AD-A265 365

REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1992	XXXXXX/DISSERTATION

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Estimating The Long Term Liability from Landfilling Hazardous Waste	
6. AUTHOR(S) James R. Aldrich, Captain	

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT Student Attending: University of Cincinnati	AFIT/CI/CIA- 92-034D

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFIT/CI Wright-Patterson AFB OH 45433-6583	

DTIC ELECTE JUN 07 1993 S E D

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for Public Release IAW 190-1 Distribution Unlimited MICHAEL M. BRICKER, SMSgt, USAF Chief Administration	

13. ABSTRACT (Maximum 200 words)

93 6 04 0 G.

93-12600

127pr

14. SUBJECT TERMS	15. NUMBER OF PAGES
	114
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

ESTIMATING THE LONG TERM LIABILITY FROM LANDFILLING HAZARDOUS WASTE

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ABSTRACT

Justifying pollution prevention investment often depends on the ability of the project's proponent to accurately estimate the long term liability costs associated with alternative hazardous waste disposal methods. Using microeconomic theory, a liability factor model has been developed to predict the long-term liability costs inherent in using the landfill option as follows:

$$P_{total} = P_{landfill} + f_L P_{destruction}.$$

The liability factor (f_L) was developed by combining the microeconomic theories of consumer surplus and externalities which allowed potential financial liability to be predicted through an expected value analysis. The two assumptions in this analysis were 1) landfills, like all manmade structures, will eventually fail and primary liner failure is defined as landfill failure, and 2) landfill design criteria outlined in the 1984 Hazardous and Solid Waste Amendments make the key element in predicting future liability costs the cost of waste destruction. The liability factor allows future liability costs to be estimated on a per unit basis independently of both landfill and destruction technology prices and negates many of the potential confounding factors such as price variations caused by regional difference, technological advances, and individual capabilities in price negotiations.

Estimating the Long Term Liability from Landfilling Hazardous Waste

A Dissertation Submitted to the

Division of Graduate Studies and Research
of the University of Cincinnati

in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY

in the Department of Civil and Environmental Engineering
of the College of Engineering

1992

by

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M.S., Clemson University, 1986

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ABSTRACT

The financial justification for pollution prevention investment often depends on the ability of the proponent of the action to accurately reflect the long term liability costs associated with alternative disposal methods available to generators of hazardous waste. Using microeconomic theory, a model has been developed which uses a liability factor to predict the long-term liability costs inherent in landfilling hazardous waste.

This factor was developed by combining microeconomics and environmental requirements as follows: 1) Microeconomic theory was combined with environmental concerns and, therefore, consumer surplus and externalities were used to predict potential financial liability and as a basis for comparing treatment/pollution prevention alternatives. 2) Landfills, like all manmade structures, will eventually fail, which implies the cost of failure can be estimated by an expected value analysis. 3) The landfill liner is the critical component in landfill design and the time to liner failure can be used as the time to landfill failure. 4) Given the advances in landfill design, the key element in predicting future liability costs will be that of waste destruction, which implies a future value analysis can be used

to predict the current value of a future liability. As such, the model encompasses the concepts of consumer surplus, externalities, and expected value; allows liability costs to be predicted on a per unit basis; and is independent of landfill/destruction technology prices.

While the model can be used in the financial analysis of various treatment alternatives, its primary function is in demonstrating the liability cost of landfilling hazardous waste when selecting between treatment alternatives and pollution prevention options. Further, since the factor was developed to be used on a per unit of waste basis, many of the potential confounding factors such as regional price variation within technologies, capabilities in price negotiations, etc., are avoided. Therefore, through the simple application of this liability factor, hazardous waste generators can more accurately predict the present value of long term liability costs which will enable them to make better investment decisions regarding environmental compliance and protection.

ACKNOWLEDGMENTS

I wish to express my gratitude to my advisor, Dr. Thomas Hauser, and my committee members, Dr. Paul Bishop, Dr. Charles Berry, and Dr. James Uber, for their guidance and encouragement throughout the compilation of this dissertation. I am the first to complete this program of study with a predominant orientation toward environmental management, which is in no small part the result of the efforts and foresight of these individuals.

I am particularly grateful to the Air Force Institute of Technology's School of Civil Engineering and Services for sponsoring my degree, and to the Civilian Institution personnel who administered my program. I am also grateful to the many staff and faculty members in the departments of Civil and Environmental Engineering and Environmental Health whose assistance was invaluable in my designing and completing this effort.

My greatest appreciation, however, goes to my wife, Caroline, and my son, Cory, who had to live with me for these past years. Without their support and encouragement, it would have not been possible to complete this degree.

FOREWORD

This research effort was accomplished in two phases. The first addressed the language "gap" between financial and environmental management. The final report from phase one of the effort, "A Practical Guide to Justifying Pollution Prevention Projects," was submitted to and approved by the American Institute of Pollution Prevention (AIPP) on 9 September 1991 and is being considered for publication.[1] The report serves pollution prevention advocates by explaining the language and mechanics (e.g., depreciation, present value, decision making variables, etc.) needed to financially justify pollution prevention projects. This effort shall enable environmental personnel to better compete for corporate resources for pollution prevention investment.

This document addresses the second phase of the research effort: the estimation of long term financial liability incurred by landfilling hazardous waste. Specifically, this phase of the research effort applies microeconomic theory to predict long term financial liability inherent to landfilling hazardous waste.

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[1] Per conversation with T. R. Hauser, Executive Director, American Institute of Pollution Prevention, 1 May 1992.

The effort is based on the hypothesis that long term financial liability can be estimated by the application of the microeconomic theory of consumer surplus and externalities (as applied in a public policy sense). Once the liability was defined, through expected value and discounting calculations, a model was developed whereby this liability could be represented as a percentage of the current cost of waste destruction.

The critical steps in developing and proving this hypothesis included:

1. Developing the required microeconomic principles:
   a. The theory of supply and demand.
   b. The theory of consumer surplus.
   c. The theory of negative externalities.
2. Applying the theory to landfill disposal.
   a. The landfill externality.
   b. The criteria for landfill failure.
   c. The expected value analysis for failure.
3. Developing the Model:
   a. The expected value costs.
   b. The liability factor.
4. Verifying the model.
   a. Data collection.
   b. Data analysis.

As a result of this effort, hazardous waste generators are provided with a simple yet more accurate method for predicting total costs (i.e., landfill charges + incurred liability) incurred in landfilling hazardous wastes.

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SECTION I

INTRODUCTION

This research effort encompasses two distinct, yet ultimately interrelated, fields of study: microeconomics and environmental engineering/management. In that each field has developed its own vernacular, there could be some confusion among the readers. For example, the terms "producer" and "consumer" have specific meanings to a micro-economist; however, they may appear vague to the environmental engineer. Similarly, a "RCRA hazardous waste" carries a specific connotation to an environmental engineer but may be vague to the economist. Hence, a preliminary explanation of the key terms will provide a common ground to aid the various readers.

Microeconomics deals first with individuals, consumers, investors, workers, firms, etc.; how and why they make purchasing decisions; and how these decisions are affected by changing prices and incomes. Then, as a natural extension, microeconomics investigates the interaction of these individuals in the formation of markets for various goods and services. Hence, the market is the basic unit for this research effort; however, it is critical to understand that the market is developed from the aggregate decisions and desires of the individual economic units.

In that this paper deals with landfill liability, much of the analysis is developed from the supply and demand functions for landfill services. The demand for landfill services, or simply landfills, is developed by taking the aggregate demand from all individual consumers of landfills. Hence, for the purposes of this analysis, "consumers" are those that dispose of waste in a landfill and can be taken as an equivalent expression to hazardous waste generators.

Similarly, the supply function for landfills is the aggregate supply of landfill space from all individual landfill owners/operators. As such, throughout this paper, "suppliers" or "producers" are those individuals which offer landfill services and can also be thought of, or referred to as, landfill firms, owners, etc.

Regarding the material that is being deposited in the landfill, throughout this paper, the terms waste and/or hazardous waste refer to a hazardous waste material as defined under the Resource Conservation and Recovery Act (RCRA) of 1976, as amended by the Hazardous and Solid Waste Act (HSWA) of 1984. Although the regulatory definition is quite lengthy[2], for the purposes of this paper a simpler definition can be used.

First, a hazardous waste must be a solid waste and would include any discarded material which is: a) abandoned (i.e.,

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2 40 Code of Federal Regulations (CFR) Sections 261.2, Definition of a Solid Waste, and 261.3, Definition of a Hazardous Waste.

disposed of, burned/incinerated, or accumulated, stored, or treated (but not recycled) before or in lieu of being abandoned); or b) recycled for a use other than that originally intended[3] and c) not specifically excluded by the regulation, such as household wastes and wastes already regulated under other legislation. Second, the solid waste must exhibit the specific characteristics defined in Subpart C (e.g., reactivity, flammability, etc.) or be specifically listed in Subpart D (e.g., specific chemicals such as benzene or waste from specific industries such as electroplating).

Additionally, for the wastes referred to in this paper, there can be no specific waste disposal method required under the hazardous waste laws (i.e., the generator is free to have the waste destroyed by incineration, treated biologically, directly deposited in a landfill, etc.). If this were not the case, the requirements of the law would obviate management's choice in disposal methods and there would be little need to perform a financial analysis. In the case of waste materials which cannot be destroyed, such as heavy metals, the analysis presented herein is still valid. However, instead of using a destruction cost in the analysis, a treatment or recovery cost relevant to the waste (e.g., vitrification, soil washing and recovery, etc., for metals) would be substituted.

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[3] For example, using a dirty solvent from an electronic part cleaning operation for cleaning a less sensitive part such as a wheel bearing would be recycle. Conversely, burning the solvent in a heating boiler would not be recycling because the solvent's original use was not as a fuel.

SECTION II

BACKGROUND

In the wake of environmental catastrophes such as Love Canal, environmental protection has received a great deal of attention in the United States. In spite of this, twenty-three billion pounds of hazardous waste were released into the environment in 1988.[4] Of this amount, 21% was treated, 25% was "landfilled," and the remaining 54% was released directly to either the air or water media. Furthermore, although landfills are a generally accepted "solution" for disposing of many hazardous wastes, of the 4615 hazardous waste landfills in the United States, 1711 have been checked by the EPA. Based on their findings, over 80% of these approved landfills are leaking.[5] These practices have led to a number of real, or potential, environmental problems: groundwater contamination, ozone depletion, global warming, etc.

The obvious answer to the situation outlined above would be to not generate the waste in the first place - pollution prevention; an idea which has the support of the nation's environmental leaders:

> "Preventing pollution is a far more efficient strategy than struggling to deal with the problems once they've occurred...It's time to reorient ourselves, using technologies and processes that reduce or prevent pollution, to stop it before it starts."
>
> - President George Bush
> June 8, 1989

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[4] Hazardous Materials Technical Center, Vol. 8, No. 5, September 1989.

[5] Hazardous Waste News, 23 April 1990.

"Let's make prevention of pollution the guiding philosophy of waste management. Let's assert a hierarchy of values that begins with pollution prevention."

- Wm. K. Reilly -
Administrator, EPA
November 27, 1989

As a result of this emphasis and the outcry from the general public, The Pollution Prevention Act of 1990 was passed. One of the critical outcomes of the act was to narrow the definition of pollution prevention by shifting emphasis away from treatment options toward avoiding waste generation. The EPA has defined the pollution prevention hierarchy in Section 2 of the Pollution Prevention Act as follows[6]:

"Findings and Policy: This section establishes a Pollution Prevention hierarchy as a national policy, declaring that:

- pollution should be prevented or reduced at the source wherever feasible;

- pollution that cannot be prevented should be recycled in an environmentally safe manner whenever feasible;

- pollution that cannot be prevented or recycled should be treated in an environmentally safe manner whenever feasible; and

- disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner.

Based on the hierarchy and subsequent interpretations, "pollution prevention" can be interpreted as any effort to

[6] US EPA Letter, 27 November 1990, Pollution Prevention Act of 1990, from Director of Office of Pollution Prevention.

reduce the quantity of industrial, hazardous, or toxic waste through changes in the waste generating or production process at the source. Therefore, pollution prevention encompasses all actions, taken prior to the waste being generated, which provide for net reductions in either waste volume or hazard/toxicity.

This emphasis on actions taken at the point of pollutant generation implies that end-of-pipe technologies which apply after the waste has been generated, such as recycling and sludge dewatering, are not true pollution prevention practices. Although this would be true in the strictest sense, it does not mean that post generation practices are not desirable; however, it does indicate that while these methods can help, there are better approaches.

Other authors have recognized that the technological variety of waste reduction options available implies some methods may be more desirable than others. Baker, et al.,[7] proposed the pollution prevention hierarchy shown in Figure 1 with the most desireable options being highest on the heirarchy.

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[7] Baker, R.D., Dunforn, R.W., Warren, J.L., Alternatives for Measuring Hazardous Waste Reduction, Hazardous Waste Research and Information Center, HWRIC RR-056, April 1991, pps 3-4.

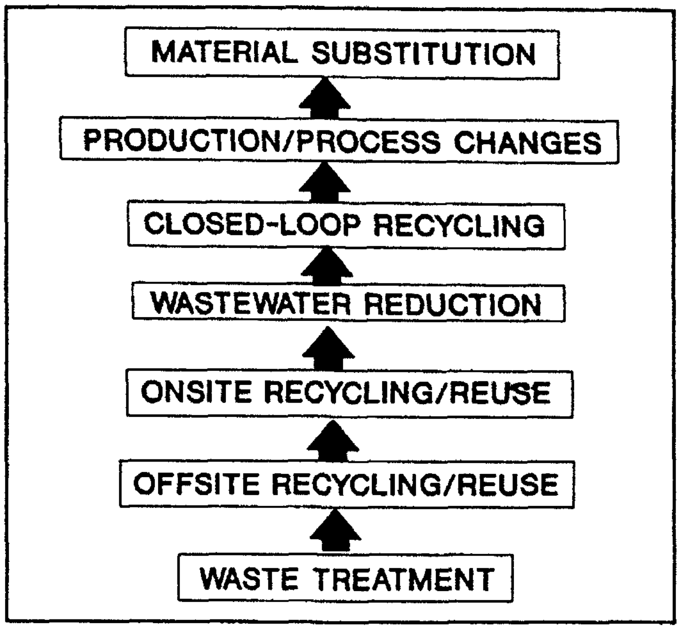

Figure 1. The Pollution Prevention Hierarchy

Similar to the 1990 Pollution Prevention Act, Baker's hierarchy can encompass nearly any pollution prevention technology, and is useful for looking at a wide range of investment possibilities. However, based on the Pollution Prevention Act's narrower definition of "prevention," these hierarchies can be simplified even further to:

1. Material Substitution: Using non-hazardous inputs to the manufacturing process in place of hazardous materials.

2. Production Process/Procedure Changes: Alteration of the manufacturing or service processes to reduce the volume or toxicity or eliminate the hazardous waste.

3. Treatment: All other end-of-pipe methods to include recycling, reuse, and discharge or release of waste for treatment or to the environment.

In interpreting the "worth" of a pollution prevention project, regardless of which hierarchy is used, the higher the potential project is on the hierarchy, the more beneficial it would be if all other technological and cost variables are equal.

When implementing pollution prevention efforts, environmental managers often experience problems in obtaining financial support. This is because pollution prevention project cashflows can extend over very long times -- decades in many cases. Because of these long-term cash flows, and the limited potential for revenue generation, when a company compares pollution prevention projects to other capital investments using criteria such as payback period or rate of return instead of present value of net benefits, pollution prevention can seem less desirable than production oriented investment alternatives.[8]

While few would argue against the value of pollution prevention, judging by the monies spent by industry for both Superfund type cleanups/investigations and compliance expenditures for hazardous waste, air and water effluent treatment, etc., it must be said that to date, there has been relatively little movement toward pollution prevention. Although there could be many reasons for this apparent lack of emphasis, a major stumbling block is the problem encountered

[8] See Appendix 1 for a discussion of investment comparison criteria.

when attempting to either develop or procure pollution prevention technologies and funding.

A study done by the University of Pittsburgh Applied Research Center[9] indicated the number one barrier that prevents having environmental technologies accepted in the market place is the lack "of clear technical and economic benefits" (emphasis added). This is given further support by Richard W. MacLean of General Electric in his paper at the 1987 Waste Minimization Workshop[10]. In referring to chemical process safety, in part he states:

> "...Management has created an infrastructure in recognition of the relationship between inferior process design and operation and potentially significant business liabilities. No comparable infrastructure exists to quantify most environmental cause/effect relationships."

Clearly, if pollution prevention is to receive the level of emphasis required and be seen as an attractive investment alternative for industry, environmental managers must be equipped with the economic, financial, and accounting tools needed to fight for a share of corporate resources to fund pollution prevention practices and equipment.

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9 Incentives and Barriers to Commercializing Environmental Technologies, University of Pittsburgh Applied Research Center, Pittsburgh, PA, March 1990.

10 MacLean, R. W., Estimating Future Liability Costs for Waste Management Options, Hazardous and Solid Waste Conference, Washington DC, 19-20 November 1987.

To a great extent, this lack of emphasis on pollution prevention can be attributed to information mismatch. Corporate management has a knowledge of investment strategy, but generally lacks the knowledge of potential environmental hazards and liabilities. Conversely, the environmental management staff has knowledge of the hazards and liabilities but lacks both the hard numbers required to support many cost estimates and the investment savvy to get their projects into industry's economic system. This mismatch is exacerbated by the extended payback periods of many of the excellent opportunities in pollution prevention investment as compared to "attractive," short term, production oriented projects. Hence, the need for hard data and investment expertise is even greater for pollution prevention investment.

To address the required investment expertise, "A Practical Guide to Justifying Pollution Prevention Projects"[11] was written. The guide explains the accounting methods used for project analysis in comparative investment studies in general, and provides specific examples of pollution prevention project justification. The reader is taken step-by-step through revenue and expense analysis, and the mechanics of project justification are explained.

The need for hard data, particularly with respect to liability issues, has been recognized by other authors. For

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[11] Aldrich, J.R., A Practical Guide to Justifying Pollution Prevention Projects, American Institute of Pollution Prevention, pending publication.

example, MacLean uses the concept of "true" cost of waste disposal in support of pollution prevention projects involving long-term cost reduction to address this information gap. By his definition, these long-term costs are made up of both direct costs (waste collection, transportation, sampling, etc.) and future liabilities (such as corrective action costs under the Resource Conservation and Recovery Act (RCRA), Superfund type actions, and third party lawsuits). Given the trends in both the tendency to bring suit and the size of the awards in environmental personal injury lawsuits,[12] and the investment in remediation of hazardous waste spills and sites, the ability to estimate future liability is the key to minimizing long-term costs.

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[12] Based on a San Francisco, CA, study, average personal injury awards for environmental mishaps have risen 358% (in inflation adjusted dollars) from 1960 to 1980. MacLean, R.W., Motivating Industry Toward Waste Minimization and Clean Technology, ISWA and EPA Conference, Geneva, Switzerland, 30 May 1989.

SECTION III

RESEARCH OBJECTIVES

At present, efforts to determine long range costs and liabilities have centered on specific events or requirements based on historical evidence. For example, the cost of a potential environmental remediation related to groundwater contamination at one site would be estimated based on industry's experience at another site. The value of the related remediation costs for the "failed" site, once summed, would be projected onto the new site and used to financially justify pollution prevention efforts. The financial justification is based on representing these potential costs as a benefit of not having generated hazardous waste.

While this practice of using related data to predict costs at different sites is a sound method in many engineering endeavors, estimating long term potential environmental liabilities, as it is practiced at present, has its limitations.

1. Once the costs at one site are identified, specific times for various events to occur at the new site must be individually estimated: the time to landfill failure, the time for a groundwater leachate plume to reach a receptor, the

time of potential lawsuits, etc. Even when assumptions are based on historical data, the investigator must contend with a great number of site specific technical variables (such as groundwater flow rates, variable soil permeability, etc.) and must estimate the potential variability in public reaction which often cannot be accurately expressed.

2. Remediation costs for a failed landfill site and the potential impacts of mitigating factors such as being named as a Potentially Responsible Party (PRP) in a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 1986, remediation must be assumed.

3. Interest rates, inflation, and price increases must be estimated over the entire liability period (e.g., 20+ years) -- a much longer time frame than presently practiced and accepted within financial norms.

While this list could be continued, it becomes clear why authors such as Carl H. Fromm and David Butler[13] have advocated less concrete methods of supporting pollution prevention, such as:

> "One way of accounting for a reduction in an identified but unquantified risk is to ease the financial performance requirements (hurdle rate) of the investment."

Unfortunately, their alternative, if unsupported by concrete

[13] Fromm, C.H., and Butler, D., Practical Guidelines for Estimating the Profitability of Waste Minimization Measures, HAZMAT Conference, Atlantic City, NJ, 3 June 1986.

financial data, constitutes little more than the arm waving and scare tactics that have hampered the environmentalist's efforts in the past.

This is not to say that the situation is without hope. Many case studies show that pollution prevention projects can often be justified on the short term (i.e., over the normal accounting period considered by firms as a reasonable payback period) by integrating increased profits due to reduced expenses with cashflow advantages. However, if long term liability cost avoidance must be used as part of the justification for a pollution prevention project, the difficulties outlined above can seem insurmountable.

To address these pitfalls, a model has been developed and presented in this dissertation which uses a liability factor to encompass future liability costs. In that it is based on microeconomic principles and theory instead of individual estimates of expenses such as cleanup, lawsuits, customer ill-will, etc., many of the potential confounding factors discussed previously are avoided. The required principles, assumptions, and methods used in this model are discussed herein.

SECTION IV

MICROECONOMIC PRINCIPLES

The Theory of Supply and Demand

Price determination through the supply and demand relationship is at the heart of microeconomics and leads directly to consumer behavior in defining the willingness to consume (demand) and the willingness to sell (supply). Both supply and demand are governed by empirical laws and parameters as follows:

> The Law of Demand: Consumers are willing to buy more at lower prices than at higher prices if the demand parameters remain constant: consumer income, tastes and preferences, relative prices of other goods (related goods and substitutes), number of consumers, and expectations of change.
>
> The Law of Supply: Sellers are willing to provide more at higher prices than at lower prices if the supply parameters remain constant: number of producers, state of technology, size of capital stock, price of inputs, and expectations of change.

Supply and demand are expressed through the market where the aggregate demand of all consumers and the aggregate supply of all producers are expressed. Although the market is dynamic, for a specific good, if the supply and demand parameters remain constant, the resultant market can be represented as a snapshot in time. Under these circumstances, both the supply and demand functions (i.e., the quantity of the good supplied and demanded at any given price) at any specific time can be represented graphically as shown in Figure 2.

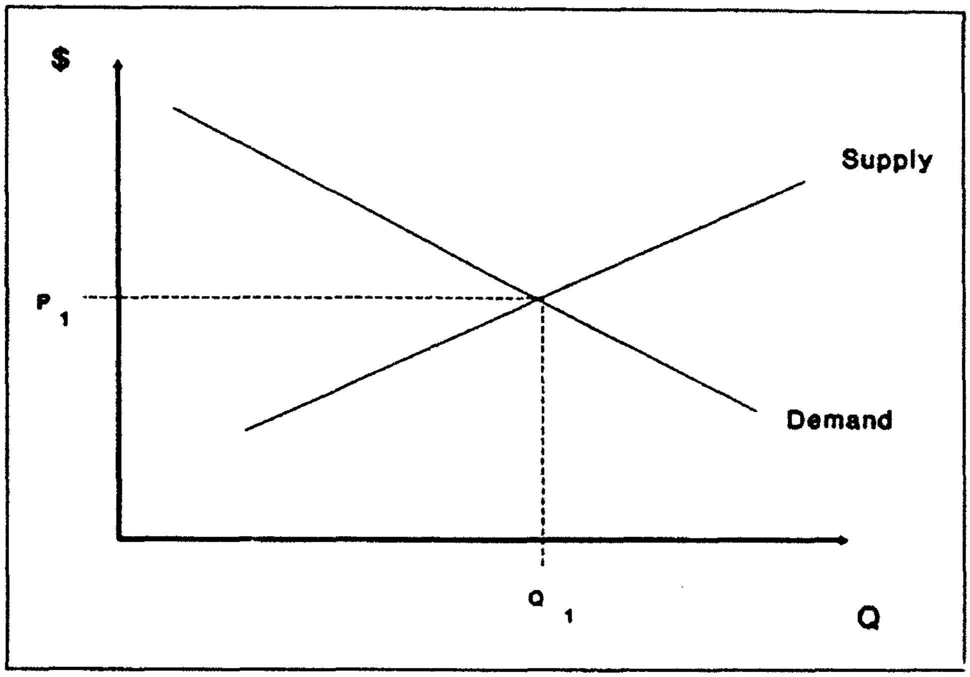

Figure 2. Theoretical Supply and Demand Relationship.

