with the deepening scarcity of air and water. Goods and services have only recently begun to reflect the costs associated with environmental cleanup. With the investment of the capital represented by these increased costs the environment is gradually improving and will continue to improve as the knowledge and data base expands.

TABLE 1.1 Economically Active Population Working in Agriculture as a Percent of The Total Work Population in Various Countries

	Total population[a]	Economically active population		
		Total	In agriculture	% in agriculture
Western Countries				
U.S.A.	204,800	81,089	3,243	4.0
Canada	21,406	8,033	642	8.0
United Kingdom	55,726	25,120	694	2.8
France	50,775	21,782	3,113	14.3
Belgium	9,683	3,689	179	4.8
Australia	12,514	5,144	430	8.4
Eastern Countries				
China	773,659	356,601	237,394	66.5
India	538,881	216,382	146,491	67.7
Pakistan	62,149	18,494	13,038	70.5
World (average)				51.0

[a]All population figures in thousands.

Source: Ref. 14.

1.4 IMPACT OF OIL CONSUMPTION

A discussion of how this problem evolved would not be complete without a description of oil consumption and the impact it has had, particularly on the United States. As described in Sec. 1.3, in the industrialized nations progress has been associated with the development of machines to do the work of people and do it more efficiently. Such a course of action requires power to drive the machines. Historically the source of power was animals, followed by water, wood, and coal. However, the cheapest form of power that has ever been discovered and exploited has been oil. Examining the history of oil from about 1880 [15] to the present demonstrates a growing dependence on the magic substance by all industrialized nations almost to the exclusion of the more traditional power sources.

The reason for this state of affairs is due to the characteristics of oil. It has been cheap; the actual cost of bringing oil to the surface in countries such as Saudi Arabia is reported to be about 10 cents/(bbl). Since oil is a liquid, it is easy to transport. In addition to the high energy content, methods have been learned through modern-day refining techniques to produce by-products that are the base for the large petrochemical companies that have developed. Because of all these factors, countries such as Britain which had a large coal supply have allowed that particular industry to deteriorate to the point where they are now dependent on the importation of oil to supply their energy needs. The spectacular rise in the world use of oil since 1945 is clearly shown in Fig. 1.1. When it is considered that World War II was fought on oil, the consumption that has taken place in the past three decades is almost unbelievable [15].

The United States, unlike the rest of the world, not only discovered oil in the late nineteenth century but had the sophisticated technology in place to exploit the new power source. At the time the United States was also blessed with what seemed an inexhaustible supply with the result that for a number of years this country was the world's largest producer, a position now occupied by Russia.

One consequence of the exploitation of oil resources has been in the agricultural industry where productivity has increased tremendously due to the many products (such as pesticides and fertilizers) derived from oil. This productivity, however, has created a situation in which modern agriculture is now largely energy consuming rather than energy producing. The dramatic switch has occurred in the years since World War II. Personal recollections of time spent on a farm during the 1940s recall a period during which horses were the main source of pulling power and natural fertilizer was used to enrich the fields. The food produced during those days represented a net gain in energy. Then in 1942 a small tractor was acquired (16 hp). Since farm implements had not yet been developed for tractors, the tongues of the previous horse-drawn equipment were simply shortened with a saw. That act can almost be regarded as the watershed when farming became dependent on fossil fuel. Thirty years later that same farm, now part of a much larger operation, is totally