The figure shows the equilibrium position for the good where the quantity Q_1 is supplied and consumed at a price P_1. Additionally, it is critical that the market clear (i.e., no goods are left over and no demand goes unsatisfied given the price P_1. If this were not the case, the excess supply or demand would alter the market.

The slopes of the two functions are determined by the governing laws of supply and demand; negatively sloping demand and positively sloping supply. Further, as a result of these laws of supply and demand, demand cannot create supply and supply cannot create demand. Unless the parameters of supply or demand are changed or the market fails to clear (i.e., all goods offered are not consumed), the relationship defined by the supply and demand functions and represented by the curves as shown above will remain valid.

The Theory of Consumer Surplus

Consumer surplus (CS) is the difference between the total monies consumers are willing to pay for goods and/or services and the actually monies paid. For example, unexpectedly finding an item on sale can be a type of individual consumer surplus. If one went shopping and would have been willing to pay $25 for a shirt or blouse, and the item was unexpectedly on sale for $15, purchasing the garment would provide the individual $10 worth of consumer surplus (i.e., the $10 would represent monies the consumer would have been willing to spend, but did not have to in order to consume the good).

On a larger scale, the total value of consumer surplus is the amount that all consumers would have been willing to spend for a good or service vs. the collective amount that was spent. However, unlike the example given above, there need be no sale or reduced price to have consumer surplus. This is because the slopes of the supply and demand functions imply that if the suppliers could single out consumers and sell their goods to individual consumers one at a time, the first unit could be sold at a higher price than the second unit, the second unit at a higher price than the next, etc., until the last unit the supplier was willing to offer was sold at a price P_1 as shown in Figure 2.[14] This individual pricing concept can be most easily shown by the standard supply and demand relationship, as is done in Figure 3.

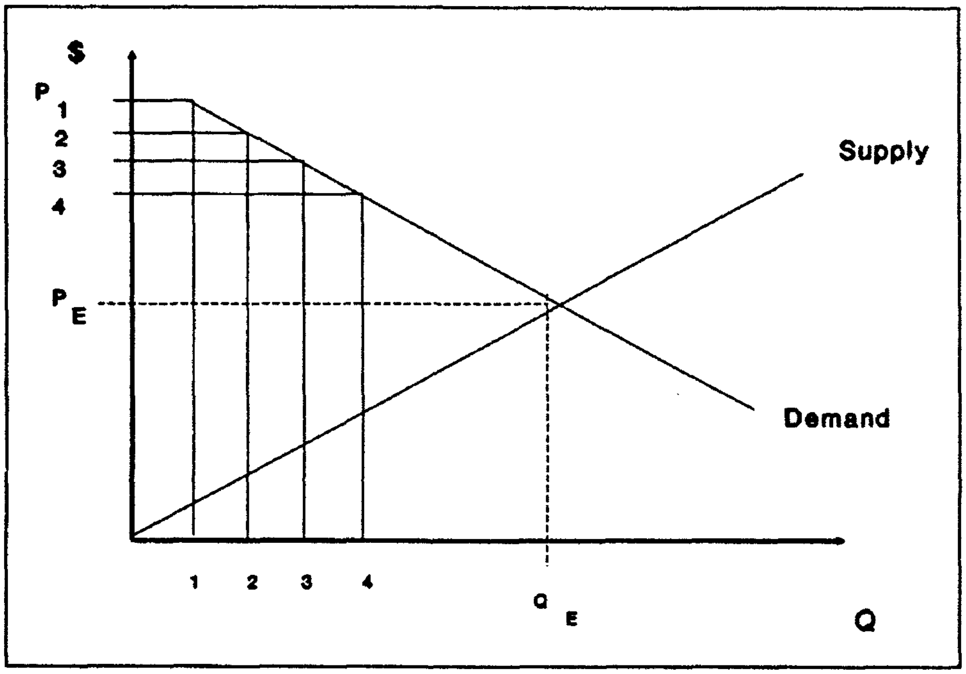

Figure 3. Supply and Demand Functions Under Unit Pricing

With the exception of a very few goods such as luxury items, custom built automobiles, etc., this individual salesmanship cannot be practiced in the market. If for no other reason than for sheer volume, most goods must be offered to all consumers at a single price. This single price scheme is

[14] Suppliers would be unwilling to offer goods at any price lower than P as predicted by the supply and demand relationship.

beneficial to the consumer in that consumers who were willing to pay a higher price for the good, receive same at a given, lower price.

Graphically, the area below the demand curve and above the price (i.e., the money consumers would have been willing to spend if items were purchased on a price per unit basis, but did not have to in order to consume the good or service) has been dubbed Consumer Surplus; this is shown with the theoretical supply/demand relationship previously discussed in Figure 4.

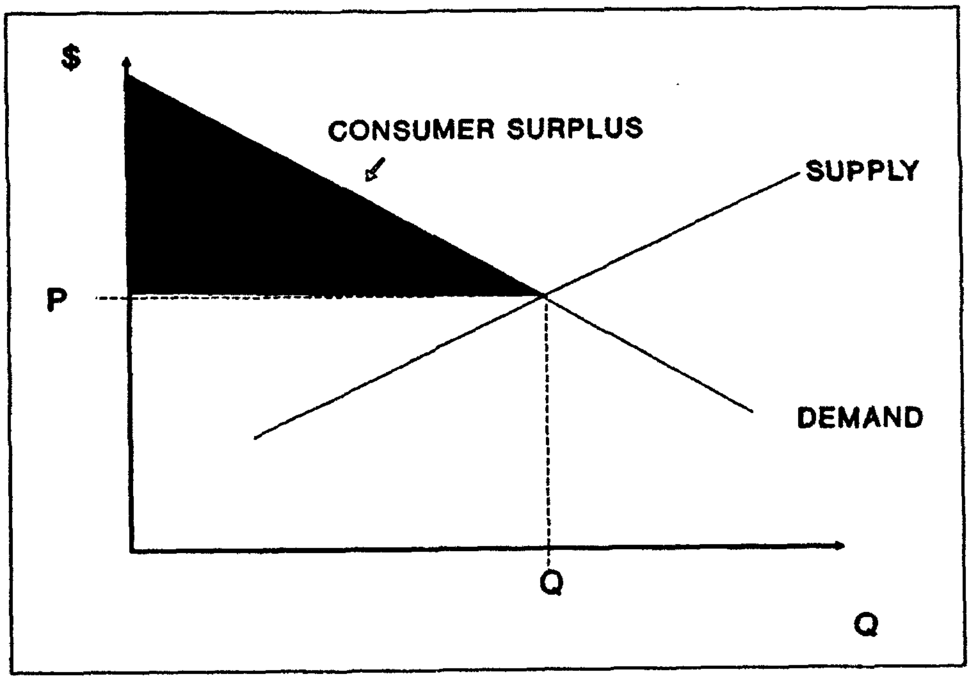

Figure 4. Consumer Surplus for a Good in Equilibrium at Price P.

Since consumer surplus represents monies consumers were willing, but did not have to spend to obtain the good or service, it is clearly a benefit to the consumer just as unexpectedly finding an item on sale would be beneficial to an individual. As a result, changes in consumer surplus, over time, or differences between consumer surplus for various options at a given time, can, and have been used as an indicator of consumer welfare. As indicated by Pindyck and Rubinfeld[15], "Because consumer surplus measures the total net benefit to consumers, we can measure the gain or loss to consumers...by measuring the resulting change in consumer surplus." This is further explained and adapted to an environmental situation by Mills and Graves[16]:

> "It (consumer surplus) is a measure of the benefit from pollution abatement in a precise sense that it is the maximum amount of money consumers would be willing to pay in order to obtain the improvement in the environment."[17]

While in this definition "pollution abatement" cannot be directly related to the current definition of pollution prevention, the utility of using consumer surplus as a measure of consumer welfare or benefit is made clear. Hence, if CS is

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[15] Pindyck, R.S., and Rubinfeld, D.L., Microeconomics, Macmillan, New York, 1989, p. 291.

[16] Mills, E.S., and Graves, P.E., The Economics of Environmental Quality, 2d Edition, Morton, 1986, p. 105.

[17] A technical analysis is available in Willig, R., "Consumer's Surplus Without Apology," American Economic Review 66 (September 1976): 589-97 and Morey, E., "Confuser Surplus", American Economic Review 74, No. 1 (March 1984): pp. 163-73.

increased (e.g., due the addition of an environmental technology such as the installation of pollution prevention equipment or due to a technological improvement which would result in a lower price), consumer welfare is similarly increased and vice versa.

To illustrate this effect, Figure 4 can be used as the baseline condition and the effects on CS can be examined as a result of price changes. If a new technology which reduced the manufacturer's production cost (i.e., a change in the supply parameter "state of technology"), was discovered, more of the good could be supplied at a lower cost. In a competitive market, this would have the effect of shifting the supply curve down (or to the right), but as predicted by the laws of supply and demand, the demand curve would remain unchanged (i.e., no demand parameters were affected). Intuitively, having more of a good available and at a lower cost would seem to benefit consumer welfare and, as shown in Figure 5, consumer surplus would increase.

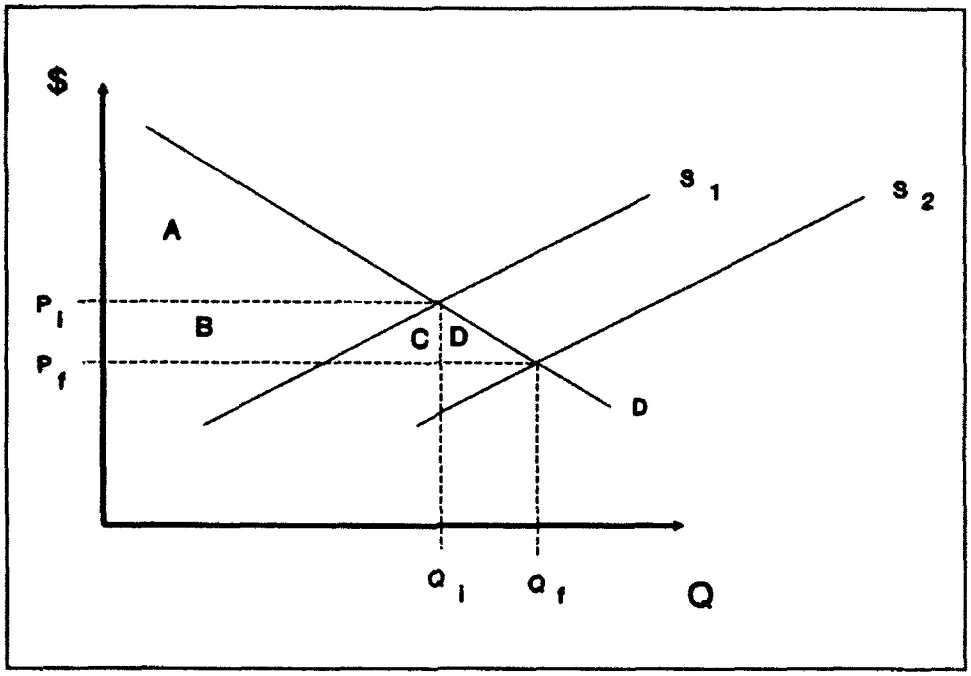

Figure 5. Increased Consumer Surplus as a Result of a Change in Supply Parameters.

In the case shown in Figure 5, because the supply parameter changed, the supply curve shifted from S1 to S2, the initial quantity supplied (Q_i) was increased to Q_f , the price was reestablished from P_i to P_f , and consumer surplus was increased from only area A, to area A+B+C+D.

Similarly, if a change in supply parameters caused a production cost increase (e.g., new environmental requirements caused a change in the supply parameter "price of inputs"), the cost of manufacturing the good would increase and the supply function would change (i.e., the good's supply curve would shift up or left). As a result, not only would fewer consumers choose to consume, but the price would be higher. Again, it would follow that this would decrease welfare and, as shown in Figure 6, this is reflected by a reduction in consumer surplus.

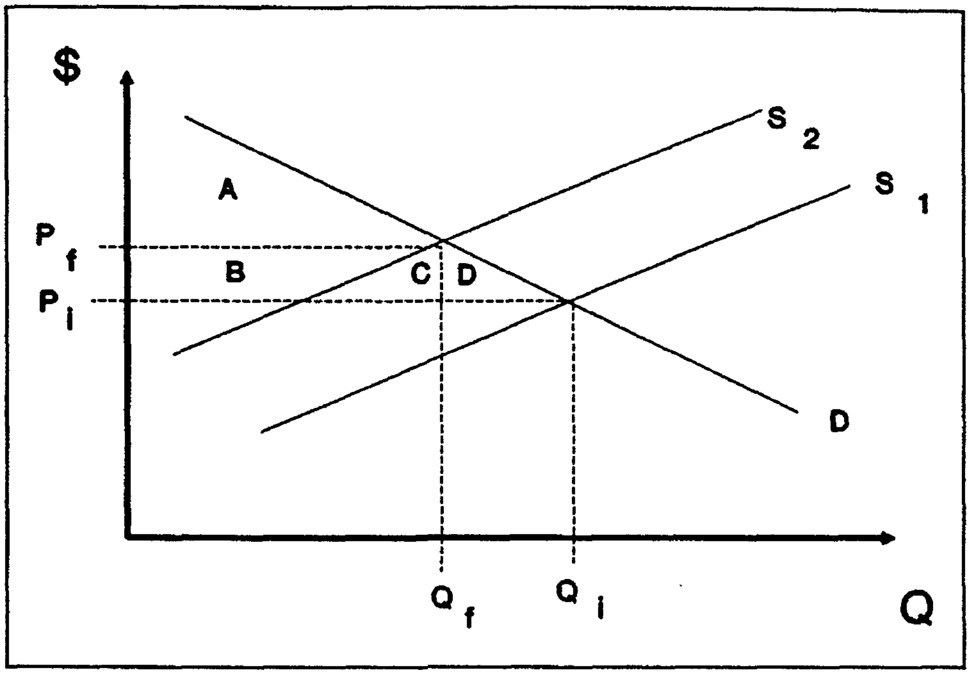

Figure 6. Decreased Consumer Surplus as a Result of an Input Price Increase.

In this second case, the change in supply parameters would cause a shift in the supply curve left from S1 to S2, the initial quantity supplied (Q_i) would be decreased to Q_f, the price would increase from P_i to P_f , and consumer surplus would decrease from areas A+B+C+D to only area A.

From the above analysis, it is apparent that changes in consumer surplus can be used as a measure of changes in consumer welfare. Although there are other techniques for measuring these changes (e.g., compensating variation and equivalent variation), as stated by Freeman[18], in most cases the differences in these measures appear to be small. As a result, "there is a strong argument for using the ordinary consumer surplus as an empirical approximation (to changes in consumer welfare)."[19] Therefore, consumer surplus comparisons should be an effective means to measure the overall social benefit implementing an environmental technology, such as landfilling as a hazardous waste disposal option.

The Theory of Negative Externalities

In economic terms, an "externality" exists when the effects of production and consumption activities are not directly reflected in the market price. If a market activity imposes a cost on another party which is not accounted for in the market place, it is a negative externality. Pollution is the classic example of a negative externality. For example, if a producer discharges a pollutant into the air, a cost is imposed on those who live in the surrounding area and must breathe the now polluted air. If the producer (polluter) has no incentive to account for the cost imposed upon the public due to air pollution in making production decisions (i.e., the

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[18] A. M. Freeman, The Benefits of Environmental Improvement, Wiley, 1982, pp. 38-50.

[19] ibid., p. 48.

cost is external to the producer), the cost of the pollution represents a negative externality.

Combining this concept with consumer surplus, the effects of negative externalities on consumer welfare can be shown. If in supplying the good represented in Figure 4, the producer polluted the air or water, a cost would be imposed upon the general population or society.[20] Hence, the total cost of producing the good would be not only the cost that the producer considers in terms of raw materials, labor, etc., but also must include the external societal costs: total cost (TC)= producer cost (C_p) + external cost (C_e). This concept is shown in Figure 7 by an additional "supply" curve which represents total cost (TC).

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[20] The affected population would be case specific and depend upon the type pollutant, the media to which the pollutant was released, dispersion factors, etc.

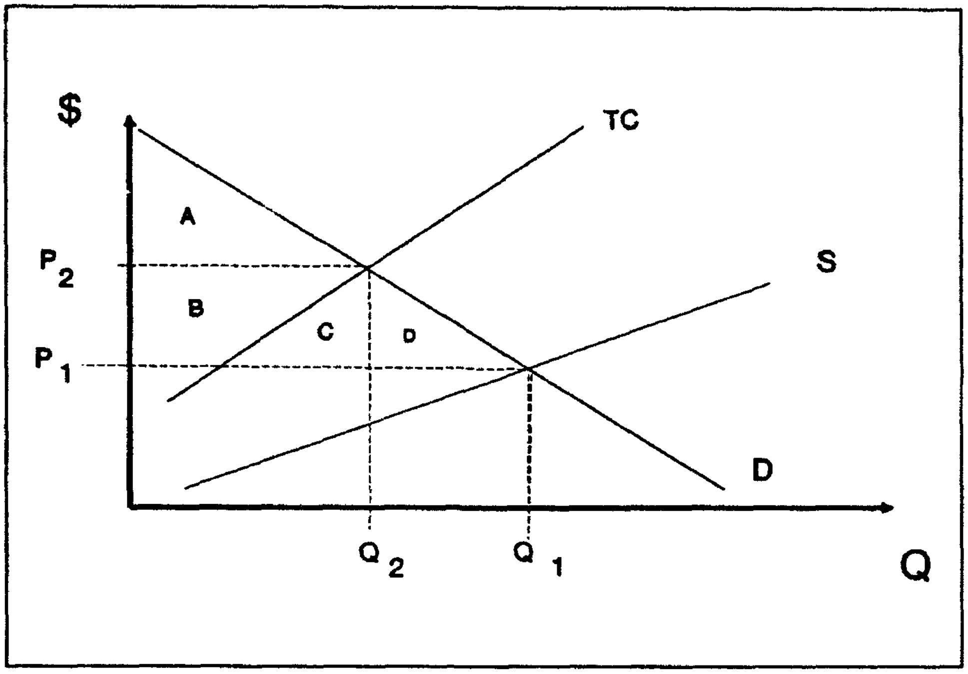

Figure 7. Change in Consumer Surplus Due to the Addition of a Negative Externality.

As was the case when the supply curve shifted up (to the left), the addition of social or external cost would decrease the level of consumer surplus from areas A+B+C+D to area A. In addition, the quantity supplied by the producer (Q_1) would be too great, given the total cost, and should be decreased to Q_2. Similarly, the associated price (P_1) is too low (i.e., it does not include the total cost of the product) and should be increased to P_2 to include the external cost. Negative externalities cause overproduction, underpricing, and reduced consumer surplus because the market system often does not include social costs. Hence, if an externality exists due to landfilling waste, and if the social cost is included in a supply and demand analysis, the externality should be evidenced by showing a reduction in consumer surplus.

In cases where a negative externality exists, the general approach to remedy the situation is to impose legislation which forces the polluter (producer) to internalize the social cost of production by forcing the firm to consider total cost ($C_p + C_e$) in production decisions. For example, regulations limiting pollutant discharges into the air and water as a result of the Clean Air Act and Clean Water Act have limited the amount of pollutants which can be discharged. This has forced polluters to treat their waste effluents, thereby forcing them to consider treatment costs as part of their production decisions by including pollution costs as part of their production costs. In essence, such regulation has altered producers' supply curves. For example, if the externality shown in Figure 7 was due to air pollution, treatment required by the Clean Air Act would change the supply curve from S to TC.

SECTION V

APPLYING MICROECONOMIC PRINCIPLES TO HAZARDOUS WASTE LANDFILL DISPOSAL

Defining the Landfill Disposal Option Externality

To perform the above theoretical consumer surplus analysis on the landfill disposal market, one of the first steps would be to establish the demand curve for landfills. However, the problems in extending theory to landfills is that, under microeconomic theory, the demand curve is the aggregate of all individual consumer demands. However, with few exceptions, individual consumers do not consume or use hazardous waste landfill services directly. As a result, rather than a summation of individual consumer demand, a derived demand relationship must be substituted.

The demand for landfill space is a result of the demand for waste disposal by firms/industries which produce products and services. Measuring this generator demand would not be a "pure" demand relationship in that it is not a direct summation of all the individual consumer demands; however, it would be a valid proxy if it can be shown that it mirrors the individual consumer's demand. This can be done with one assumption. For firms/industries which generate hazardous waste as a by product of producing goods and services, their cost of hazardous waste disposal must be passed onto the consumer via product price. Simply stated, over the long term, firms must cover production costs to remain in business. As a result, the cost of landfilling waste, or the cost of any other environmental treatment technology required, either must be paid for by the consumer through price, or by the producer by reducing economic profit.[21] In the long run, if the firm's production costs are not covered, the firm (e.g., polluter) will operate at a loss, the entrepreneur will not receive a sufficient profit, and the capital invested in the firm will be withdrawn and moved to a more profitable investment. As a result, by consuming a product or a service from a successful firm or industry, consumers are essentially showing their preference or acceptance for the firm's waste disposal practices. Hence, if the firm disposes of waste in a landfill, it is a result of the consumer's demand for the goods or services offered. As a result, consumers and waste generators can be taken as synonymous in this paper.

Although a few refinements can be made, the shape of the actual supply/demand functions for hazardous waste landfills must be similar to those shown in the hypothetical example in Figure 2, because they are governed by the laws of supply and demand. Looking first at the demand function, if the price of landfill disposal is reduced, more waste would be landfilled. For example, with lower costs, fewer waste minimization

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[21] The proportion of the cost that can be passed to the consumer is dependent upon the elasticities of the supply and demand functions.

efforts would be profitable and more landfill space would be demanded and vice versa. However, with landfills, there is an implied price ceiling or maximum cost on how much can be charged; the price of alternative treatment technologies. For example, if the landfill price was increased to the point where it was equivalent to, or higher than, competitive technologies (e.g. incineration), consumers would shift their demand for landfills to the other, less expensive treatment technologies and there would be no demand for landfilling waste.

With respect to the supply function, the uniqueness of the landfill industry imposes a time sensitivity which governs the quantity of landfill service that can be supplied. As explained earlier, increases or decreases in supply can only be caused by changes in the supply parameters. For example, when entrepreneurs move into or out of a business endeavor, the supply parameter "number of suppliers" changes, which causes the supply of a good or service to increase or decrease. However, this assumes that entrepreneurs are free to move their capital into and out of the industry and in the case of a hazardous waste landfill, this may not be an easy task. Because of environmental permits, public opposition, etc., in addition to the normal construction and production time requirements, constructing and starting a landfill is a long and expensive process. In addition, because of regulatory requirements, merely shifting resources into the landfill industry does not guarantee the entrepreneur will be able to operate the landfill which would increase supply.

Similarly, if an entrepreneur wishes to exit the landfill market, the mere fact that the landfill is closed and will no longer accept waste does not release the entrepreneur's resources for other endeavors. Instead, not only does financial liability for closure actions such as capping and long term groundwater monitoring remain with the entrepreneur, the land itself is unavailable for other uses. As a result, over the time period required to site, permit, build, and start to accept waste at a new landfill (8-10 years), there is no way to increase either the number of landfills or the available volume in the current landfills which leads to a maximum landfill supply, Q_{max}. At levels slightly less than Q_{max}, the landfill supply can be only slightly affected by opening additional cells within the existing landfills.

To show these specific maxima and minima graphically, the supply and demand functions for landfills under these constraints are postulated and shown in Figure 8.

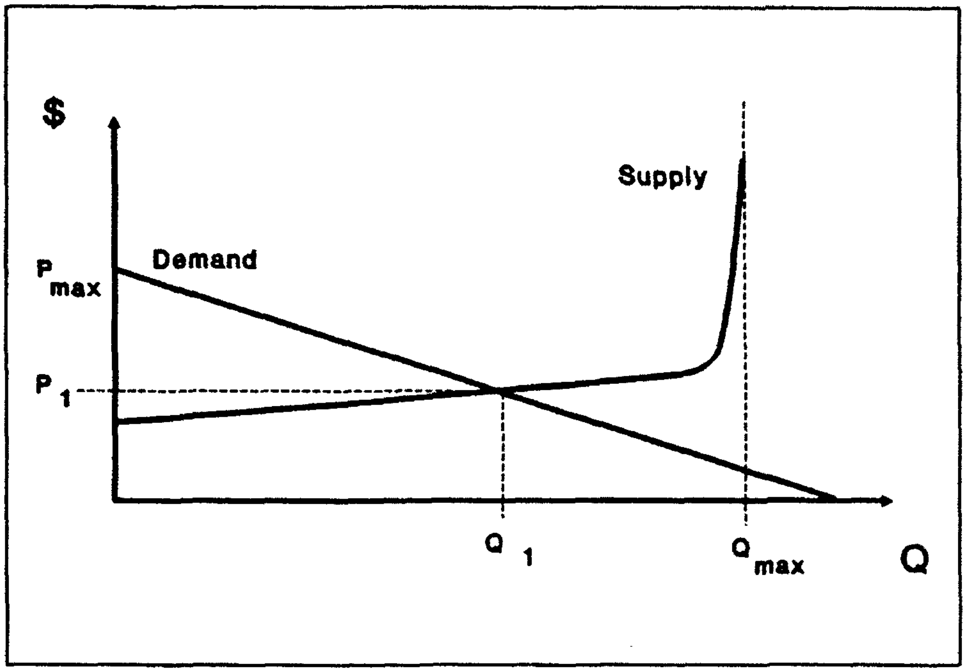

Figure 8. Supply/Demand Relationship for Landfills

The price P_{max} reflects the cost of competing technologies and represents the maximum price that suppliers can charge for landfill services. Similarly, the near vertical portion of the supply function reflects Q_{max}, the maximum volume available to those demanding services from the landfill industry. As drawn, waste producers would dispose Q_1 units of volume at the given unit price of P_1.

Even though the shape of the supply/demand function in Figure 8 varies from the hypothetical model described in Figure 3, the measure of consumer surplus remains straight forward and can be graphically represented as in either Figure 9a or 9b, depending upon the demand curve which will establish the point of intersection of the supply and demand functions.

In either case, the existence of consumer surplus can be readily identified and any increases or decreases in CS from this "baseline" can be used to indicate changes in consumer or social welfare.

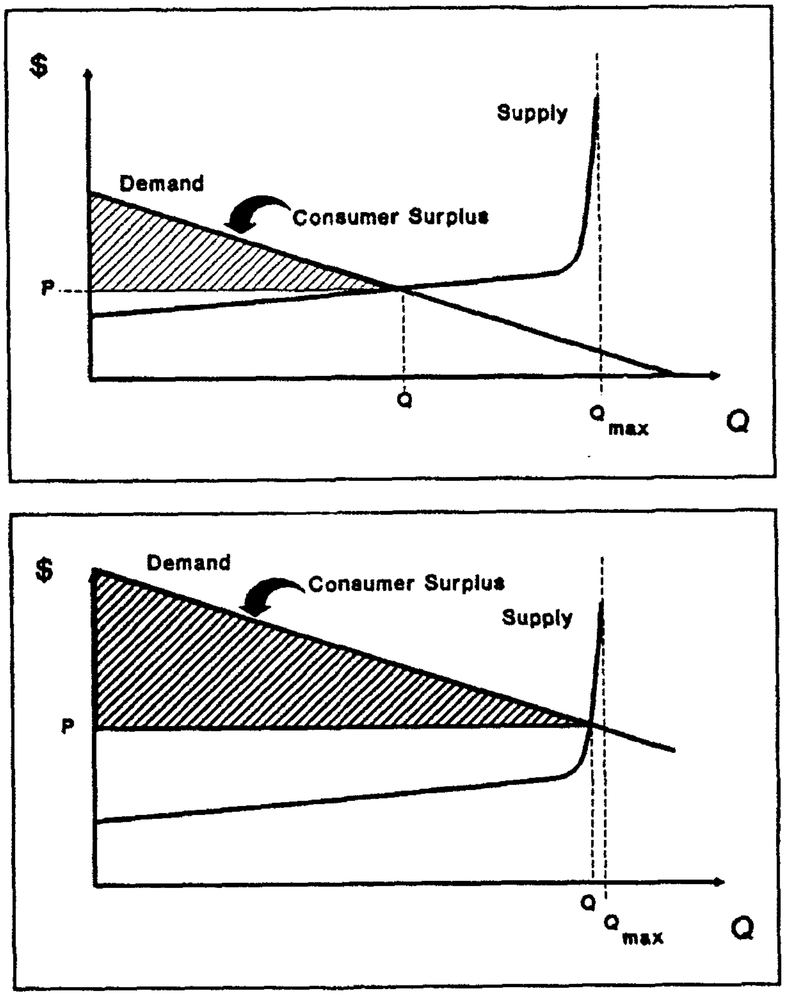

Figure 9a and b. Consumer Surplus in the Landfill Industry.

There are many sources of potential financial liability associated with landfilling hazardous waste which could lead to negative externalities: corrective actions under the

Resource Conservation and Recovery Act and third party lawsuits for personal/property damages under the Comprehensive Environmental Response Compensation and Liability Act just to name two. However, this paper considers only one: the cost involved in destroying the waste, because destruction eliminates any further financial liability for the waste generator (i.e., the individual who generated the waste and disposed of same in the landfill).

Ignoring potential costs for groundwater cleanup, legal actions, etc., may seem to eliminate the largest potential expenses from the analysis; however, given the state-of-the-art technology used in current landfills, the problems associated with environmental catastrophes at abandoned landfills such as Love Canal are abated to a great extent. Landfills in the past typically had only earthen liner systems (or, in the extreme, no liner at all) and little groundwater monitoring or leachate control. Landfills were treated simply as holes in the ground. As a result there was a great potential for chemicals to leach from landfills and spread throughout the groundwater system or environment before being detected, and environmental catastrophes such as Love Canal occurred.

Conversely, current landfill design calls for both earthen and synthetic liner systems, leak detection, leachate collection, etc., as shown in Figure 10.

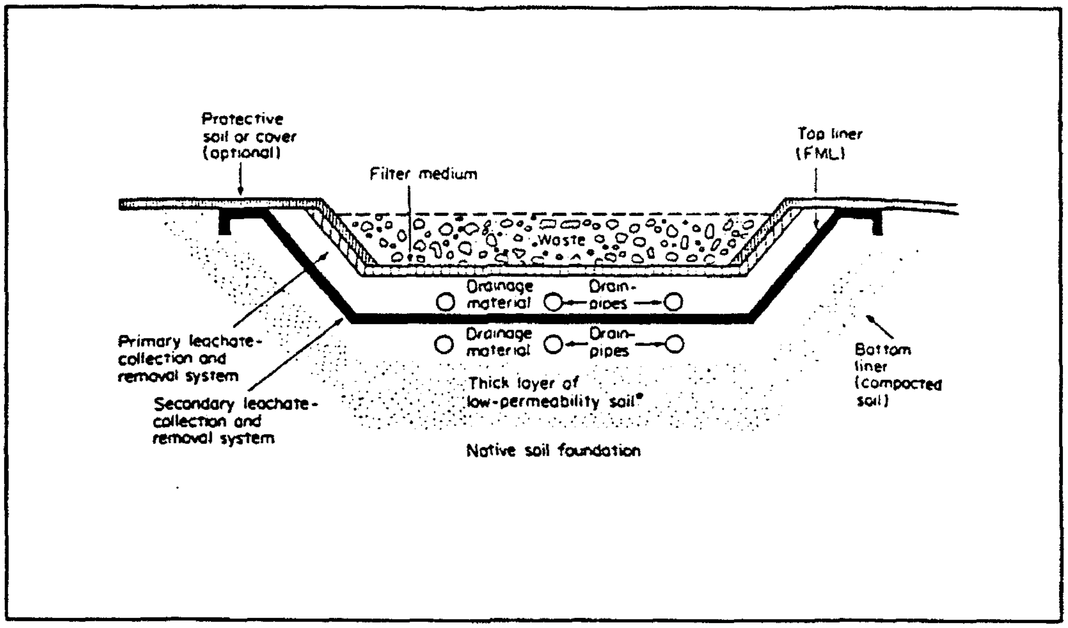

Figure 10. Schematic of a Flexible Membrane Liner Plus Compacted-Soil Double-Liner System

(U.S. EPA, EPA/530/SW-85-012, Washington, D.C., 1985)

Although these additional safeguards serve to better contain the waste, in that all manmade structures will eventually fail, these design improvements do not totally eliminate potential failure. Instead, these safeguards limit the potential for uncontrolled/undetected problems, thereby reducing the magnitude of future financial liability.

Modern landfill design not withstanding, once failure occurs, the site will have to undergo remediation. Hence, while design improvements have minimized future liability, it is not eliminated. There will always be the requirement for waste destruction, either upon generation of the waste or during remediation of the landfill. Hence, the cost of destroying the waste is the focus of this study.

Under this scenario, the landfill fees paid at the time of disposal represent little more than storage charges, and any additional financial liability for waste destruction should be considered and added to the cost of disposal. Since the users of landfills generally only consider the landfill (storage) cost in computing the cost of waste disposal, the destruction of the waste appears to be a negative externality.

Social Cost Analysis

Since destruction costs are inherent when waste is sent to a landfill, and if this cost is not accounted for in the market, it implies that there is an external or societal production cost. However, because the life of the landfill (i.e., time to failure) is so long, expressing the magnitude of this cost becomes a problem in dealing with the time value of money.[22] A zero discount rate would imply that the cost of destroying the waste in the future would be the same as the cost of destruction at today's price. Therefore, the social cost of landfilling the waste would be equivalent to the current destruction cost. Hence, at a zero discount rate, the

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[22] The reader is again referred to Appendix 1 for a discussion of discount rates and present value calculations.

total cost of disposing of one unit of waste (P_t) would be the landfill price (P_l) plus the social cost (P_s).

Given that the discount rates are positive, there are two possible events. First, if the cost of waste destruction remained constant, the positive discount rate would imply the present value of the cost of destroying the waste at a future date would be less than the current destruction price. Conversely, if the combined effects of inflation and waste destruction price increases were greater than the discount rate, the present value of the future expenditure could be higher than current price. Under any circumstance, however, there is still a social cost to consider.

The social cost of the landfill externality can be added to the landfill supply and demand graph in the same way theoretical social costs were reflected in Figure 7. The social cost (P_s) is the present value of the future destruction cost and can be added to the supply function for landfills. This relationship is shown in Figure 11.

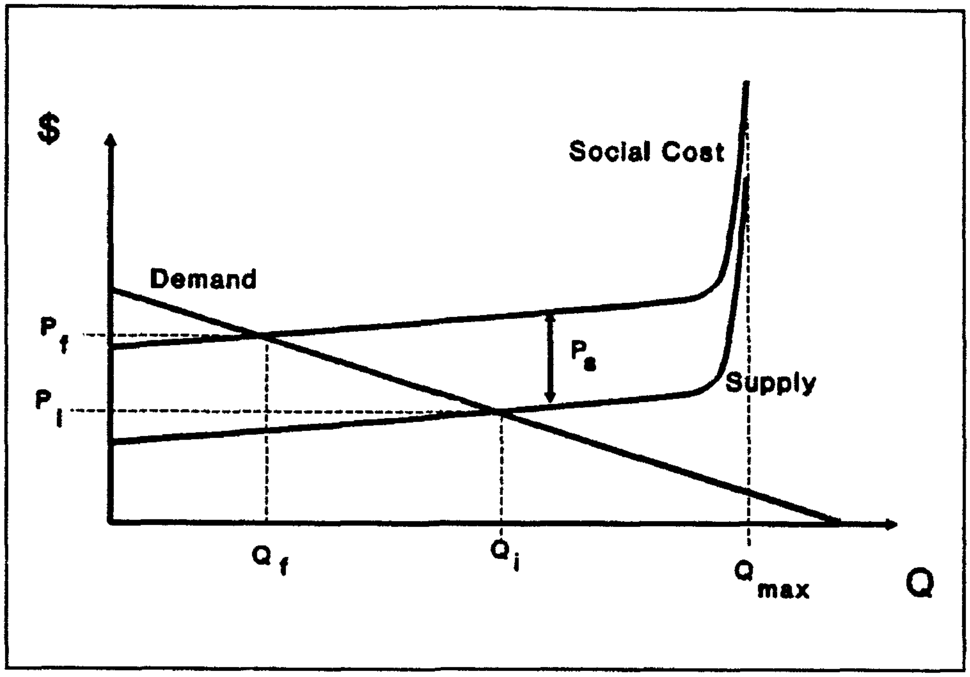

Figure 11. Social Cost of Landfilling Hazardous Wastes.

As before, the amount of waste sent to the landfill should be limited to Q_f vs. Q_i, and the price charged should be P_f. The addition of social cost reduces the actual consumer surplus from landfilling as compared to that reflected in the market by just the landfill price. Instead of the area below the demand function and above the price P_i, it is actually the area below the demand function and above P_f.

The Landfill Negative Externality Analysis

Because landfill pricing does not include all costs, landfilling wastes is underpriced and too great a quantity is sent for disposal. To the waste generator, the social cost does not represent a direct expense and is not considered in financial decision making. Hence, on the surface, it appears to be a failure of the market to internalize all relevant costs to the generator of the waste which, under normal circumstances, would require the government to pass legislation to internalize this cost.

The two general options to eliminate the externality both involve governmental intervention in the market. The first would be to directly limit the amount of waste that is allowed to be sent to landfills (such as done with effluent limitations in the Clean Air and Clean Water Acts). The second would be to force an increase in the cost of disposal. Recalling the relationship shown in Figure 11, if the amount of waste allowed to be sent for disposal was limited to Q_f, either by issuing or selling disposal permits or assuming a command and control position on hazardous waste "emissions," the quantity of waste landfilled would be correctly set.

Conversely, the price of waste disposal as seen by the generator of the waste could be increased from P_i to P_f by a tax or a Pigovian fee[23] on the generator of the waste. This price increase would raise the disposal cost which would also have the effect of limiting the quantity of waste sent to disposal to the correct amount. Either option would force

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[23] A Pigovian Fee is a charge levied on the polluter which is equal to the social cost of the pollution. The fee acts to impose an additional cost on the polluter above and beyond normal production costs which internalizes the cost of pollution to the firm.

waste generators to consider the "total" cost ($P_l + P_s$) for waste disposal in their market decisions.

The above government options share one major assumption: namely, that a negative technological externality actually exists which requires additional regulatory intervention. While it is true that most waste generators routinely do not include destruction costs in their price analyses for landfill technologies, it is not certain that it is a result of market failure and may not require additional legislation. Instead, the apparent externality is a failure of the generators to recognize the full costs of their waste disposal options. This could be caused by a lack of understanding, short term profit outlook vs. the long term responsibility considerations, a feeling of financial security in that the waste was handled "correctly" under current environmental law, or the inability of the generator to estimate the magnitude of this cost. In any event, current environmental law already designates the party generating the waste as the financially responsible party; and if the market has the capability to internalize these costs, no further legislative intervention is required.

Under the Resource Conservation and Recovery Act, the generator of the waste (or consumer of landfill services) is financially liable for the waste from "cradle to grave."[24]

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[24] Resource Conservation and Recovery Act, Subtitle C, Section 3001.

While this seems to imply that once the waste is in a landfill, the RCRA "grave" has been attained, the waste producer's financial liability for the waste does not end. The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (as amended by the Superfund Amendments and Reauthorization Act (SARA)) extends this liability for as long as the waste exists.[25]

In explaining this legal responsibility, the laws define two concepts of liability. The first, Joint and Several Liability, allows the EPA to assign the full financial liability for destruction of <u>all</u> waste in a landfill to any generator who has deposited waste at the facility. Hence, in the strictest sense, any generator who has deposited waste in a landfill can be legally held financially liable for the entire cost of a landfill remediation. The second concept, Strict Liability, limits the government's requirements in proving the waste generator's "guilt" in the event of environmental damage. Under strict liability, in a landfill situation, the only issues that a government agency such as the EPA needs to prove in order to assign financial liability are whether or not the environment was damaged, to what extent it was damaged, and the identity of the owner of the landfilled waste. Circumstances that may otherwise be considered extenuating, such as recent changes in the

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[25] Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), Sections 106 and 107(a-b).

prevailing regulations or the state-of-the-art technologies that were available at the time of disposal, are irrelevant and need not be considered in assigning financial responsibility. Hence the requirement to address issues such as intent to commit environmental harm, negligence in waste disposal, etc., are eliminated by the law.

The net effect of the hazardous waste legislation is clear: the waste producer's financial liability exists as long as the waste exists. As a result, to internalize this cost, it only is required that this financial responsibility be communicated to waste generators, not the passage of further legislation. As shown earlier, defining this cost through microeconomic theory (i.e., determine the cost of P_s from Figure 11), is valid and forms the basis of this analysis.

SECTION VI

LANDFILL FAILURE ANALYSIS

Landfill Failure

A landfill is considererd to be a containment vessel for hazardous waste. Hence, failure can simply be defined as the time when the vessel no longer contains the waste. Given the current landfill design criteria shown in Figure 10, the critical failure variable is the liner system. If the liner fails and excessive waste is detected in the leachate between the liners by the collection system, remediation will be required.

This seems to negate site factors such as soil permeability, contaminant transport, adsorption, etc. which could effect leachate flow; however, these concepts are relevant to an exposure risk analysis centering on the receptor such as would be performed in a landfill remediation under CERCLA. Because the landfill remediation portions of CERCLA specifically address the potential for uncontrolled releases of contaminants to the environment from abandoned landfills, it must be concerned with controlling exposure at the receptor. Conversely, RCRA addresses treatment, storage and disposal facilities for hazardous waste generated during current operations and, as such, emphasizes the facility vs.

the potential exposure to the receptor. As a result, the requirement for remediation under RCRA would be determined solely by the the performance of the facility (i.e., the capability of the landfill to contain the waste), and site specific variables such as soil permeability do not enter into the remediation decision. Hence, the time to landfill failure can be defined by the time to liner failure.

There are and have been a number of studies regarding landfill liner failure; however, they are often simulations of landfill conditions done in a laboratory. For example, EPA's Test Method 9090 involves testing the actual (or simulated) waste compatibility with the liner in the lab over months.[26] While valuable, they are of limited use in defining the actual time to landfill failure due to the number of potential variables.

Conversely, one of the most comprehensive insitu efforts[27] studied field data on leachate flows from the leakage detection layers of double-liner systems at 30 different landfills. The most critical aspect of this study is that the landfills were all designed to the specifications

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[26] U.S. Environmental Protection Agency, Method 9090, Liner Compatibility Test, US EPA Office of Solid Waste, Federal Register, Vol. 49, No. 191, 1 October 1984.

[27] Bonaparte, A. M., and Gross, A. M., "Field Behavior of Double-Liner Systems," Waste Containment Systems: Construction, Regulation, and Performance, Geotechnical Special Publication No. 26, American Society of Civil Engineers, New York, Nov. 1990.

required by the 1984 Hazardous and Solid Waste Amendments to RCRA, as shown in Figure 10.

Included in the study are data on leachate flow measurements taken at the end of construction where consolidation water, secondary compression of the clay liners, etc., are critical aspects of leachate flow; flow rates during landfill operation and during the post operational phases. During the operational period, the study includes 109 separate flow measurements taken on 50 separate landfill cells. The flow rate data from the study is broken down in Table 1.

Table 1

Average Leachate Flow Rates from 50 Individual Landfill Cells*
(in liters per hectare per day (lphd))

0 < Cell Flow < 50	**50 ≤ Cell Flow < 200**	**Cell Flow ≥ 200**
18	19	13

* Table reflects the final flow rate measured during the study (e.g., if the leakage flow rates were collected at 1, 12, 23 and 33 months only the 33 month measurement is reflected in the table.)

The critical aspect in defining landfill failure becomes a complex question. First, what is an "excessive" leachate flow rate; second, will the landfill have failed if the leachate collection system can recover the leachate; and third, if an "excessive" flow occurs, how much of the landfill will require remediation.

With respect to excessive flows, the US EPA has proposed "action leakage rates" between 50 and 200 liters per hectare of lined area per day[28] as measured by the volume removed by the leachate collection system. Given this action level, the question arises as to whether the landfill will be considered as failed if the leachate collection system can handle the leachate flow. Given the intent of the landfill design criteria, to protect groundwater supplies, there is little doubt that failure of the primary system will be sufficient to warrant remediation.

This assumption is based on two major factors. First, there is no similar system to detect leakage in the secondary liner, the liner under the leachate collection system, save groundwater monitoring wells. Hence, a leak in the second liner would not be detected until after the damage to the environment had already occurred. Second, the purpose of double liners is similar to that of double hulled oil tankers for ocean shipment. The second liner is a backup system and not the primary holding system. Allowing a landfill to continue operation with a primary liner leaking would be the same as allowing a double hulled oil tanker to continue in operation with only one hull intact. As a result, even though the landfill may still be potentially containing the waste, there is little doubt, given the intent of the design

[28] ibid.

criteria, that primary liner failure will dictate landfill failure from a regulatory standpoint.

Regarding the areal extent of remediation, the EPA had not yet determined any requirements. However, general design and operational procedures for landfills separates landfills into separate cells. Not only do separate cells allow for separation of incompatible wastes, it makes the landfill operation more manageable. A typical design for such a grid system is shown in Figure 12.

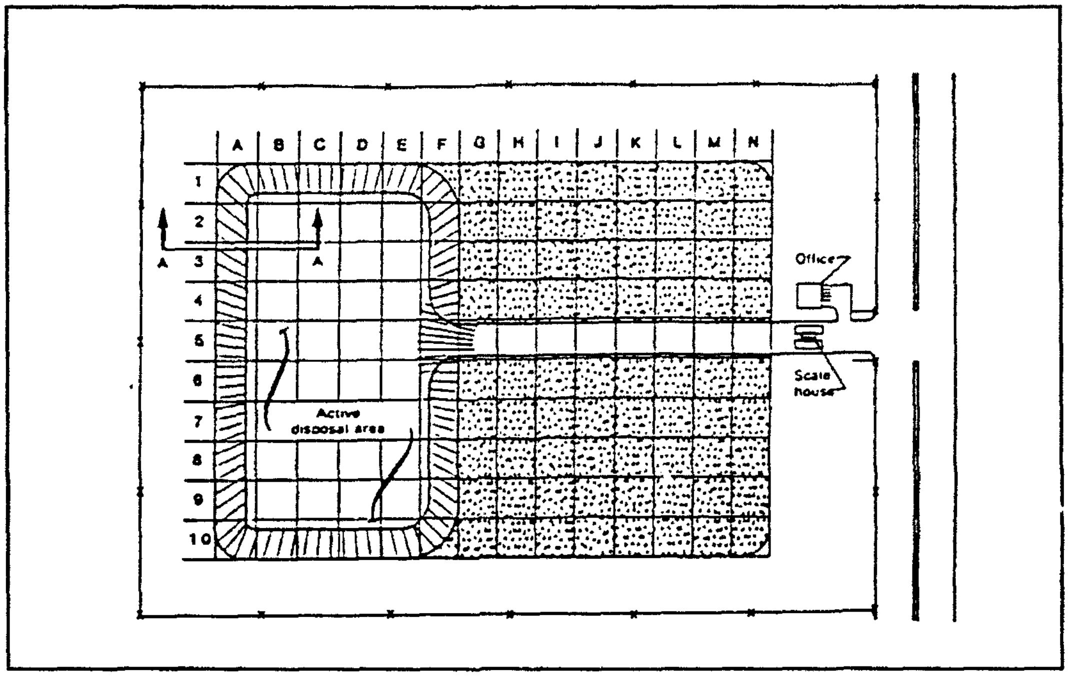

Figure 12. Conceptual Design for Hazardous Waste Landfill Grid System.

(From Freeman, Standard Handbook of Hazardous Waste Treatment and Disposal, Wright, T.D., et al., "Hazardous-Waste Landfill Construction: The State of the Art," McGraw Hill, 1989)

Given this commonality of cells within landfills, and assuming the purpose behind controlling or limiting leachate flows would be to protect groundwater resources, it is likely that restrictions governing excessive flows will be applied to the flow from any given cell vs. an average flow for the entire landfill. Given this assumption, if the 50 lphd action level proposed by the EPA were used as an action level in Bonaparte's data, 64% of the cells shown in Table 1 would require remedial action.

Since the regulation has not yet been promulgated, there is an additional regulatory option that needs to be considered. The EPA has often defined effluent standards in terms of maximum and average allowable emissions. In view of this tendency, it is possible or probable that the final leachate requirement for landfills will include a double standard to cover both average and maximum flows, similar to the Clean Air Act standard for carbon monoxide[29]. Not only is this reasonable given the potential fluctuations in the flow caused by precipitation, spring snow melt, etc., it makes sense from the standpoint of groundwater protection. In the extreme, if there were not a maximum and average standard, it would be possible for a single cell to be leaking hazardous waste into an aquifer at an excessive rate; however, as long as the landfill was large enough, the average flow rate for the entire area could be within the regulatory limitations. Given the available information, an average flow rate not exceeding 50 lphd and a maximum flow rate not exceeding 200 lphd in each cell would be a reasonable estimate of the requirements to be expected in the upcoming regulation.[30]

In light of these potential average and maximum flow standards, the analysis of Bonaparte's data becomes particularly interesting. If one were to take each of the 109

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[29] The 1 hour maximum for carbon monoxide is 4 times higher than the 8 hour average (35 ppm vs. 9 ppm). Source: Code of Federal Regulations, 40 CFR 50.4 - 50.12.

[30] The Resource Conservation and Recovery Act of 1976, reauthorized in 1984 by the Hazardous and Solid Waste Amendments, is due for reauthorization in 1992 and it is probable that leachate flow rates shall be included in the promulgation of the regulation.

measurements as being an individual regulatory check on a landfill, the data in Table 2 would result.