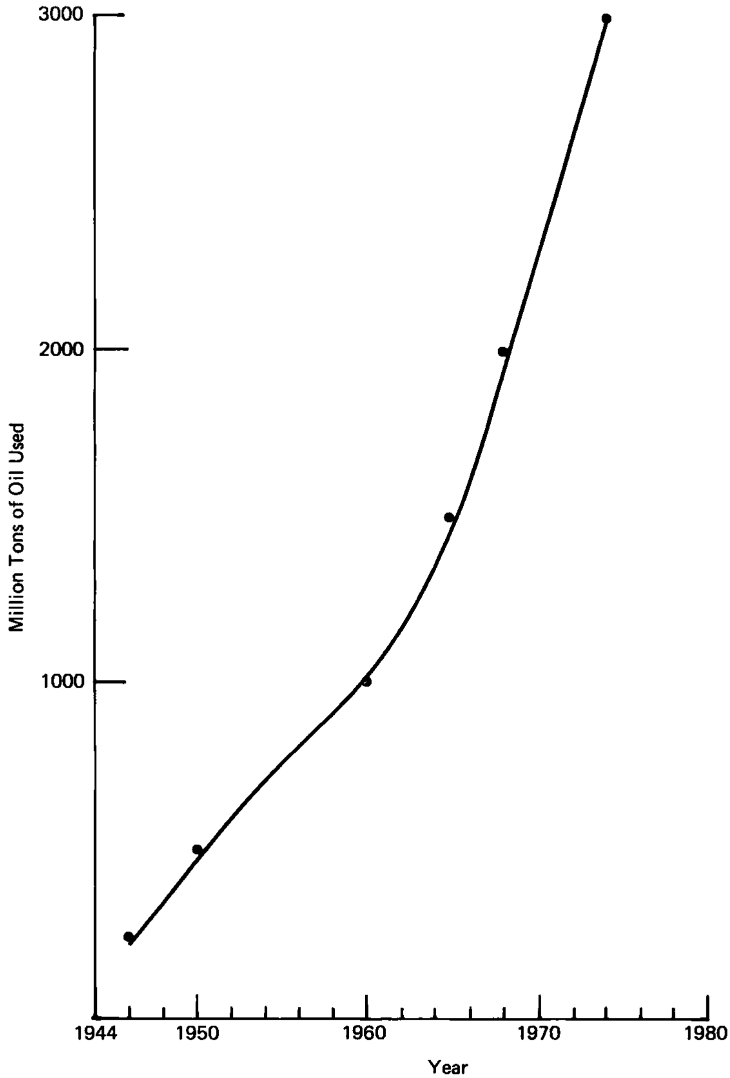

FIG. 1.1 World oil consumption in millions of tons since 1944. (Source: Ref. 15.)

dependent on fossil fuel. Large tractors (120 hp) plow and cultivate the 75 acres in hours. Massive applications of pesticides and commercial fertilizers replace cultivation for weed control and barnyard manure for nutrients. From a pure energy balance the new system requires large inputs of fossil-based fuel. A study in 1969 [16] attempted to quantify these energy relationships. The investigation showed that in a primitive African tribe one man required 1040 ha (hectares) of land to provide food for himself plus 3 other people. His energy output/input ratio was 7.8. By contrast, a British agricultural worker required only 0.78 ha to provide food for 48 people. However, this increase in productivity was at the expense of fossil fuel where the output/input ratio was now only 0.4. With the subsequent release of labor has come the increase in the standard of living that is desired and enjoyed by all.

Another consequence of oil exploitation has been the dramatic rise in the use of oil by-products as feedstock for the petrochemical industry. Through the ingenious use of applied chemistry society has learned to manipulate these molecules in many diverse ways. For those who have lived through the transition, the change has appeared gradual. Only when comparisons are made over several decades does one realize the major influence that oil has had on both lives and industries. Companies such as E. I. DuPont and DeNemours and Company and the Dow Chemical Company began in the late nineteenth century as inorganic-based companies--DuPont in explosives and Dow in brine technology--and have since become large producers of oil-based products relying on petrochemical feedstocks. However, it should be mentioned that only 4% of the U.S. supply of natural gas and oil is used as feedstocks [17]. *Chemical and Engineering News* [18] published a compilation of statistics on production and compared 1965 with 1975. A sampling of these data is shown in Table 1.2 and illustrates the growth in several products based on petrochemicals. This table also shows the decline in production of fiber based on cellulose to indicate what has happened in the use pattern of one natural renewable resource.

There is no question that oil and the many associated products have created a life-style unsurpassed in history. By the same token, there is no doubt that the careless use of this natural resource has been largely responsible for the environmental problems that are now present. The major task in the years ahead will be to maximize the benefit and minimize the damage generated by the world's dependence on oil.

1.5 COST-BENEFIT ANALYSIS REQUIRED

When the benefit of the many diverse chemicals is weighed against the energy that is required for their production, the second law of ecology must be considered [9]: "There is no free lunch." Every action that is taken has a price either in economic or social cost. For many years our society quite understandably tried to push off onto the environment all the costs it possibly could: discharge of raw sewage into pristine water or the emission of noxious gases from industrial smokestacks and automobiles. Environmentalists say that this is not fair since these costs are real and should be paid. However, industry and municipalities cannot pay the cost because these terms are abstractions. Costs must be attributed to the product in the case of industry or the taxpayer living in the community. The real problem comes in making sure that the public pays these costs knowingly. In doing so the first law must be kept in mind; whenever one problem is eliminated, another is implicitly proposed. One cost is replaced with another--it is a question of trade-offs. As Hardin points out in another essay [19], the whole idea of trade-offs is essentially a tragic one. Nevertheless, they must be dealt with.

When the concept of trade-offs is ignored, the ridiculous position that is found in the Delaney Amendment to the Pure Food and Drug Act of 1957 results [20]. This particular amendment says that there shall be a zero residue for any carcinogenic substance that has been added to food. As any scientist realizes, this is an impossible target since what is zero or undetected today will be found tomorrow as analytical methods improve. To demand that any material be absolutely