Table 2

Ranges for the Average Leachate Flow Rates for the 109 Individual Cell Measurements
(in liters per hectare per day (lphd))

0 Flow	0 < Flow < 50	50 $\leq$ Flow < 200	Flow $\geq$ 200
10	27	39	33

Given the estimated maximum and average standards of 50 and 200 lphd, the number of cells exceeding the average criteria would not change (66% vs 64%); however, in considering the measurements of maximum flow data available, nearly 45% of those cells which were in the < 50 lphd category would violate the 50 lphd standard and nearly 70% of the 50 to 200 lphd cells would violate the 200 lphd standard. Hence, the "double" standard could increase the number of landfills which require remediation by a considerable number.

Additionally, Bonaparte's study included data on ten closed (e.g., capped) landfills in the study. Of these closed cells, 9 violated the 50 lphd standard based on average flow and 6 violated the 200 lphd standard based on maximum flow. With data such as this available, there can be little doubt that the EPA will act to establish and enforce action to maintain leakage rate standards similar to those estimated above.

The critical question becomes not one of whether or not a landfill will fail but one of landfill age at failure. In the past, the EPA has been cited as expecting most landfill liners to fail after approximately 20 years.[31] Although this failure age has been argued as being both too long (failure can be accelerated by contact with chlorinated organic solvents in the landfill or exposure to ultra-violet light, etc.,) and too short (once in a stable environment there is no driving force to alter the liner and it should remain stable for decades[32]), it has been used because it coincides with most liner manufacturer's warranty period.[33] Conversely, given the fact that the average age of the landfill cells in the Bonaparte study was 24 months (range: 1 to 52 months since operations began), the 20 year lifetime expectation appears to be somewhat optimistic.

In that the key issue is financial responsibility for remediation vs. landfill failure, the liner manufacturer's product warranties must be considered. The general wording of

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[31] Freeman, H.M., Hazardous Waste Minimization, "The Economics of Waste Minimization," McHugh, R.T., McGraw Hill Publishing, 1990, pg 132, and Hovater, L.R., "Synthetic Linings", Standard Handbook of Hazardous Waste Treatment and Disposal, Freeman, H.M., McGraw Hill, 1989, p. 10.31.

[32] Conversation with Mr. Bob Landreth, Center Hill Research Center, Cincinnati, Ohio, 8 October 1991.

[33] Hovater, L.R., "Synthetic Linings", Standard Handbook of Hazardous Waste Treatment and Disposal, Freeman, H.M., McGraw Hill, 1989, p. 10.31.

liner warranties indicates they are often prorated,[34] and the manufacturer can normally only be held financially responsible for fixing the liner system due to defects in materials/ workmanship in the liner itself. If the leaching is due to a failure caused by or during installation (such as leaking seams, construction damage, etc.) vs. the liner itself, the manufacturer is not responsible and the firm installing the liner would have had to issue a separate warranty regarding installation defects. While individual warranties and guarantees can vary, the common denominator is that they are limited in coverage and, except in specific circumstances, probably would not cover full remediation costs. Hence, warranties cannot be considered as a financial fail-safe.

Landfill regulations require consideration of an additional variable. Namely, if an excessive leachate flow occurs, what actions will be required? While this is open to conjecture, if liner leaks can be found and isolated, repairs would be allowed. In these cases, if the leaks can be attributed to either guaranteed liner failure or warranted installation problems, the waste generators should not be held responsible for repair cost. However, given the limitations on liner warranties it would be unreasonable to presume that the liner manufacturer's/installer's compensation would include costs attributed to waste destruction. Hence, if the flow rates were high enough to preclude repair, or if the

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[34] ibid.

repair process required that waste be removed from the landfill and treated vs. being returned to the landfill, the waste generator, under RCRA and CERCLA liability rules, could be held responsible for the destruction costs.

Because of these considerations, the time to landfill failure has been selected to be at a landfill age of 20 years. This is based on two assumptions. First, most "early leaks" (such as reflected in Bonaparte's study) would be repaired under warranty and would occur in the first few years of operation. Hence, any destruction costs would be minimal and be incurred and paid by the landfill owner. Second, it is assumed that the landfill liner market is competitive. As a result, in order to secure the largest share of the market, the liner manufacturers offer their product at the most competitive price possible and guarantee their product for the longest possible time. Simply put, if a manufacture could give a longer guarantee, they would be in a more advantageous market position and they would not hesitate to do so. As a result, this analysis will share the liner manufacturer's confidence in the 20 year liner life and use it as the age to landfill failure. In the event of error, because most other potential failure mechanisms (e.g., solvent exposure, ultra-violet degradation, etc.) shorten the liner life, using a 20 year liner life in the economic analysis would tend to result in a more conservative estimate of the expenses.

Given the strong influence of the time value of money in financial analysis and the uncertainty of the time to failure, rather than a single time to failure, a standard distribution of failure probabilities must be established. If a standard bell shaped probability curve with a 95% confidence limit for failure between 20 and 25 years is used and expressed on a cumulative basis, the resulting failure probability distribution would be as shown in Figure 13.

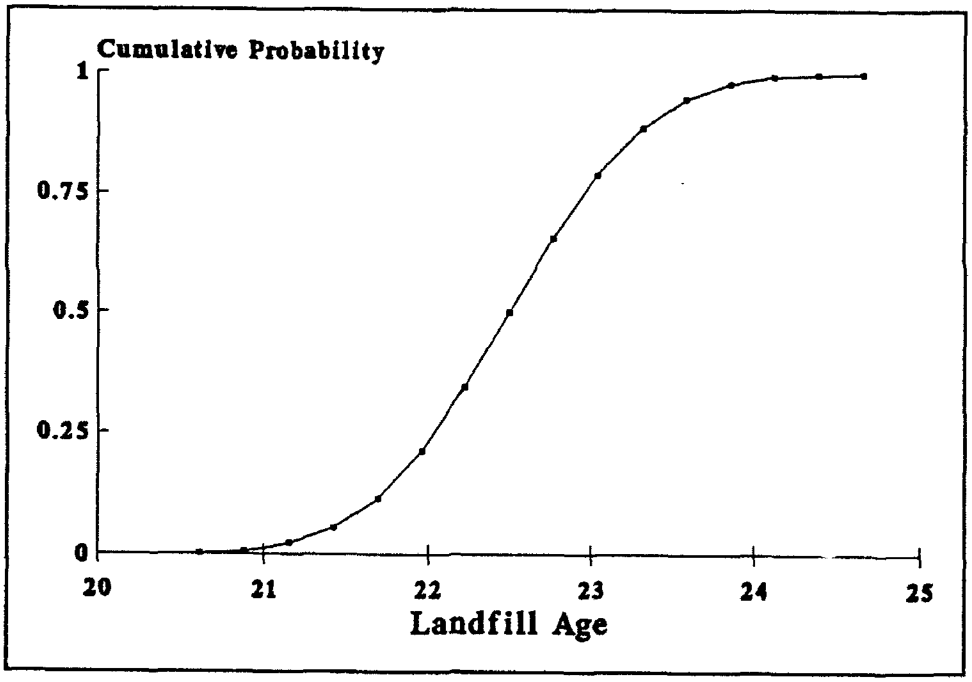

Figure 13. Probability of Landfill Failure (22.5 ± 2.5 Year Life and a 95% Confidence Limit)

This cumulative probability distribution leads logically to the concept of expected value, which when combined with present value calculations, can be used to derive the cost factor for landfill failure.

Expected Value Analysis

The expected value of an event is the sum of the probabilities of all outcomes multiplied by either the cost or benefit of each outcome and is a measure of the central tendency or the value that an outcome would have on the average. For example, if an event had only two possible outcomes, success or failure, the analysis would be as follows:

(benefit of success)x(probability of success)

\- <u>(cost of failure)x(probability of failure)</u>

expected value of the event.

Once all expected values are determined and totaled, the financial impact of the event (either benefit or expense), can be determined given all potential outcomes. For example, there are a number of games at county fairs that involve wagering on numbers or colors, much like roulette. If the required bet is $1, the prize is worth $5, and there are 10 selections (e.g., the numbers 0-9), the expected value of participating in the game can be computed as:

(benefit of success)x(probability of success)

\- <u>(cost of failure)x(probability of failure)</u>

($5)x(.1) - ($1)x(.9) = -$.40.

Hence, on the average, the player will lose (i.e., the game operator will win) $.40 on every $1 wagered.

Expressing The Expected Value of Landfill Failure

In the specific case of landfills, the probability of failure at any given time can be directly calculated from the Figure 13 distribution, but because the events occur over time, the cost of the event is more complicated than that shown in the above example. In present value terms, the cost is a function of the expectation of failure, the discount rate used, and the cost of destruction. In addition, since future costs must be discounted, the age of the landfill is an important consideration. Given the estimated 20 year liner life, the present value of the cost of failure would be considerably higher in a landfill that was 17 years old (i.e., failure expected within 3 years) than it would be if the landfill were nearly new. As a result, there is no single factor than can be used. However, the analysis lends itself to a family of factors with each representing a specific landfill age.

Discount Rates

The number of discount rates used by individual firms leads to an almost infinite number of possible liability factor values. To illustrate the effects, three discount rates are discussed. First, as a minimum rate, the rate for federal long term bonds can be used (approximately 6%). Second, in that the federal government requires a 10% discount rate be used in bidding for government contracts, it shall be used as a mid-range figure. Finally, most firms use much higher rates in that they feel they can realize much higher returns on their invested capital than this government rate. If this was not the case, rather than risk capital in entrepreneurship, owners and stockholders of firms would simply purchase bonds. As a result, 20% shall be used as the upper limit for this discussion. To show the magnitude of the effect of varying discount rates, Figure 14 shows how the present value of $1 would vary at the above three discount rates: 6%, 10%, and 20%.

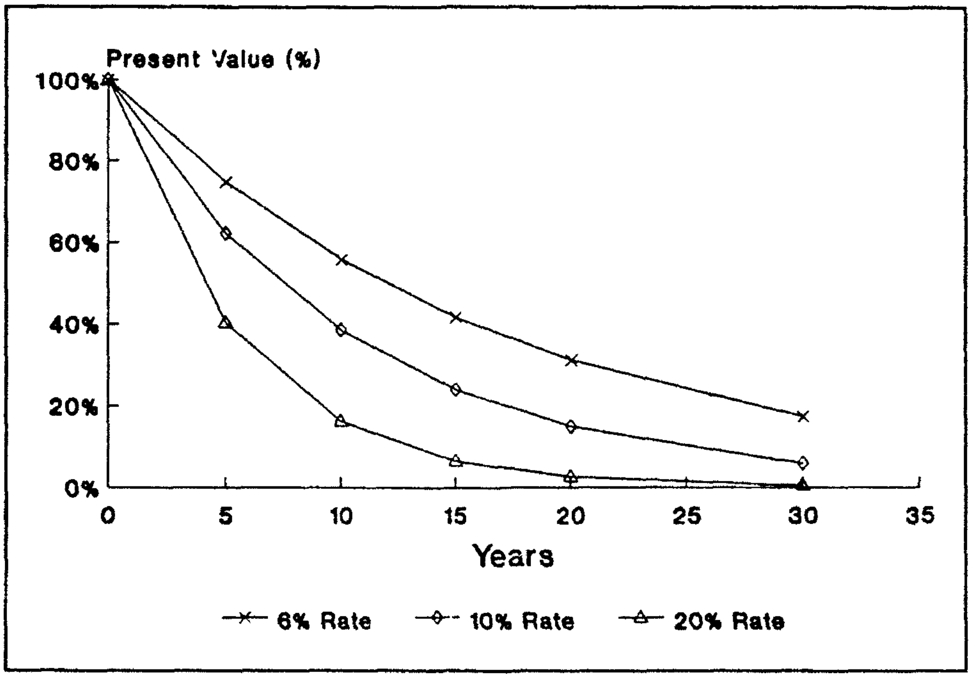

Figure 14. The Effects of Discount Rate with Time.

From the Figure 14 curves, the effect of the discount rate and the requirement to incorporate same into the landfill failure (i.e., future destruction cost) is clear. Simply due to the time value of money, a $1.00 payment to be received in 10 years has a present value of only $0.56, $0.39 and $0.16 for the 6%, 10%, and 20% rates, respectively.

SECTION VII

MODEL DEVELOPMENT

The critical aspect of applying microeconomic methods to predicting long term landfill liability cost lies in the ability to predict the social cost (P_s in Figure 11 - reproduced below as Figure 15 with social cost labeled P_d).

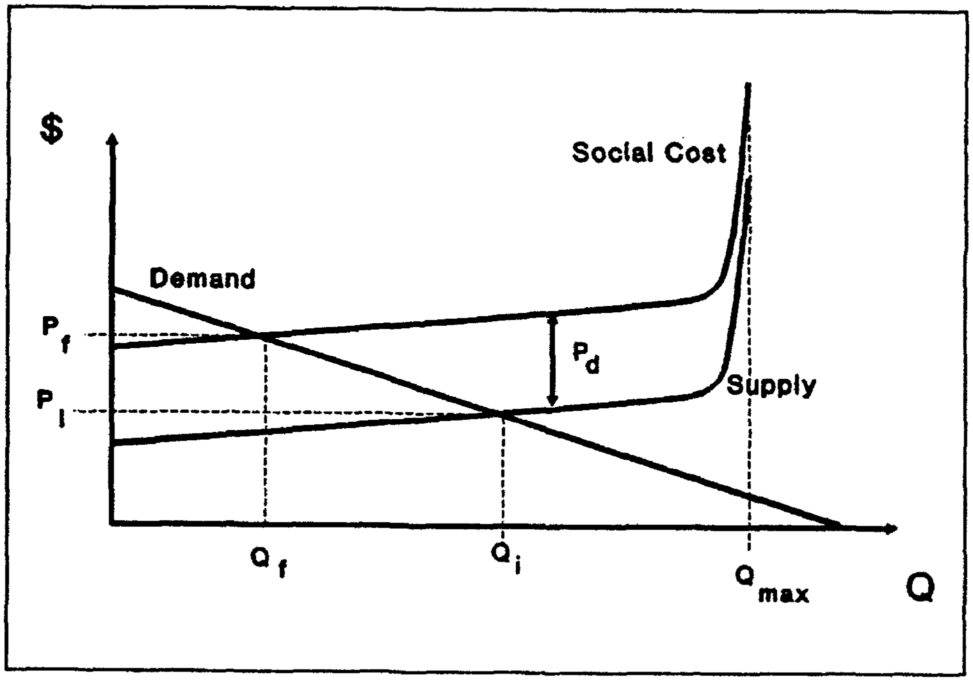

Figure 15. Social Cost of Landfilling Hazardous Waste (Figure 11 reproduced)

Since the validity of using P_d to determine the total cost was established in the consumer surplus discussion, it only remains to predict its magnitude through combining the failure probability, expected value, and discount rate, into a single function. This function is shown in Figure 16, using the federal government's 10% rate.[35]

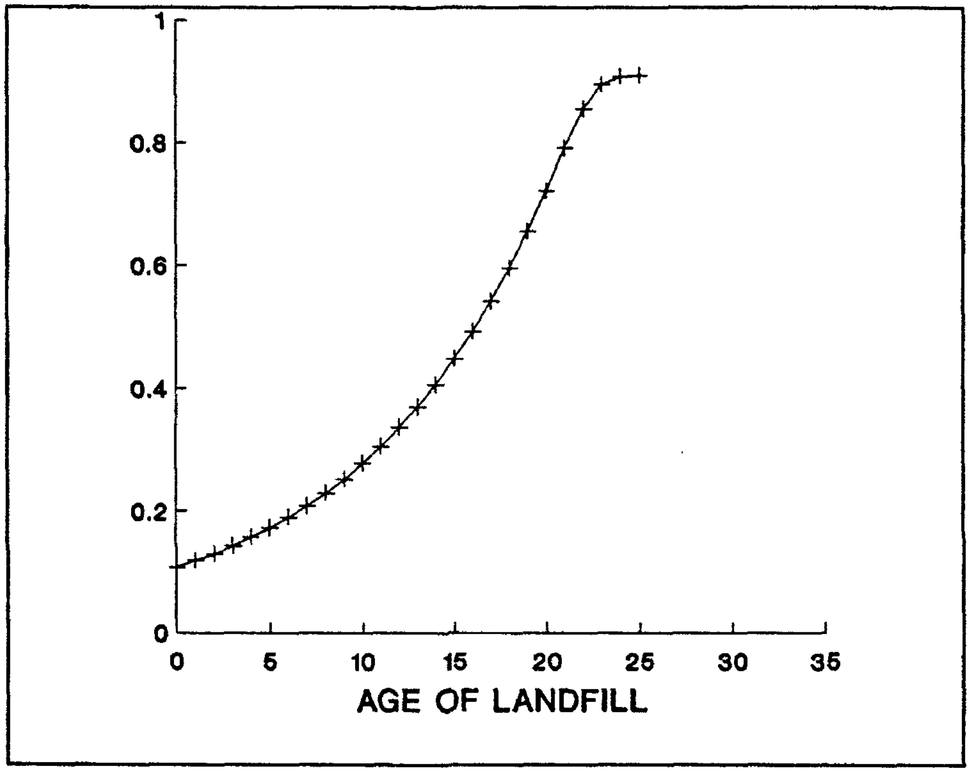

Figure 16. Liability Factors for 10% Discounting.

The line represents the liability factor function for a 10% discount rate and was constructed from present worth analysis and the expected values based on the probability curve shown in Figure 13. The first step was to compute the present worth

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[35] Example calculations are shown in Appendix 2.

factors at the selected discount rate for each year. Next, assumed landfill ages were selected to set the number of years under consideration. Then the present value factors for each year were multiplied by their respective expected value factor, and summed over all years. The result is a liability factor (f_L), which represents the total percentage of the destruction cost that should be added to the landfill cost to represent the total cost of landfilling the waste at a 10% discount rate.

The factor can be read directly off the graph by entering from the horizontal axis at the age of the landfill being used or being considered, moving vertically up to the line that represents the selected discount rate, and reading the expected value factor off the vertical axis. The resultant factor, when multiplied by the cost of waste destruction, represents the present value of the future destruction cost (i.e., P_s, the social cost of disposing of the waste in the landfill.) For example, if a landfill being considered for use is 10 years old, the discount rate is 10 percent, and the costs for landfilling and destruction are $100 and $300 per unit of waste, respectively, as shown in Figure 17, the liability factor can be read directly.

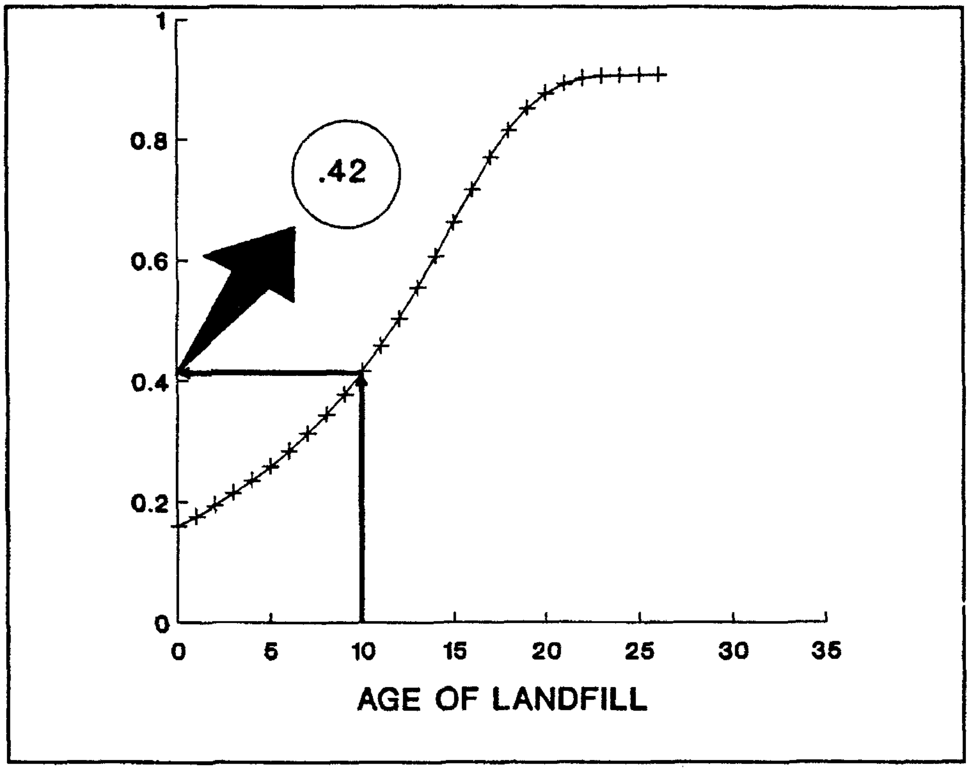

Figure 17. Example Liability Factor Calculation.

The factor from the graph, 0.42, represents the fraction of the cost of destroying the waste that must be considered in the present value of landfilling the waste according to P_l + $(f_L)P_d$, making the total landfill cost \$100 + (0.42)(\$300) = \$226.

As was the case with the time value of money, the value of the liability factor varies greatly at different discount rates. To show the possible range of f_L, Figure 18 shows the six, ten, and twenty percent liability factor functions on a single graph.

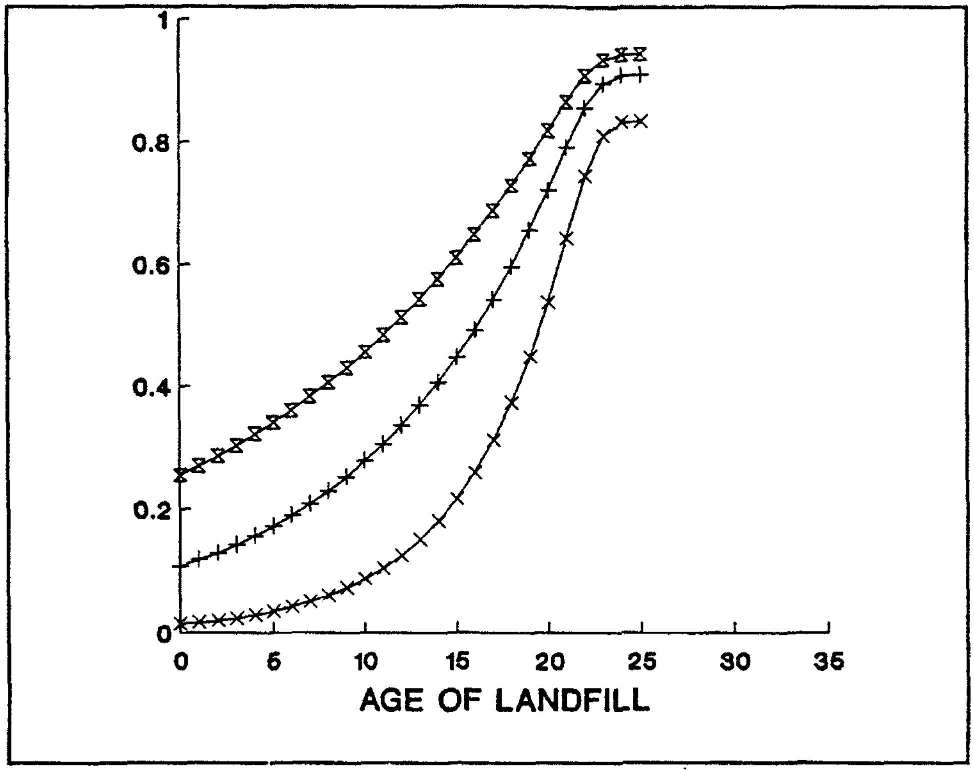

Figure 18. Liability Factors for 6%, 10%, and 20% Discounting

Although selecting the discount rate would seem to be a variable that should be left up to the individual firm, given that the resultant factor determines the monies that must be available for future liability costs, only the most secure investments should be made. Given the financial performance of previously successful companies in the early 1990's to guarantee the availability of funds, it is only reasonable to use the rate for long term government securities. Even given the large variations in prime rate that were common in the early 1990's, a 6% rate represents a reasonably available return and shall be used for all subsequent calculations.

SECTION VIII

MODEL VERIFICATION

Data Collection

The hypothesis of this dissertation is that to perform accurate financial decision making, hazardous waste generators must use the full cost associated with landfilling (i.e., $P_t = P_l + f_L P_d$) in considering and comparing waste disposal options. To test this hypothesis, a derived supply and demand curve for waste disposal as described earlier is not required. The critical points in the analysis are the intersections of the supply and demand functions (i.e., the cost and quantity) and not the supply and demand functions themselves. Further, if the assumption can be made that the market is in equilibrium, the intersection can be estimated from just price data. The assumption justification follows.

While this may seem like a sweeping assumption that could invalidate the analysis, given the uniqueness of the hazardous waste landfill market, this is not the case. The landfill market never truly "clears" as would be the case in a general commodities market. First, the landfill space does not spoil or go out of style; second, the management of the landfill is designed only to open a given percentage of the total number of cells at any time so that operational expenses (such as labor costs) can be incurred at a constant rate over the life of the landfill; and finally, there is the difficulty in entering the market. These factors combine to limit the importance of the landfill market clearing at the equilibrium position and, as a result, price can be used as a single indicator of the equilibrium position. In that each supply/demand function graph (e.g., the Figure 8 graph), represents the economic picture at a given time, if this can be done for a number of years, the result would be a graph similar to Figure 19.

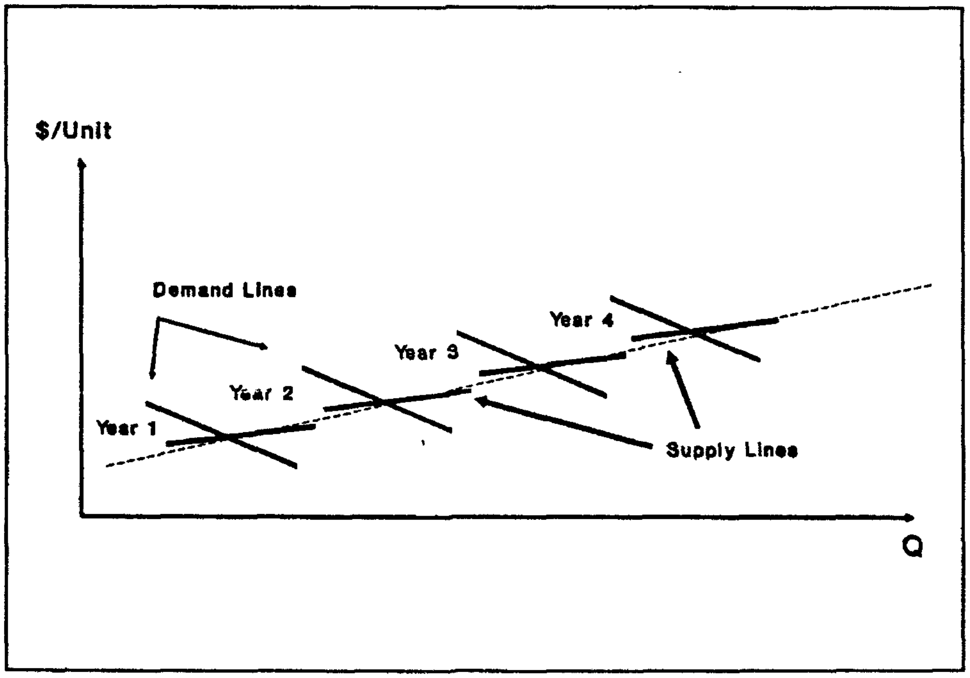

Figure 19. Equilibrium Positions for the Landfill Market

Ideally, such data would be obtained from landfills which were operated under current RCRA statutes[36] but which had since failed, which would mean destruction cost data would be available from remediation efforts under either RCRA or CERCLA/SARA. This would have allowed all critical costs to be identified: a) the costs of landfilling the waste at the time of initial disposal, (P_l), b) the costs of waste destruction for the generator that were available at the time of disposal, (P_d) and c) the costs of waste destruction at the time of cleanup ($P_{d'}$). With this data, verification of the model would involve nothing more than computing the equation and checking for agreement between the predicted and actual destruction costs. The liability factors could be applied to the cost for destruction at the time of disposal, and that value, moved in time, compared to the future destruction costs at the time of cleanup.

Figure 20 shows the intersections of the supply and demand functions as outlined in Figure 19. The data is represented as cost ($/ton) vs. the year.

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[36] The RCRA amendments of 1984 (Hazardous and Solid Waste Amendments - HSWA) increased the design and operational requirements for landfills. Hence, the costs associated with operation (and in turn the generator's cost of disposal) for the period prior to HSWA would tend to be underestimated.

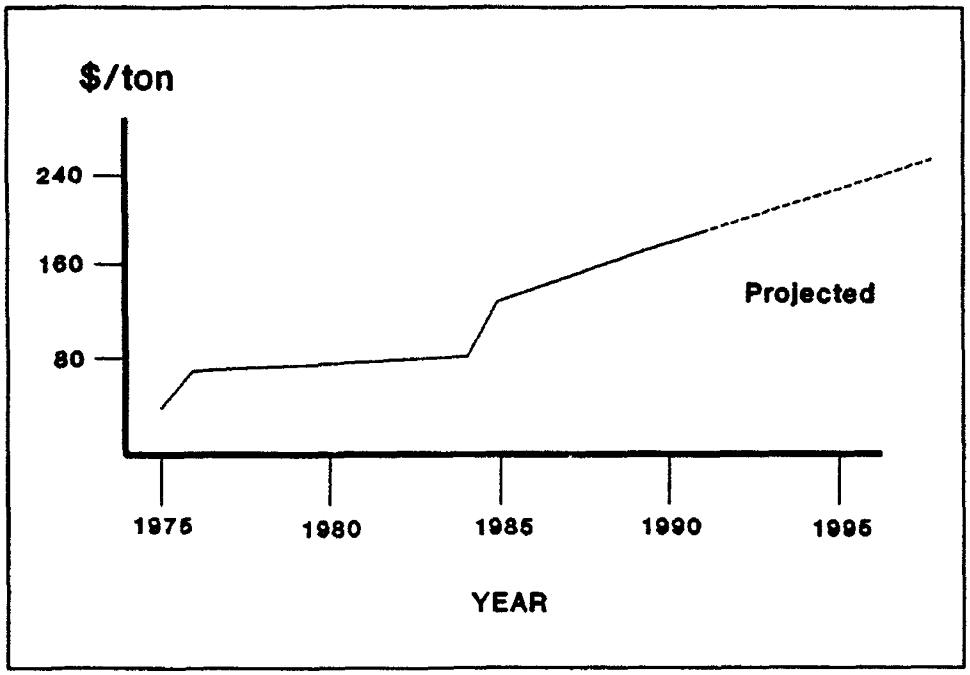

Figure 20. Historic Landfill Costs

While the data set may seem limited in that it only goes back to 1976, it was selected to coincide with the dates of major hazardous waste legislation. The first major legislation was RCRA, which caused the sharp increase in landfill disposal cost in the 1975-1976 time frame. Next, HSWA in 1984 similarly caused a step function in the cost curve. This sharp price increase occurred because, prior to HSWA, there were relatively few restrictions on landfill operations. Because these pre-1984 costs did not include many of the HSWA requirements, they can be viewed as artificially low and, as a result, should not be directly compared to post HSWA costs. Hence, the cost data collected must be limited to those landfills which comply with the 1984 amendments. Pre-

1984 has been included only to serve as a basis to estimate future "step" increases due to reauthorizations of the legislation.

Restricting the time frame, however, led to additional data limitations. The "HSWA" landfills have only been in operation for 8 years. This, combined with the fact that there is currently no definitive legislation which defines landfill failure, means there are no "failed" HSWA landfills currently undergoing remediation.

The cost determination for destruction technologies is further complicated by the variability of costs both between technological options (e.g., liquid oxidation vs. fluidized bed) as well as within any given destruction technique. Freeman[37] cites destruction costs as shown in Table 3.

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[37] Freeman, Harry M., Standard Handbook of Hazardous Waste Treatment and Disposal, "Cost Perspectives for Hazardous Waste Management", Evans, G.M., McGraw Hill, 1989, pp. 14.11-14.17.

Table 3
Hazardous Waste Disposal Option Costs ($/ton)[38]

Technology	Price (1981)	Price (1985)
Oceanic Incin.	200-250	n/a
Land Based Incin.	395-791	
Off-Site (low BTU)		250-725
Off-Site (high BTU)		50-250
On-Site		300-425
Fluidized Bed		45-300
PCBs	500-800	350-1350
Dicxin Soils		600

Even if the liquid wastes (banned from landfills by HSWA) and the more exotic wastes such as PCB (incineration required under the Toxic Substance Control Act - TSCA) or dioxin, are eliminated from consideration, the range of destruction costs is startling: from $40/ton to $791/ton. In addition, prices within an individual technology vary up to an order of magnitude.

Under microeconomic theory this variation would be of little consequence; consumers are assumed to be rational in that they elect to consume the least cost service if all other aspects of the purchase are equal. However, because of the characteristics of the competitive market itself, this level of detail could not be achieved in data collection. As

[38] Oceanic Costs from Freeman, Harry M., Standard Handbook of Hazardous Waste Treatment and Disposal, Ackerman, D.G., Jr., and Venezia, R.A., "Oceanic Incineration," p. 8.109, and Evans, G.M., "Cost Perspectives for Hazardous-Waste Management, p. 14.15, McGraw Hill, pp. 8.105-8.120.

explained by Evans[39], not only do prices reflect the supply and demand conditions, therefore they are subject to regional variability, but they are generally the result of both negotiations between buyer and seller and price strategies employed by suppliers; both can influence the price setting process. For example, vendors may be prepared to set a price which is less than cost to maintain or gain market share. As a result of all of these factors, destruction technology suppliers do not have (or are unwilling to provide) concrete unit costs, which makes it impossible to get definitive values for P_d and $P_{d'}$ above.[40]

Price Variability Analysis

Despite these limitations, the prospect of using liability factors for estimating long term liability is still valid, because many of the variables can be either eliminated or defined. For example, regional variability of costs is not unexpected. One only needs to consider potential supply/demand factors for landfills in the EPA's Region IV (near a major landfill at Emile, Alabama) vs. Region IX (landfills have been banned in California).

Under basic microeconomic analysis, if waste producers could use a "cheaper" landfill, they would. Conversely, if

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[39] ibid.

[40] Verified via telephone conversations with John Greenberg, Management Analysis for BFI Waste Systems, Inc., Washington, DC.

they are limited in their choice of landfill sites, they must likewise be in a limited market for destruction technologies or else they would landfill less waste. As indicated earlier, the price of related goods and services is a demand function parameter which would help set the quantity of destruction services provided. In areas where landfilling waste is inexpensive, destruction technologies would likewise have to be inexpensive for the industry to remain competitive. Hence, the same regional price variation would have to be present in both the cost of destruction technologies and landfills. As a result, regional variations in the values of P_l, P_d and $P_{d'}$ would be the same for any given consumer in any given region.

Similar arguments can be made for the other causes of price variations discussed by Evans. If a supplier of either landfill or destruction technology were to set the price artificially low to draw market share, the entrepreneurs of competing technologies would have to take the same actions to maintain their market share (e.g., the classic price war as seen in the gas station industry). Likewise, if a company is very good at negotiating prices (because of personnel, consistency of waste, etc.), these factors would apply for negotiations with both the landfill and destruction technology suppliers. Again, the apparent problems would washout due to market operations.

Waste Destruction Cost Variables

Since there is no concrete destruction cost data, the greatest challenge, and the greatest difficulty, therefore centers around the prediction of the future cost for waste destruction. The most relevant parameters are:

a. Inflation: For the model to be most useful, there must be some method to account for price inflation. The baseline liability factor at the 6% discount rate selected for the model is shown below in Figure 21.

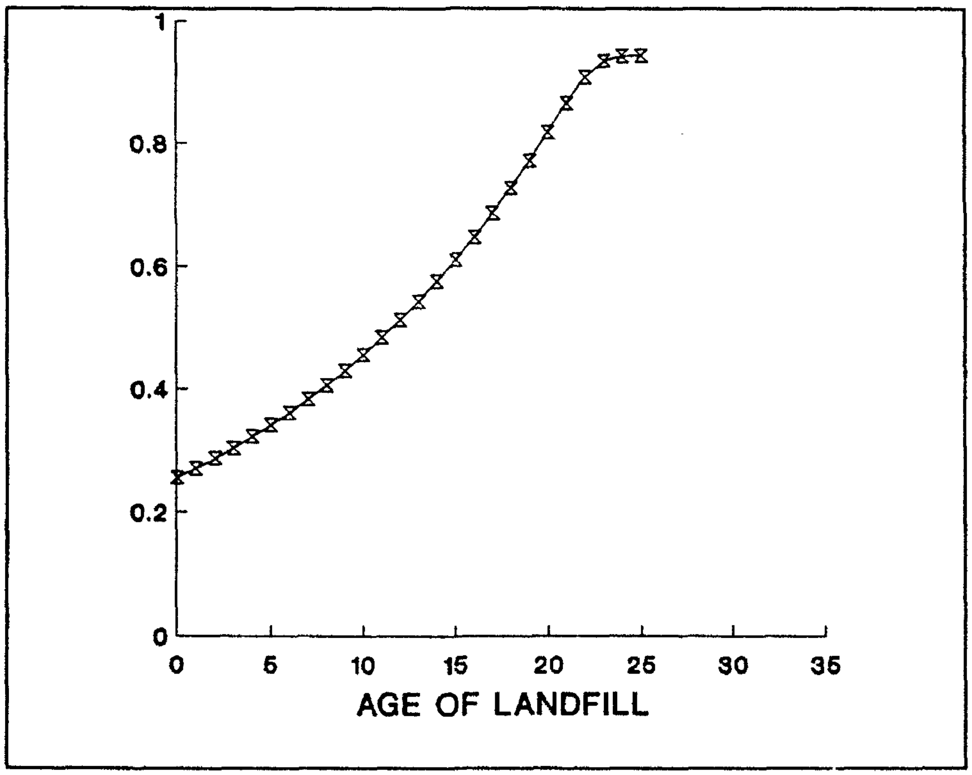

Figure 21. The Liability Factor Model for a 6% Discount Rate

One of the assumptions made in constructing the curve was that the destruction costs were constant; hence, the curve actually shows the liability factors for zero inflation. Although this may be desirable, it is improbable that the country will enjoy a zero inflation rate over a 20 year projected landfill life.

To account for inflation, the concepts of present value and expected value must be revisited in the calculation. As done initially with the liability factor, the expected value of failure during any year for a landfill of a given age was computed; however, it was then inflated at given inflation rates. The results of these calculations for a 3% discount rate is shown in Figure 22, with the initial model (i.e., 0% inflation) as a baseline.

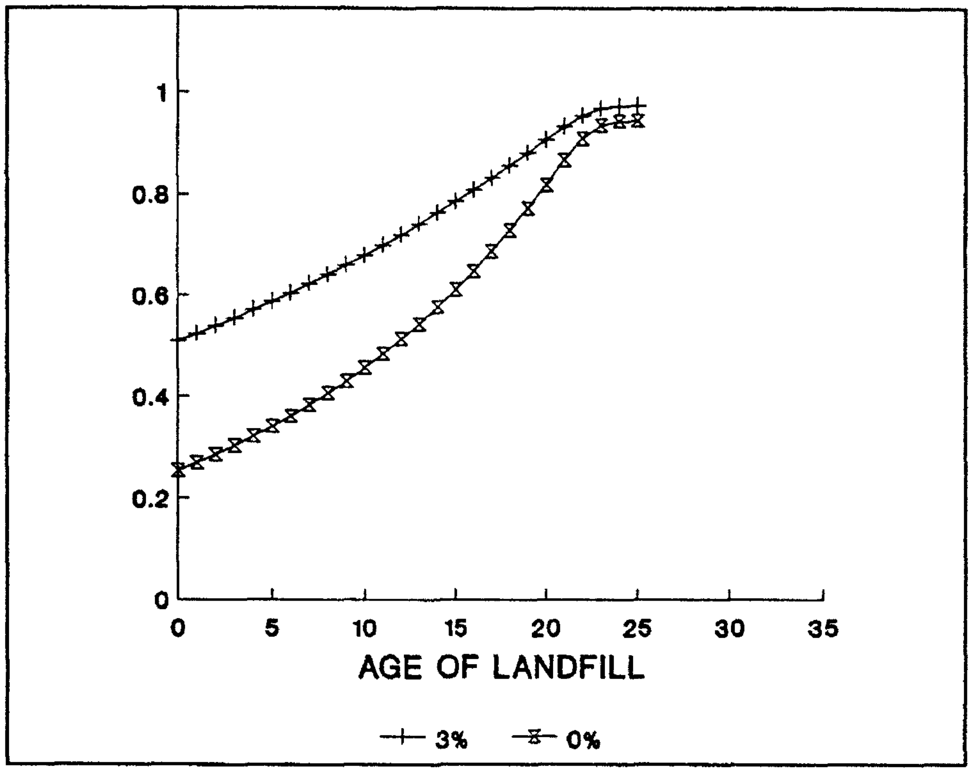

Figure 22. The Effects of 3% Inflation on the Liability Factor

As shown in the graph, the effects of price inflation on the cost of waste destruction are greater for younger landfills and wash out with increasing age; the younger the landfill, the longer time period that destruction costs have to inflate. However, Figure 22 also implies that inflation could overcome the 6% rate of return used in the model and actually make the destruction cost in the future more expensive than destruction at current prices. Figure 23 shows the model with curves representing inflation rates from 0 to 7-percent.

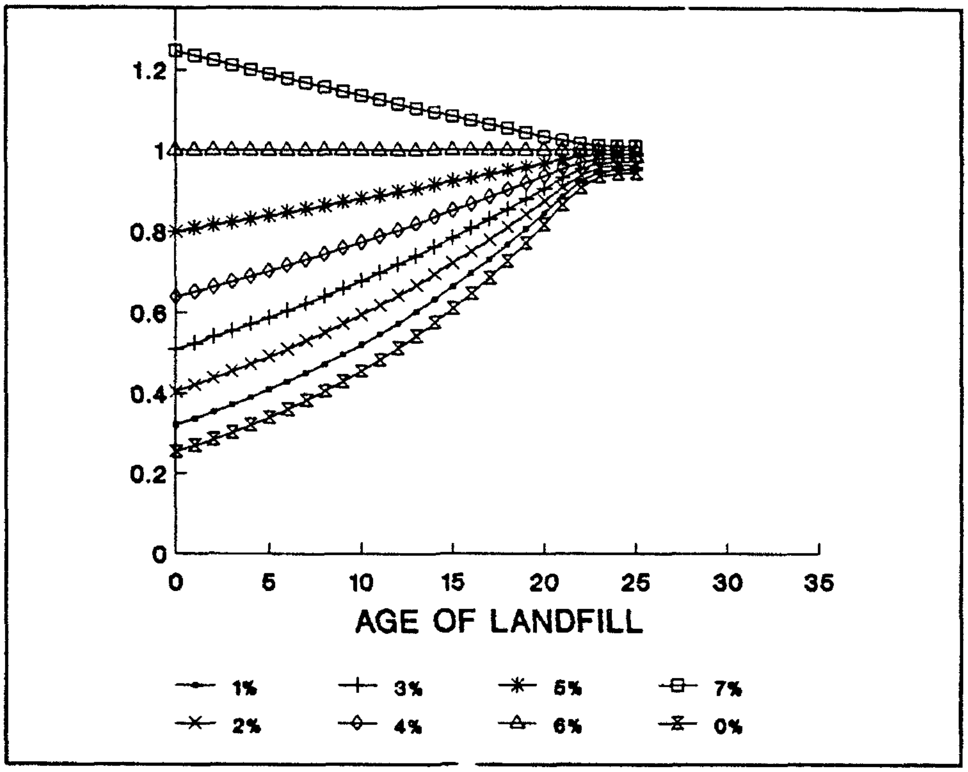

Figure 23. The Inflated Liability Factors

Again, there is an innate sensibility with this model. At a 6-percent inflation rate, the return on the money set aside for future destruction is exactly counterbalanced by inflation so the factor appears as a straight line.

b. Legislation: Upon first consideration it may seem that future changes to RCRA would not be an issue. Given that this single law governs both landfilling and destroying waste, the step price increases apparent in the past should affect both destruction and landfill technologies equally. However, this will not be the case in the future. Except for banning additional types of waste from landfills (similar to the liquid landfill ban), there is little technological improvement that can be applied to a landfill. Given that a landfill is nothing more than a hole in the ground and the current regulations have already addressed the potential areas where leakage could occur (leak detection, containment and collection, groundwater monitoring, closure actions, etc.), there is simply very little that can be added to the technological requirements already in place.

Conversely, the regulations could easily become more stringent for destruction technologies, and the cost would be drastically affected. For example, an order of magnitude change in the emission requirements (e.g., from 99.9999% to 99.99999% destruction efficiency) may seem small; however, the resultant change in price could be drastic (at least one order of magnitude). Countering this possible price increase is developing technology. Unlike the landfill where there is little improvement to be made, there are significant strides that can be made in waste destruction technology. Given the technological improvements possible, and the demand that would be incurred if additional wastes are banned from landfills, landfill closure actions, etc., it can be assumed that the price increases caused by future regulations will be offset by technological advances in destruction techniques.

c. Market Factors: The analysis thus far has been predicated on microeconomic theory concerning a competitive market, so that the parameters of supply and demand are the sole determinants of their respective functions and price is the only independent variable. Historically, this seems to have been a reasonable assumption. This is most apparent in looking at recent landfill prices. Although landfill prices were rising at approximately 14% per year prior to 1991, they were relatively stable from 1991 to 1992 due to the decreased demand caused by the "recession". Since inflation should have driven the price higher during this '91 - '92 time period, the stable prices reflect lower costs and support the contention that prices reflect market conditions.

Three factors could change this competitive situation drastically. The first, difficulty in entering/ exiting the market, has been previously addressed. Second, actions taken outside the market could have a drastic impact. The current supply of landfill space and destruction technology capacity is permit limited. All of the hazardous waste landfills and destruction facilities of concern must be permitted under RCRA, and these permits must be renewed periodically to allow continued operation. Given the public's current concerns regarding these facilities and the overwhelming NIMBY[41] attitude, it is doubtful that many of these facilities will be able to continue to operate. This loss of suppliers could greatly affect the competitiveness of the market.

The final factor is a political movement by the states to enact legislation to make the importation of hazardous waste

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[41] Not In My Back Yard.

for disposal/destruction from sources outside the state illegal.[42] If this ban on imported waste is allowed, it would change the market considerably. Instead of being competitive, the suppliers would have captive consumers (all waste generated within a state would have to be kept in the state) and a monopoly over the landfill/destruction market. If the market were to change so dramatically, the assumptions of free market contained in this analysis would have to be changed.

Liability Factor Testing

The investigation of whether or not the liability factor was accurate in predicting the total cost of landfilling hazardous waste ($P_t = P_l + f_l P_d$) required that a baseline destruction cost be selected. As apparent from the equation, as long as P_d can be assumed constant due to technological advances, any cost of destruction can be used with this model. For this verification, the value of $375 was selected as mid-range in the Evans' data previously referenced and used as the present value of P_d. Further, in that the initial landfill cost (P_l) would have been spent at the time of disposal, it can be considered a sunk cost for this verification testing and there is no need to verify its accuracy; the concern is with the future liability issue.

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[42] The United States Supreme Court is scheduled to consider a case in 1992 in which the State of Michigan is trying to prevent an instate landfill from accepting waste from New York City.

To allow for "reasonable" inflation rates, the selected initial value for destruction costs ($375/ton) was inflated at one and five-percent to serve as upper and lower future cost limits. This created an envelope of future values for destruction and is shown in Figure 24.

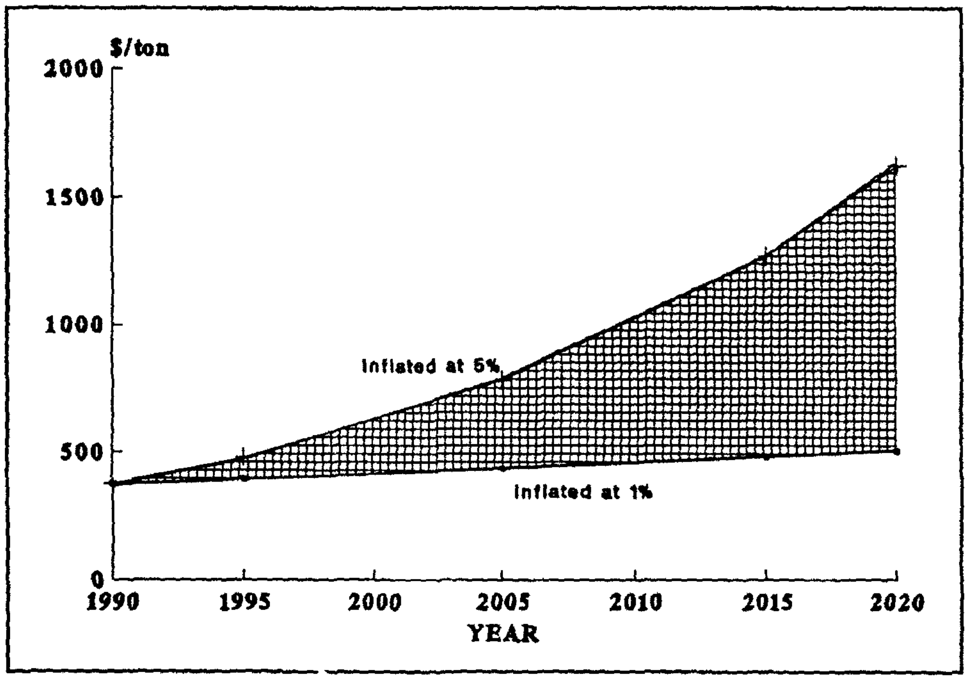

Figure 24. The Acceptability Envelope

The criterion to judge the success of using the liability factor would be whether the future value of $f_l P_d$ (i.e., the predicted cost of the liability for landfilling waste invested at a 6-percent rate) was within the envelope of inflated destruction costs; both landfilling and destruction costs would be equally affected by inflation.

Three different landfill ages were assumed for the test: new, 10 years, and 20 years, with initial deposition in the landfill occurring in 1990. Under the previous landfill liner failure assumptions, this implies there would be a 100-percent probability that the landfills would require remediation in the years 2115, 2005, and 1995, respectively. The inflation adjusted liability factors from Figure 23 were used in these tests. Table 4 summarizes the data verification.

Table 4.
Liability Factor Verification Testing

Failure Year	Liability Factor	$f_L P_d$	Value at Failure	P_d at Failure	Percent Error
1% Inflation					
2115	.322	$121	$518	$481	8%
2005	.521	$195	$468	$435	8%
1995	.845	$317	$424	$394	8%
2% Inflation					
2115	.405	$152	$652	$615	6%
2005	.595	$223	$535	$505	6%
1995	.875	$328	$439	$414	6%
3% Inflation					
2115	.510	$191	$821	$785	5%
2005	.679	$255	$610	$584	4%
1995	.905	$339	$454	$435	4%
4% Inflation					
2115	.639	$240	$1028	$1000	3%
2005	.773	$290	$695	$675	3%
1995	.936	$351	$470	$456	3%

Table 4. (con't)
Liability Factor Verification Testing

Failure Year	Liability Factor	$f_L P_d$	Value at Failure	P_d at Failure	Percent Error
5% Inflation					
2115	.800	$300	$1288	$1270	1%
2005	.880	$330	$791	$780	1%
1995	.967	$363	$485	$479	1%

As evidenced by the data in Table 4, as the inflation rate increases, the predicted liability cost becomes more accurate. Figure 25 shows the data superimposed over the acceptability envelope in Figure 24.

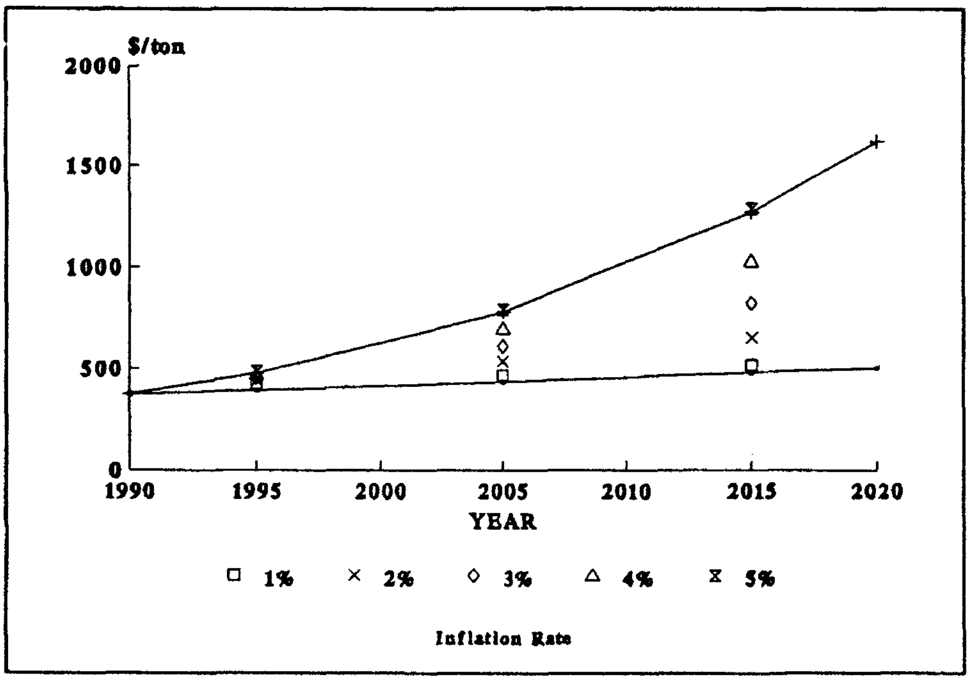

Figure 25. Projected vs. Inflated Destruction Costs

SECTION IX

CONCLUSIONS

There are a number of assumptions required in developing the model. The most significant assumptions and their potential impact on the utility of the liability factor are:

a. Due to advances in landfill design, the key factor in determining future liability costs for landfills will be the ultimate destruction of the waste. This assumption ignores the costs of waste removal, transportation, etc., during the remediation; however, if incurred, these costs will add to the expense, making the liability factor prediction conservative.

b. Landfill "failure" shall be determined by restrictions on the maximum and average leachate flow from the landfill. If the EPA takes a different track in promulgating the upcoming RCRA reauthorization, the only effect would be to extend/contract the time to failure. In this case, the liability factor analysis outlined herein will remain valid; however, the time to landfill failure may have to be adjusted.

c. Destruction cost increases (in excess of inflation) shall be balanced by cost decreases due to technological development. Although this is impossible to accurately predict, as with the effect of limiting the analysis to destruction costs, if the prices do increase, the net effect will be to underestimate the total long term liability, again leading to the liability factor being conservative.

The key to this analysis was the use of microeconomic principles to predict the total cost of landfilling hazardous waste. As shown in Figure 12, the magnitude of the negative externality in landfilling hazardous waste (P_s) is a cost over and above the actual tipping fee (P_l). Hence, the theoretical total cost of landfilling was the actual cost of the landfill, considered by the waste producer, plus the cost of the negative externality ($P_t = P_l + P_s$).

In terms of the liability factor, the total cost can also be written as $P_t = P_l + f_L P_d$. Combining these two equations leads to:

$$\mathbf{P_t = P_l + P_s = P_l + f_L P_d.}$$

In other words, the negative externality is equivalent to the liability factor prediction, or

$$\mathbf{P_s = f_L P_d.}$$

The importance of this equation is that the prediction of the social cost becomes independent of the landfill cost. Further, there are no limitations on the destruction cost variable. It can be the cost of any form of waste destruction, relocating waste at remediation to a different landfill, or even a pollution prevention technology. The only variable of concern is that of inflation. Given that most firms or individuals involved in business either have set guidelines or personal estimation techniques, predicting inflation can be left up to the investor. The only requirement is to select an inflation rate and enter the proper Figure 23 curve[43].

The liability factor is based in sound microeconomic theory and provides a number of advantages. First, transferring costs, either estimated or historical, from site to site (as currently practiced in liability estimation) is eliminated. Second, there is little doubt that the liability factor is conservative in that it could underestimate the total cost that a waste generator would face; however, this does not detract from its value. On the contrary, because of its conservative nature, there can be little technical or financial argument against using it in financial analysis. Third, because the factor was developed on a per unit basis, there is no scale factor that is common in many business decisions. Finally, the liability factor eliminates potential problems in regional cost variation and price differences due to the ability of firm's to negotiate.

While not the final answer to the problem of predicting future liability, the development of the liability factor represents a major step toward more accurate cost reflection. It provides waste producers an elegant, simple tool to use to obtain their share of limited resources and a valuable lever to force pollution prevention.

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[43] The inflation adjusted values for the liability factors are shown in Appendix 3.

SECTION X

SIGNIFICANCE OF RESEARCH

Given the stands taken by President Bush and EPA Administrator Reilly, there is little doubt that this country is moving directly toward pollution prevention from the regulatory viewpoint. Similarly, evidenced by the public opposition to new landfill sites, the general public also appears to give a great deal of support to this position. This research effort enables environmental personnel to assess the total cost of landfilling waste in pollution prevention strategies and make concrete, defensible decisions regarding the financial advantages and disadvantages of each option. Similarly, the liability factor can serve administrators in the EPA, landfill owners, etc., in defining the economic effect of various landfill pricing policies.

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APPENDICES

APPENDIX 1

Investment Comparison

Present Value:

While this paper does not allow for a complete treatise of the time value of money, it is useful to review the basics of the concept.[44] The importance of present value lies in the fact that time is money. What is the preference between a dollar now or a dollar a year from now? Obviously, the dollar in hand is preferred because it could earn interest. Because money can "work," at 5% interest, there is no difference between $.95 now and $1.00 in one year because they both have the same value at the present time.[45] Mathematically, this relationship is as follows:

$$P = \frac{F}{(1 + r)^n}$$

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[44]. For a more complete review including equal payment series, future value, etc., the reader is referred to any of a number of accounting texts such as Davidson, Stickney, and Weil, Financial Accounting, An Introduction to concepts, Methods, and Uses, Fifth Edition, Harcourt Brace Jovanovich, Publishers, 1988.

[45]. Economically, there is an additional factor at work in present value: pure time preference (or impatience) - Pearce and Turner, Economics of Natural Resources and the Environment, 1977, pg 213. However, this issue is generally ignored in business accounting in that the firm has no such emotions and opportunities can be measured in terms of pure financial return.

where P is the present value, F is the future value, r is the interest (or discount) rate, and n is the number of periods. In the above example, $1 in one year at 5% interest would have a computed present value of:

$$P = \frac{\$1.00}{(1 + 0.05)^1} = \$0.95$$

Similarly, if the $1 was to be received in 3 years, the present value would be:

$$P = \frac{\$1.00}{(1 + 0.05)^3} = \$0.86$$

In looking at either multiple payments or cash both into and out of a firm, the present values are additive. For example, at 5% interest, the present value of both $1 in one year and an additional $1 in 3 years would be $0.95 + $0.86 = $1.81. Similarly, if one was to receive $1 in one year, and pay $1 in 3 years the present value would be $0.95 - $0.86 = $0.09.

This allows both costs and benefits which are expended or earned in the future to be expressed at their current or present value. Besides being a method of evaluation in and of itself (Present Value of Net Benefits), Present Value is used in performing any of the normally used economic comparisons (benefit cost ratio, return on investment, etc.).

The Effects of Interest/Discount Rates

In determining the value of a pollution prevention project, the discount rate used becomes critical. If pollution prevention project benefits are accrued far into the future, or if a larger discount rate is used, the effect on the present value (and hence the apparent value of the pollution prevention project) can be dramatic. Figure A1 shows the relationship between percent of future worth regained over 12 years at varying interest rates.

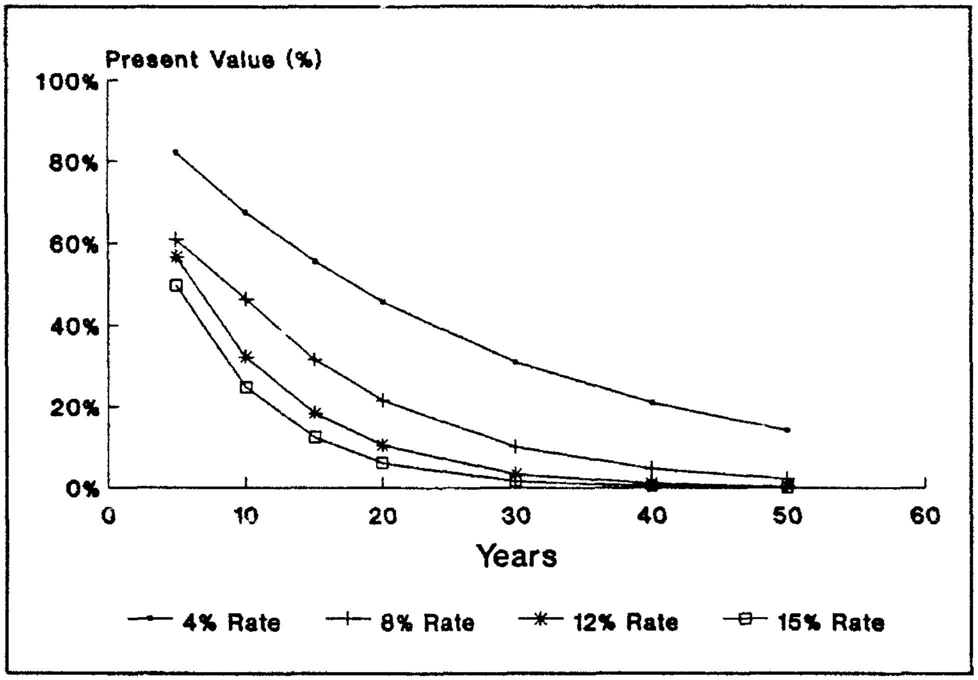

Figure A1. The Effect of Time on Present Value.

In that most companies prefer a return on investment (ROI) or hurdle rate in the range of 10-15% (the Federal Government uses a 10% standard), over half of the benefit stream can be lost due to the time value of money within the first 10 years.

Present Value of Net Benefits:

This method of financial comparison evaluates all benefits and costs at their current or present values over the life of the project being analyzed. If the net benefit (i.e., the benefits less costs) is greater than zero, the project is worth undertaking; if the net is less than zero, the project should be abandoned on a financial basis.

This technique is firmly grounded in microeconomic theory and is ideal for total cost analysis (TCA) and pollution prevention financial analysis. Even though it requires a preselected discount rate which can greatly discount long term benefits, it assures all costs/benefits over the entire life of the project are included in the analysis. Once the present value of all options with positive net values are known, the actual ranking of projects using this method is straight forward; those with the highest Present Value of Net Benefits would be funded first.

Payback Period:

This method is often used in the research and development arena. Conceptually, projects which return invested capital quickest are better investments. The technique for determining payback period again lies within present value;

however, instead of solving the present value equation for the present value (P), the cost and benefit cash flows are kept separate over time. The present values of the benefits are set equal to costs, and the equations are solved for time (t) at a given discount rate. Successive years' benefits and costs are brought back to present value until the net becomes zero. The time it takes for the benefits to outweigh the costs is a measure of the Payback Period. Ranking projects then becomes a matter of selecting the projects with the shortest payback period.

While some firms have gone to the point of establishing a minimum payback time standard, this method is not recommended for comparing investment options dealing with pollution prevention because of two factors. First, because the pollution prevention benefit stream generally extends far into the future, discounting makes its payoff period very long. Second, the highest costs and benefits associated with most environmental projects are generally due to catastrophic failure, also a far future event. Since the payback period analysis stops when the benefits and costs are equal, the projects with the shortest term cashflows will dominate. Hence, for a pollution prevention project, with a high discount rate, the long term costs/benefits may be so far into the future that they are not even competitive. In essence, the importance of life-cycle costing is lost in using this method because it only considers costs and benefits to the point where they balance, rather then over the entire life of the project.

Benefit/Cost Ratio:

Again, the present values of the benefits and costs are kept separate and expressed in one of two ways. First, there is the pure benefit/cost ratio which implies that if the ratio is greater than 1, the benefits outweigh the costs and the project is acceptable. Second, there is the net ratio which is the net benefit (i.e. benefits less costs) divided by the costs. In this latter case, the decision criteria is that the benefits must outweigh the costs, which means the net ratio must be greater than zero (e.g., if the benefits exactly equaled the costs, the net B/C ratio would be zero). In both cases, the highest B/C ratios are considered as the best projects.

There is a potential for altering the actual ratios using this method. For example, if the present value of a project's benefits was $100 and costs were $60, the B/C ratio would be $100/$60 or 1.67. If, however, the proponent of the project were to reassess the project and declare that some of the costs were not "true" costs, but instead simply cffsets to benefits, then the ratio could be changed considerably. In our above example, if $50 of the $60 total cost was for waste disposal, and $70 of the $100 in benefits was due to waste minimization, then one could use them to offset each other.

Under this line of thinking both the numerator and denominator of the ratio could be reduced by $50 with the following effect: ($100 - $50) / ($60 - $50) = 5.0. Hence, without changing the project, the new B/C ratio would make the project seem to be considerably better.

Internal Rate of Return:

Again, this method is based in the net present value of benefits and costs; however, it does not use a predetermined discount rate. Computationally, the present value equation is solved for the discount rate (r), given equal benefits and costs over the life of the project. In other words, what discount rate yields a net present value of zero, given the stream of benefits and costs over time? The discount rate that satisfies the zero benefit is the rate of return on the investment and project selection is based on the highest rate. Although this method is frequently used in business, the net benefits and costs must be determined for each time period and brought back to present value separately. Computationally, this could mean dealing with a large number of simultaneous equations.

Appendix 2

Example Liability Factor Calculations

Each point on the line in Figure 15 represents a liability factor function. The computations combine the probability curve shown in Figure 13, expected value, and present worth factors at the selected discount rate of 6% for landfill ages from 0 years (i.e., a new landfill) through 25 years. The formulas used for calculations in the following tables are:

Present Value Factor = PV Factor = $(1+r)^n$
r = discount rate = 6%
n = number of years till failure

Risk Factor = probability of failure in specified year at the given landfill age. For example, if the landfill was new, there would be a 2% chance of failure in 21 years, 14% in 22 years, 34% in 23 years, etc.

Expected Value = (present value factor) * (risk factor)

Liability Factor = sum of expected values

The resulting liability factor (f_L) for the given landfill ages, when multiplied by the cost of waste destruction, would represent the present value of the future destruction cost (i.e., P_d from Figure 15 - the social cost of disposing of the waste in the landfill.)

		Landfill age = 0		Landfill Age 1 yr	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Liability Factor
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0.02	0.006236
21	0.294155	0.02	0.005883	0.14	0.041181
22	0.277505	0.14	0.038850	0.34	0.094351
23	0.261797	0.34	0.089011	0.34	0.089011
24	0.246978	0.34	0.083972	0.14	0.034576
25	0.232998	0.14	0.032619	0.02	0.004659
26	0.219810	0.02	0.004396	0	0
	Liability Factor =		0.254733		0.270017

		Landfill age = 2 yrs		Landfill Age 3 yrs	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Liability Factor
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0.02	0.007006
19	0.330513	0.02	0.006610	0.14	0.046271
20	0.311804	0.14	0.043652	0.34	0.106013
21	0.294155	0.34	0.100012	0.34	0.100012
22	0.277505	0.34	0.094351	0.14	0.038850
23	0.261797	0.14	0.036651	0.02	0.005235
24	0.246978	0.02	0.004939	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.286218		0.303391

Year	PV Factor	Landfill age = 4 yrs Risk Factor	Expected Value	Landfill Age 5 yrs Risk Factor	Liability Factor
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0.02	0.007872
17	0.371364	0.02	0.007427	0.14	0.051991
18	0.350343	0.14	0.049048	0.34	0.119116
19	0.330513	0.34	0.112374	0.34	0.112374
20	0.311804	0.34	0.106013	0.14	0.043652
21	0.294155	0.14	0.041181	0.02	0.005883
22	0.277505	0.02	0.005550	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.321595		0.340891

Year	PV Factor	Landfill age = 6 yrs Risk Factor	Expected Value	Landfill Age 7 yrs Risk Factor	Liability Factor
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0.02	0.008846
15	0.417265	0.02	0.008345	0.14	0.058417
16	0.393646	0.14	0.055110	0.34	0.133839
17	0.371364	0.34	0.126263	0.34	0.126263
18	0.350343	0.34	0.119116	0.14	0.049048
19	0.330513	0.14	0.046271	0.02	0.006610
20	0.311804	0.02	0.006236	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.361344		0.383025

		Landfill age = 8 yrs		Landfill Age 9 yrs	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Liability Factor
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0.02	0.009939
13	0.468839	0.02	0.009376	0.14	0.065637
14	0.442300	0.14	0.061922	0.34	0.150382
15	0.417265	0.34	0.141870	0.34	0.141870
16	0.393646	0.34	0.133839	0.14	0.055110
17	0.371364	0.14	0.051991	0.02	0.007427
18	0.350343	0.02	0.007006	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.406006		0.430367

		Landfill age = 10 yrs		Landfill Age 11 yrs	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Liability Factor
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0.02	0.011167
11	0.526787	0.02	0.010535	0.14	0.073750
12	0.496969	0.14	0.069575	0.34	0.168969
13	0.468839	0.34	0.159405	0.34	0.159405
14	0.442300	0.34	0.150382	0.14	0.061922
15	0.417265	0.14	0.058417	0.02	0.008345
16	0.393646	0.02	0.007872	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.456189		0.483560

		Landfill age = 12 yrs		Landfill Age 13 yrs	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Liability Factor
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0.02	0.012548
9	0.591898	0.02	0.011837	0.14	0.082865
10	0.558394	0.14	0.078175	0.34	0.189854
11	0.526787	0.34	0.179107	0.34	0.179107
12	0.496969	0.34	0.168969	0.14	0.069575
13	0.468839	0.14	0.065637	0.02	0.009376
14	0.442300	0.02	0.008846	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.512574		0.543328

Year	PV Factor	Landfill age = 14 yrs Risk Factor	 Expected Value	Landfill Age 15 yrs Risk Factor	 Liability Factor
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0.02	0.014099
7	0.665057	0.02	0.013301	0.14	0.093107
8	0.627412	0.14	0.087837	0.34	0.213320
9	0.591898	0.34	0.201245	0.34	0.201245
10	0.558394	0.34	0.189854	0.14	0.078175
11	0.526787	0.14	0.073750	0.02	0.010535
12	0.496969	0.02	0.009939	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.575928		0.610483

Year	PV Factor	Landfill age = 16 yrs Risk Factor	Expected Value	Landfill Age 17 yrs Risk Factor	Liability Factor
1	0.943396	0	0	0	0
2	0.889996	0	0	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0.02	0.015841
5	0.747258	0.02	0.014945	0.14	0.104616
6	0.704960	0.14	0.098694	0.34	0.239686
7	0.665057	0.34	0.226119	0.34	0.226119
8	0.627412	0.34	0.213320	0.14	0.087837
9	0.591898	0.14	0.082865	0.02	0.011837
10	0.558394	0.02	0.011167	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.647112		0.685939

		Landfill age = 18 yrs		Landfill Age 19 yrs	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Liability Factor
1	0.943396	0	0	0	0
2	0.889996	0	0	0.02	0.017799
3	0.839619	0.02	0.016792	0.14	0.117546
4	0.792093	0.14	0.110893	0.34	0.269311
5	0.747258	0.34	0.254067	0.34	0.254067
6	0.704960	0.34	0.239686	0.14	0.098694
7	0.665057	0.14	0.093107	0.02	0.013301
8	0.627412	0.02	0.012548	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.727096		0.770721

		Landfill age = 20 yrs			Landfill Age 21 yrs	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Liability Factor
1	0.943396	0.02	0.018867	0.16	0.150943
2	0.889996	0.14	0.124599	0.34	0.302598
3	0.839619	0.34	0.285470	0.34	0.285470
4	0.792093	0.34	0.269311	0.14	0.110893
5	0.747258	0.14	0.104616	0.02	0.014945
6	0.704960	0.02	0.014099	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.816965		0.864851

		Landfill age = 22 yrs		Landfill Age 23 yrs	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Liability Factor
1	0.943396	0.50	0.471698	0.84	0.792452
2	0.889996	0.34	0.302598	0.14	0.124599
3	0.839619	0.14	0.117546	0.02	0.016792
4	0.792093	0.02	0.015841	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.907685		0.933844

		Landfill age = 24 yrs		Landfill Age 25 yrs	
Year	PV Factor	Risk Factor	Expected Value	Risk Factor	Liability Factor
1	0.943396	0.98	0.924528	1.00	0.943396
2	0.889996	0.02	0.017799	0	0
3	0.839619	0	0	0	0
4	0.792093	0	0	0	0
5	0.747258	0	0	0	0
6	0.704960	0	0	0	0
7	0.665057	0	0	0	0
8	0.627412	0	0	0	0
9	0.591898	0	0	0	0
10	0.558394	0	0	0	0
11	0.526787	0	0	0	0
12	0.496969	0	0	0	0
13	0.468839	0	0	0	0
14	0.442300	0	0	0	0
15	0.417265	0	0	0	0
16	0.393646	0	0	0	0
17	0.371364	0	0	0	0
18	0.350343	0	0	0	0
19	0.330513	0	0	0	0
20	0.311804	0	0	0	0
21	0.294155	0	0	0	0
22	0.277505	0	0	0	0
23	0.261797	0	0	0	0
24	0.246978	0	0	0	0
25	0.232998	0	0	0	0
26	0.219810	0	0	0	0
	Liability Factor =		0.942328		0.943396

Appendix 3

Inflation Adjusted Liability Factors

Each point on the line in Figure 21 represents a liability factor function adjusted for a selected inflation rate. As before, the computations combine the probability curve shown in Figure 13, expected value, and present worth factors at the selected discount rate of 6% for landfill ages from 0 years (i.e., a new landfill) through 25 years, but they also include an inflation factor. The formulas used are:

Present Value Factor = PV Factor = $(1+r)^n$
  r = discount rate = 6%
  n = number of years to failure

Risk Factor = probability of failure in specified year at the given landfill age. For example, if the landfill was new, there would be a 2% chance of failure in 21 years, 14% in 22 years, 34% in 23 years, etc.

Inflation Factor = $(1 + i)^m$
  i = inflation rate
  m = number of years to failure

Expected Value = (present value factor) * (risk factor)

Liability Factor = sum of expected values

As before, the resulting liability factor (f_L) is multiplied by the cost of waste destruction to represent P_d in Figure 15 - the inflation adjusted social cost of disposing of the waste in the landfill. The choice of the inflation rate is left up to the discretion of the user.

Example Calculations for a New Landfill (i.e., age = 0) with 3% Inflation

Year	PV Factor	Risk Factor	Inflation Factor	Expected Value
1	0.943396	0	1.03	0
2	0.889996	0	1.06	0
3	0.839619	0	1.09	0
4	0.792093	0	1.13	0
5	0.747258	0	1.16	0
6	0.704960	0	1.19	0
7	0.665057	0	1.23	0
8	0.627412	0	1.27	0
9	0.591898	0	1.31	0
10	0.558394	0	1.35	0
11	0.526787	0	1.39	0
12	0.496969	0	1.43	0
13	0.468839	0	1.47	0
14	0.442300	0	1.52	0
15	0.417265	0	1.56	0
16	0.393646	0	1.60	0
17	0.371364	0	1.65	0
18	0.350343	0	1.70	0
19	0.330513	0	1.75	0
20	0.311804	0	1.81	0
21	0.294155	0.02	1.86	0.01
22	0.277505	0.14	1.92	0.07
23	0.261797	0.34	1.97	0.18
24	0.246978	0.34	2.03	0.17
25	0.232998	0.14	2.09	0.07
26	0.219810	0.02	2.16	0.01
			Liability Factor =	0.51

Comparing this value, 0.51, to the initial liability factor (i.e., zero inflation), 0.255, can show the magnitude of the effects of inflation.

If similar calculations for all other age landfills and inflation rates of 0 - 7 percent were done, the results would be as shown below and as expressed by Figure 21.

Liability Factors for Landfills of Various Ages and 0% - 7% Inflation

Age	0%	1%	2%	3%	4%	5%	6%	7%
0	.255	.322	.405	.510	.639	.800	1.0	1.247
1	.270	.338	.421	.524	.652	.808	1.0	1.235
2	.286	.354	.438	.540	.664	.816	1.0	1.224
3	.303	.372	.455	.555	.677	.823	1.0	1.212
4	.322	.390	.473	.572	.690	.831	1.0	1.201
5	.341	.410	.491	.588	.703	.839	1.0	1.190
6	.361	.430	.510	.605	.717	.847	1.0	1.179
7	.383	.451	.531	.623	.730	.855	1.0	1.168
8	.406	.473	.551	.641	.744	.863	1.0	1.157
9	.430	.497	.573	.660	.759	.872	1.0	1.146
10	.456	.521	.595	.679	.773	.880	1.0	1.135
11	.484	.547	.619	.699	.788	.888	1.0	1.125
12	.513	.574	.643	.719	.803	.897	1.0	1.114
13	.543	.603	.668	.740	.819	.905	1.0	1.104
14	.576	.633	.694	.762	.835	.914	1.0	1.093
15	.610	.664	.722	.784	.851	.923	1.0	1.083
16	.647	.697	.750	.807	.867	.931	1.0	1.073
17	.686	.731	.779	.803	.884	.940	1.0	1.063
18	.727	.768	.810	.854	.901	.949	1.0	1.053
19	.771	.806	.842	.879	.918	.958	1.0	1.043
20	.817	.845	.875	.905	.936	.967	1.0	1.033
21	.865	.866	.908	.931	.953	.976	1.0	1.024
22	.908	.923	.938	.953	.969	.984	1.0	1.016
23	.934	.945	.956	.967	.978	.989	1.0	1.011
24	.942	.952	.962	.971	.981	.990	1.0	1.010
25	.943	.953	.962	.972	.981	.991	1.0	1.009

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Canadian Contribution to the 1991 United Nations Round Robin Analytical Verification Exercise.

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D'Agostino, P.A., Hancock, J.R., Boulet, C.A., Provost, L.R., Lough, C.E., Hicken, R.P. Hansen, A.S.

5. DATE OF PUBLICATION (month and year of publication of document)

March 1993

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)

61

6b. NO. OF REFS (total cited in document)

3

6. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

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Nine samples, typical of those taken during inspection of a military facility, were received by Defence Research Establishment Suffield as part of a United Nations sponsored international round robin analytical exercise designed to evaluate laboratory capabilities. This report summarizes Canada's contribution to the round robin analytical verification exercise. Canada confirmed the presence of all the spiked CW relevant compounds, including mustard and mustard related compounds following analysis of the provided samples by capillary column GC-MS, GC-MS/MS, GC-FTIR, GC-FID and GC-FPD.

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Chemical Agent Detection
Mustard
H-Agents
Mass Spectrometry
Tandem Mass Spectrometry
Gas Chromatography
Fourier Transform Infrared

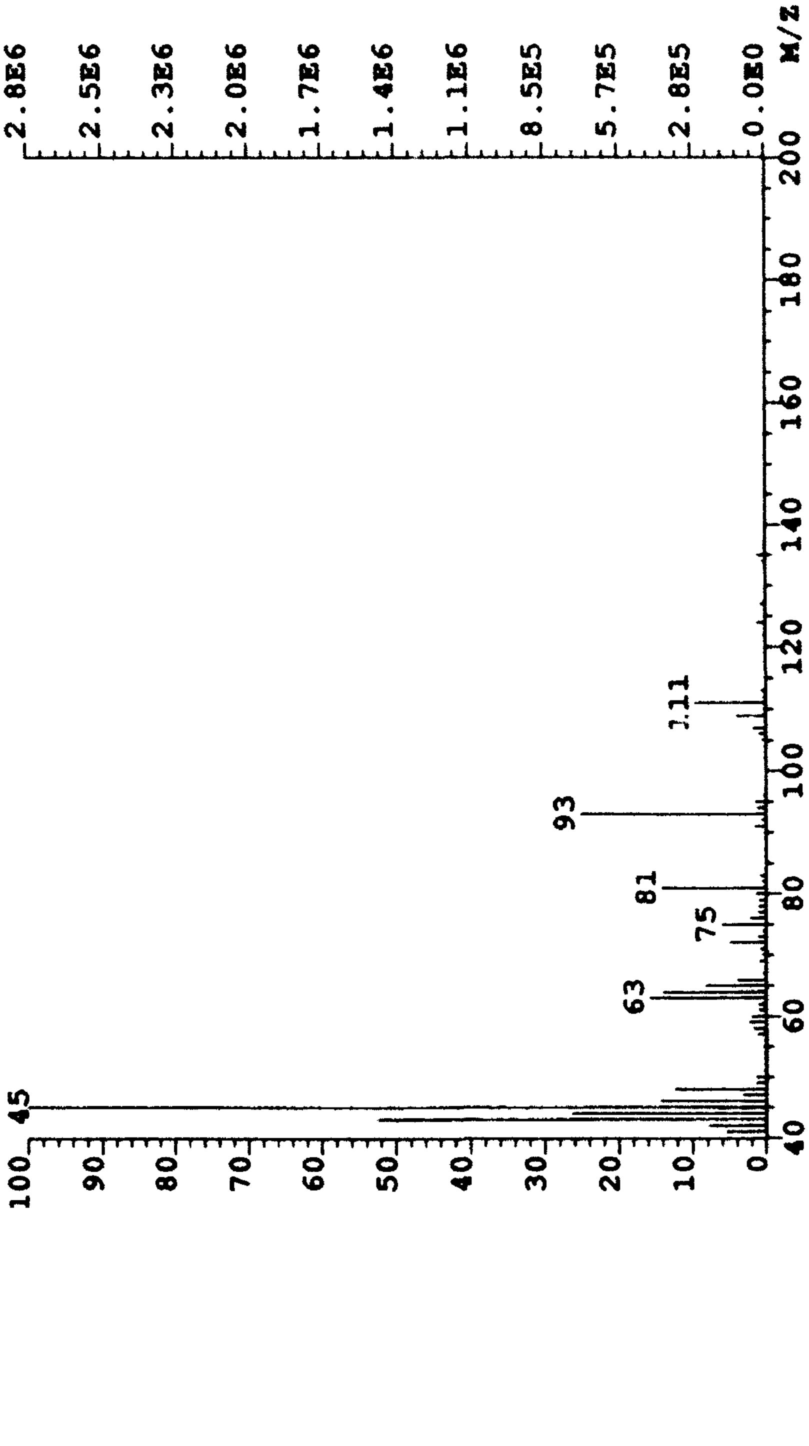

Figure A5: EI mass spectrum of thiodiglycol sulfone.

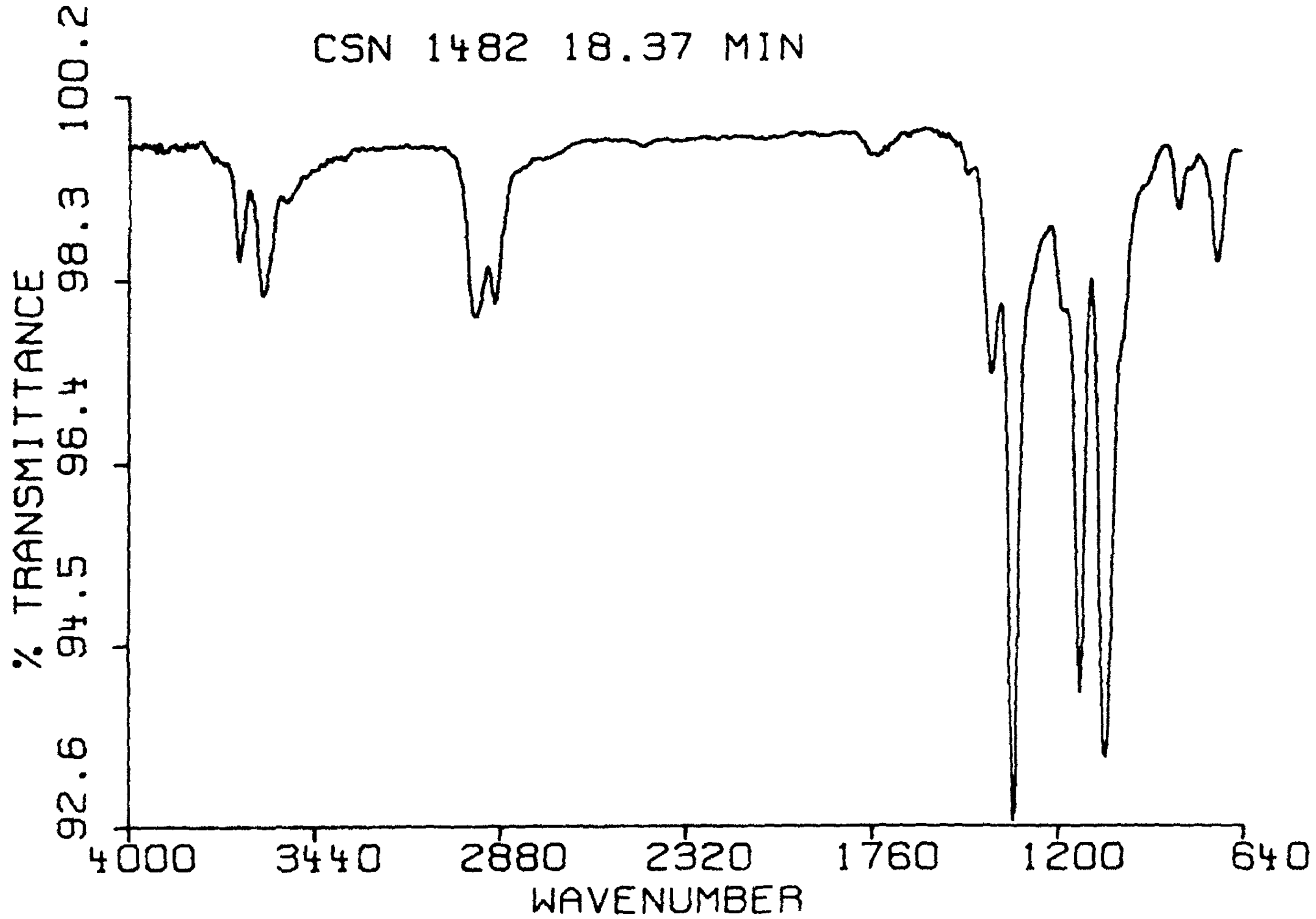

Figure A4: **FTIR** spectrum (gas phase) of thiodiglycol sulfone.

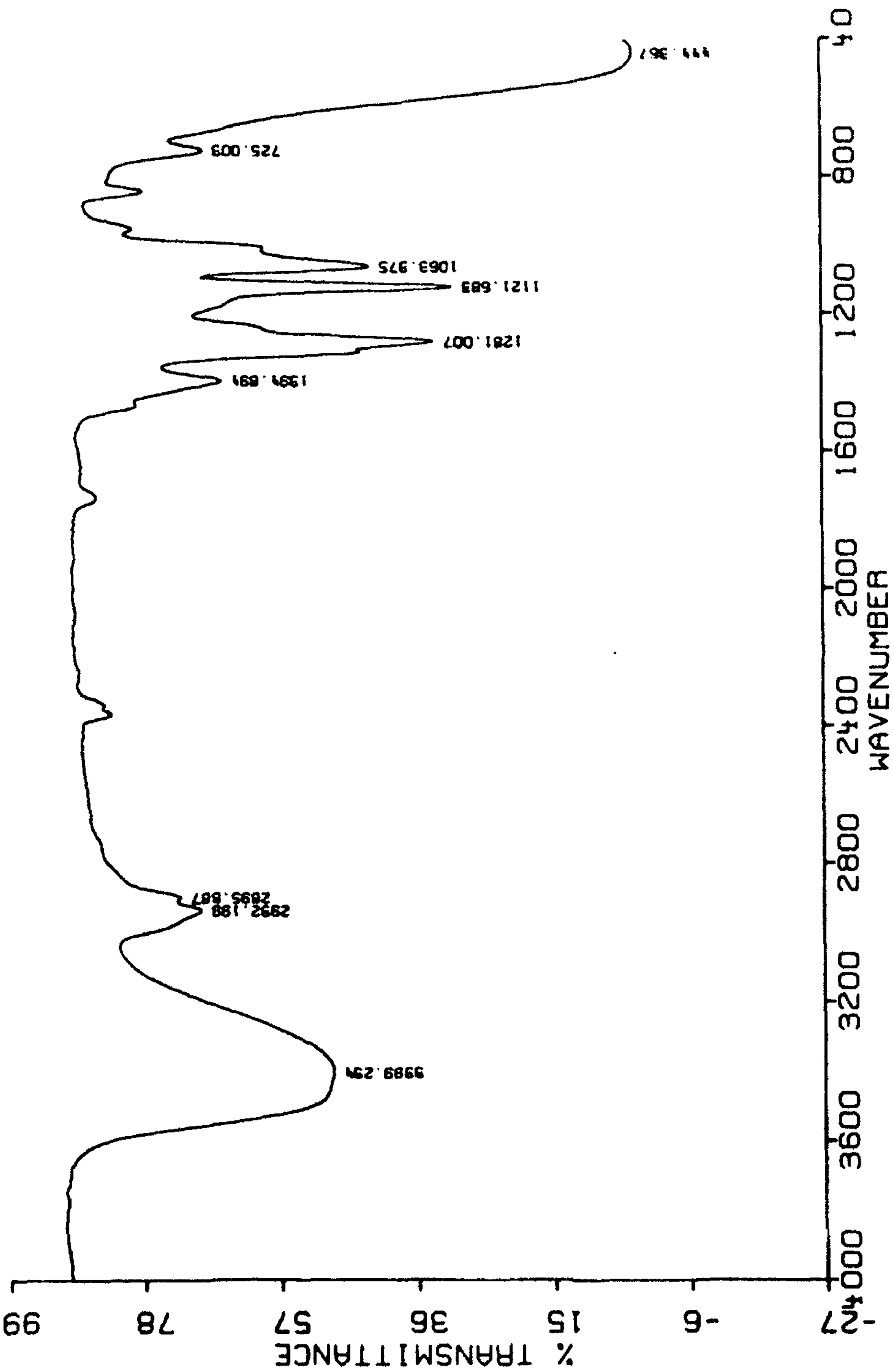

Figure A3: Fourier transform infra-red (FTIR) spectrum (thin film) of thiodiglycol sulfone.

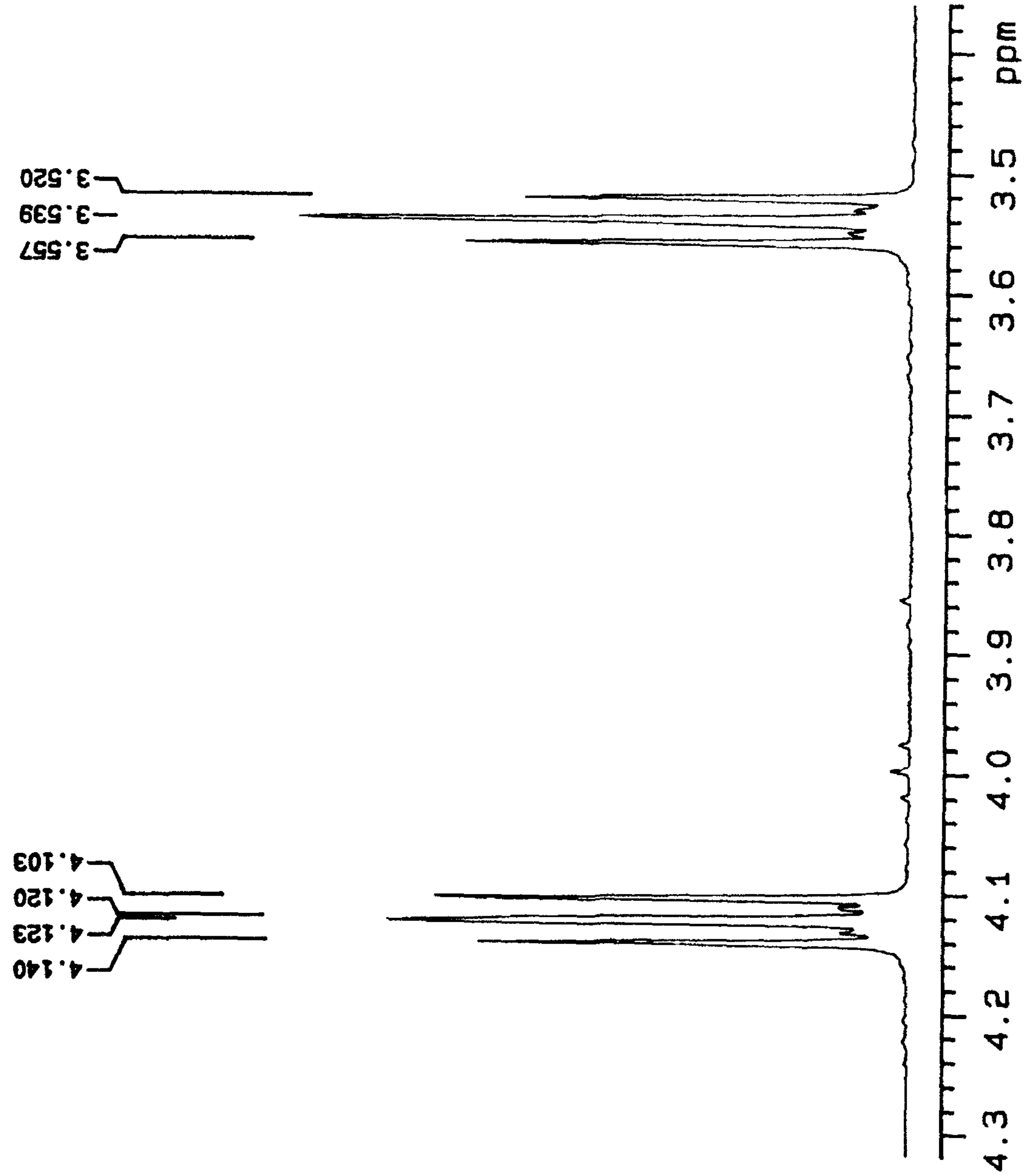

Figure A2: Expansion of the 4.6 - 2.6 ppm region of Figure A1.

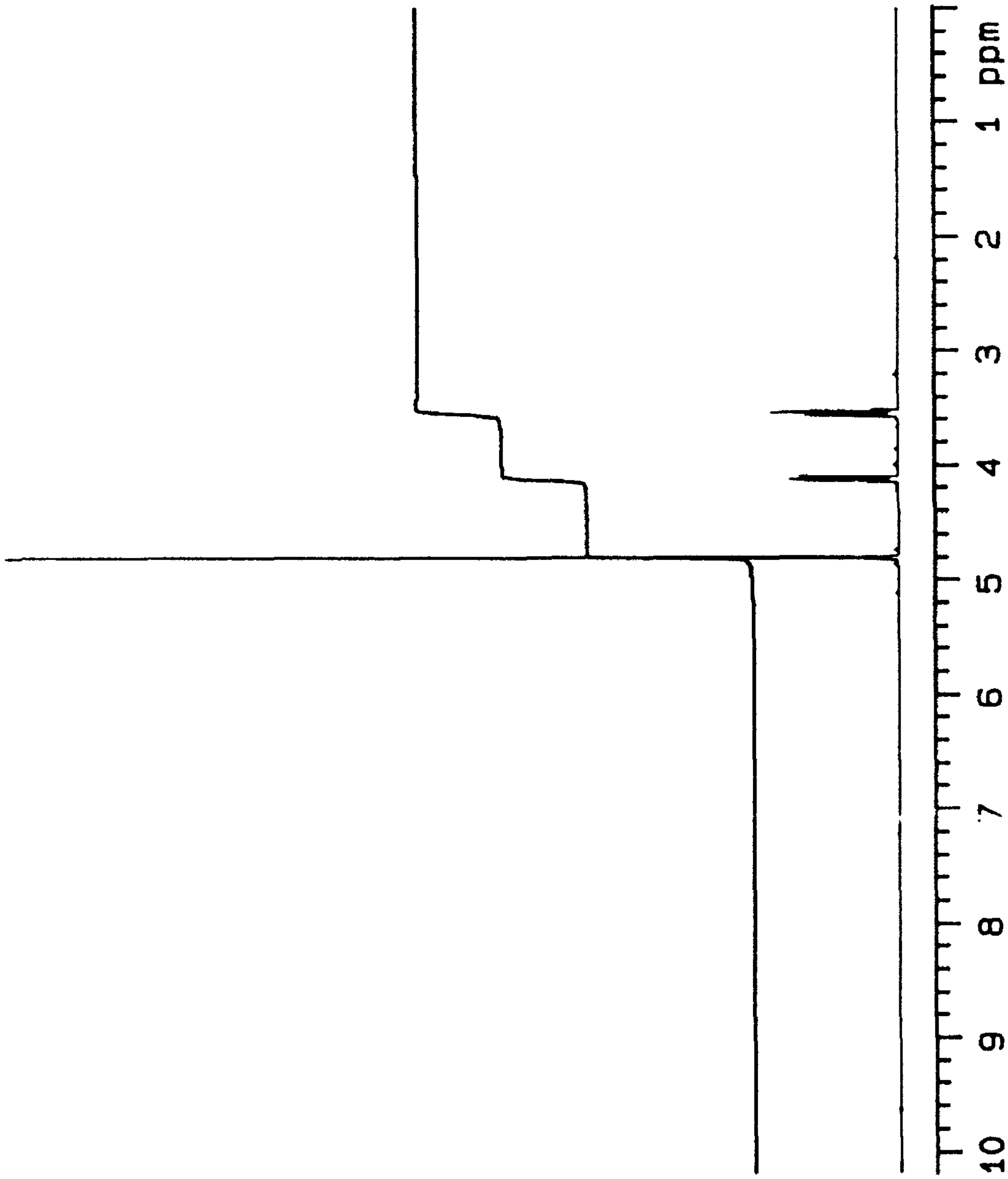

Figure A1: Proton nuclear magnetic resonance spectrum of thiodiglycol sulfone.

(starch paper) was obtained. The solid was filtered off and the filtrate was concentrated under reduced pressure to give a clear, viscous oil. The product was dried overnight under high vacuum to give 0.55 g of a viscous oil; ^{13}C NMR (δ, ppm): 56.93, 55.68. Other spectroscopic data (^{1}H NMR, FTIR) are given in Figures A1-A5.

Instrumental Conditions

GC-MS and GC-FTIR instrumental conditions are given in the experimental section of the main text.

NMR Conditions		
NMR Spectrometer	Varian VXR 300	
Nucleus	^{1}H	^{13}C
Frequency (Hz)	299.429	75.429
Acquisition Time (s)	3.744	1.815
Spectral Width (Hz)	4000	16000
Pulse Width (μsec)	7	8.7
NT	16	256
Solvent/Reference	D_2O/δ 4.8 (D_2O)	D_2O/δ 67.40 (dioxane)
Temperature (°C)	25	25

ANNEX A

SYNTHESIS AND REFERENCE SPECTROSCOPIC DATA OF THIODIGLYCOL SULFONE

THIODIGLYCOL SULFONE

Registry Number:	2580-77-0
Molecular Formula:	$C_4 H_{10} O_4 S$
Chemical Abstract Name:	2,2'-sulfonylbisethanol
Other Names:	Ethanol, 2,2'-sulfonyldi-; Bis(2-hydroxyethyl) sulfone; β,β'-Dihydroxy ethyl sulfone; Bis(β-hydroxyethyl) sulfone; β-Hydroxyethyl sulfone; 2,2'-Sulfonyldiethanol; Sulfonyldiethanol.
Structure	$HOCH_2CH_2SO_2CH_2CH_2OH$

EXPERIMENTAL

Preparation

Thiodiglycol sulfone was prepared from thiodiglycol sulfoxide and hydrogen peroxide using the procedure of Rheinboldt and Giesbrecht.[1] Thiodiglycol sulfoxide (1 g, 7 mmol) was dissolved in acetone and hydrogen peroxide (32%, 15 mL) was added slowly at room temperature. The reaction mixture was then heated to 50° for 1 hour. The crude reaction mixture was treated with saturated aqueous sodium sulfite until a negative test for peroxide

[1] H. Rheinboldt and E. Giesbrecht, *J. Am. Chem Soc.*, 68, 973, **1946**.

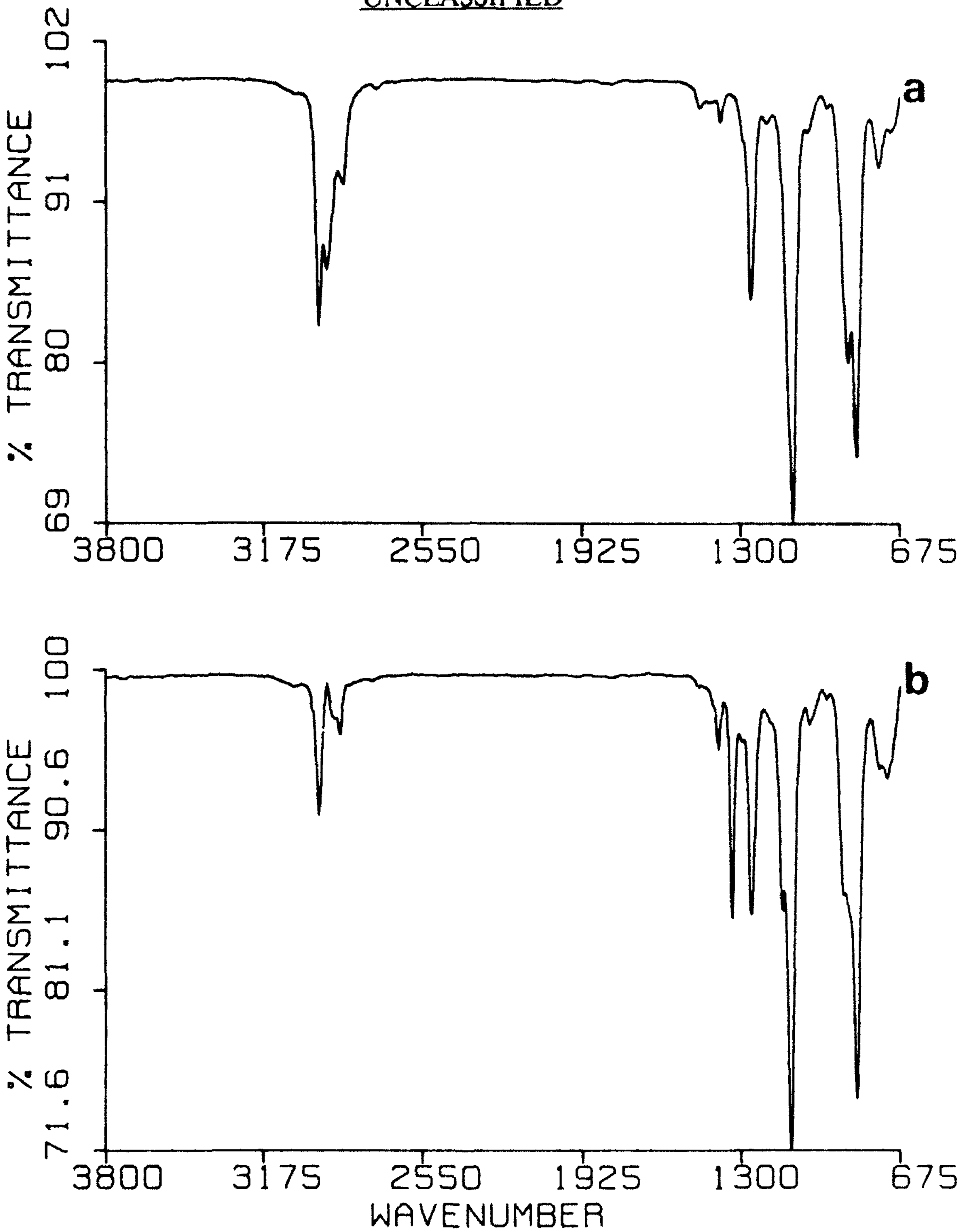

Figure 34: FTIR spectra of a) di-TMS derivative of thiodiglycol and b) di-TMS derivative of thiodiglycol sulfone (found in C47 and C48).

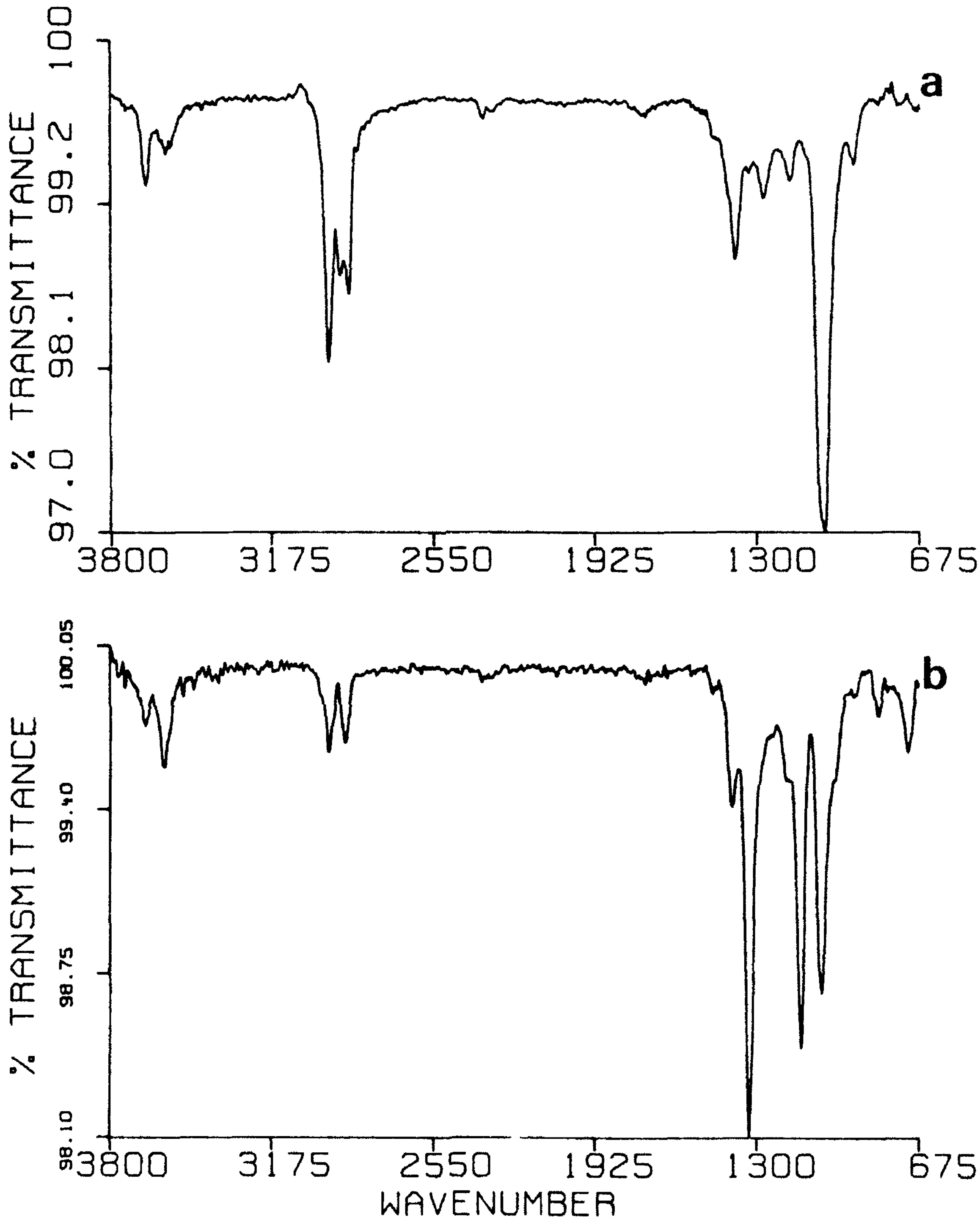

Figure 33: FTIR spectra of a) thiodiglycol and b) thiodiglycol sulfone (found in C47 and C48).

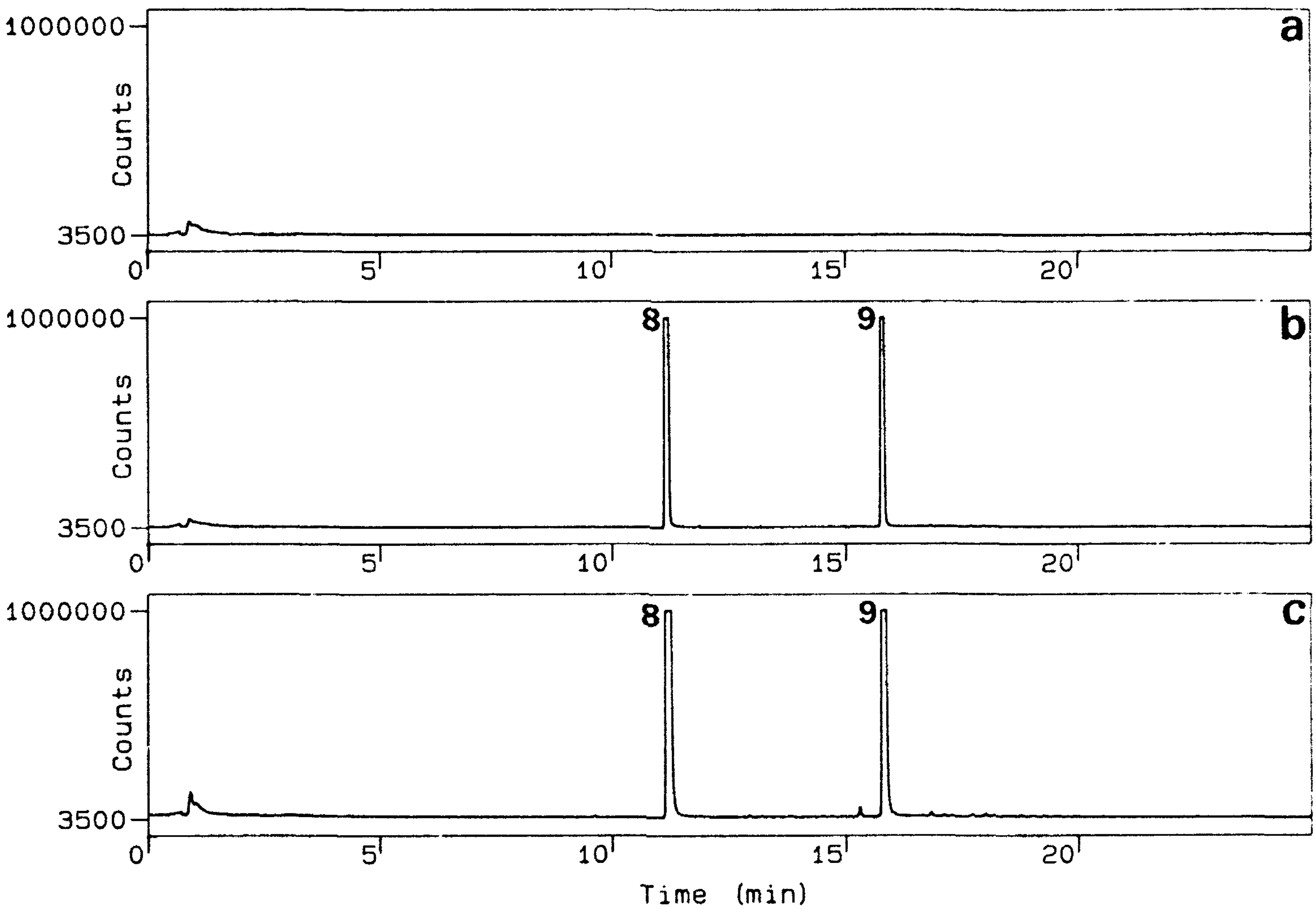

Figure 32: Capillary column GC-FPD (sulfur mode) chromatogram of trimethylsilylated acetonitrile extract of a) C46, b) C47 and c) C48 concrete samples. Numbered components are listed in Table I.

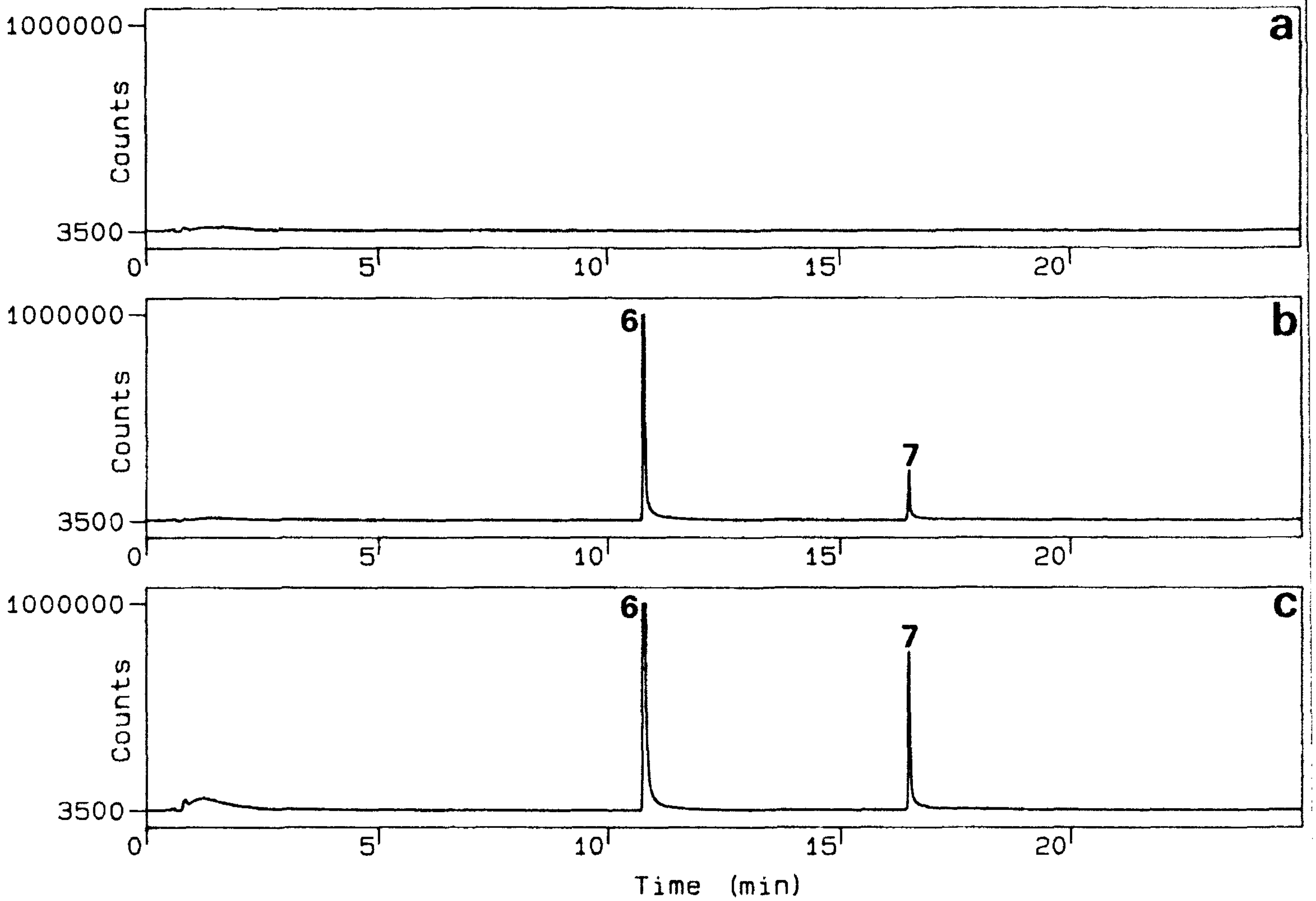

Figure 31: Capillary column GC-FPD (sulfur mode) chromatogram of the acetonitrile extract of a) C46, b) C47 and c) C48 concrete samples. Numbered components are listed in Table I.

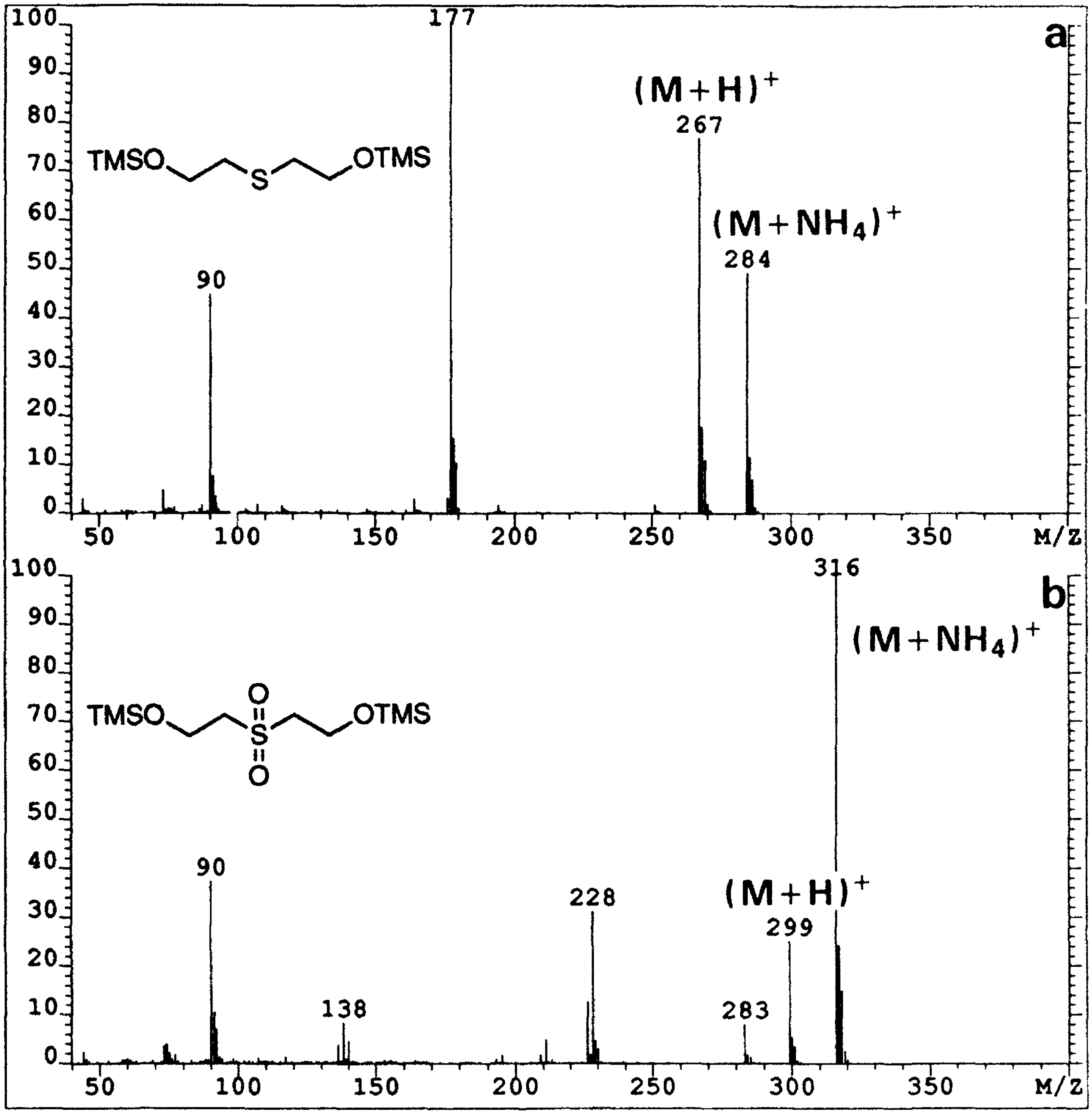

Figure 30: Ammonia chemical ionization mass spectra of a) di-TMS derivative of thiodiglycol and b) di-TMS derivative of thiodiglycol sulfone (found in C47 and C48).

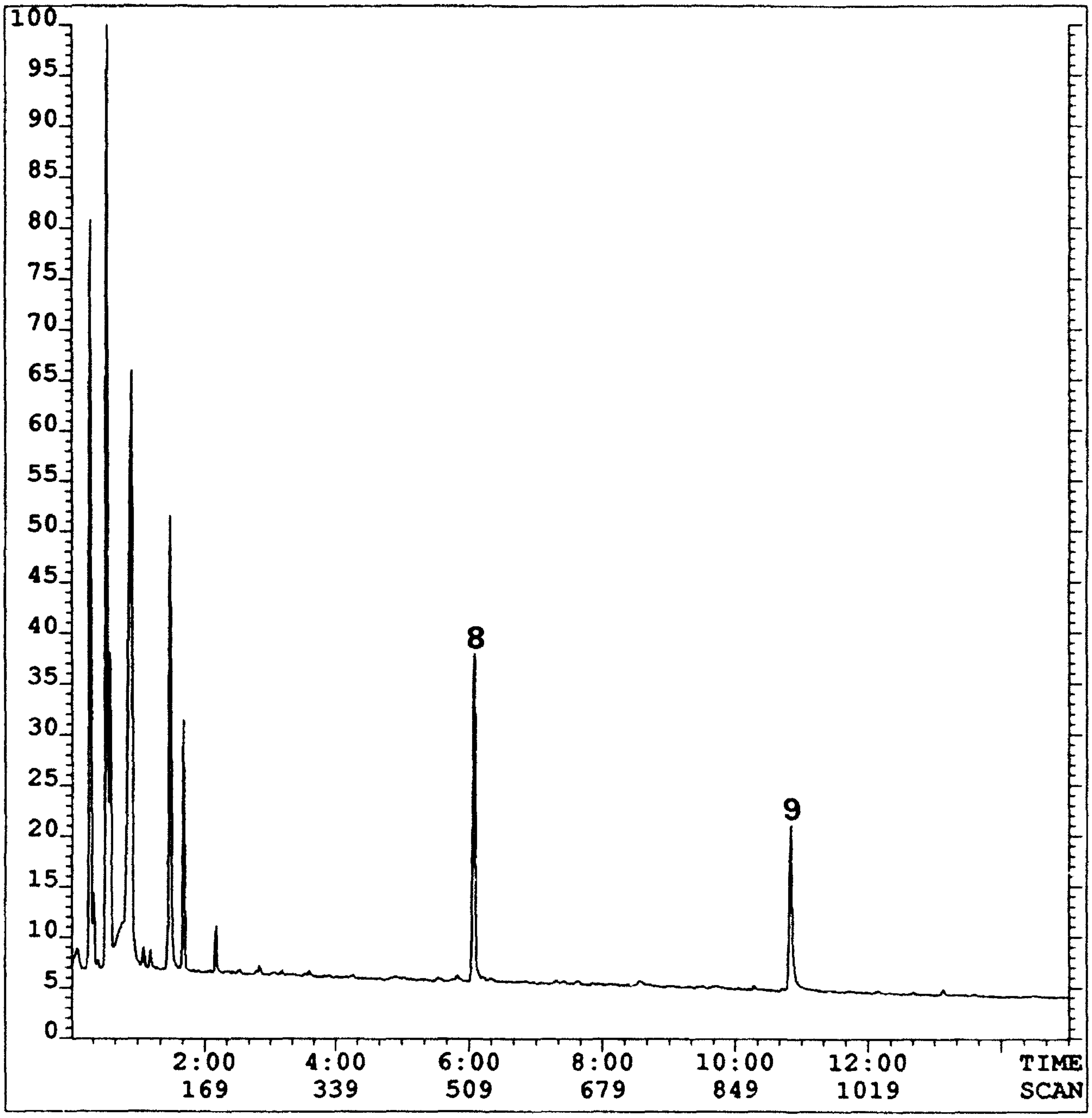

Figure 29: Capillary column GC-MS (ammonia CI) total-ion-current (400 to 60 u) chromatogram of trimethylsilylated acetonitrile extract of C48 concrete sample. Numbered components are listed in Table I.