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A POLICY ANALYSIS MODEL FOR THE EVALUATION OF DIOXIN
DIOXIN REGULATIONS IN MICHIGAN

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A POLICY ANALYSIS MODEL FOR THE EVALUATION OF DIOXIN REGULATIONS IN MICHIGAN

By

Erich Peter Ditschman

A THESIS

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ABSTRACT

A POLICY ANALYSIS MODEL FOR THE
EVALUATION OF DIOXIN REGULATIONS IN MICHIGAN

By

Erich Peter Ditschman

A policy analysis model using the economic concept of "optimality," is used to assess Michigan's dioxin policy by evaluating potential private costs to the pulp and paper industry and the social benefits of decreased risk to adverse effects of dioxin contaminated surface water. Mead Corporation's Escanaba integrated mill and the Delta County fish eating population are used to illustrate the model. Three different bioconcentration factors are used to evaluate Michigan Department of Natural Resource's water quality based effluent limits and Michigan Department of Public Health's health advisory triggers. Three willingness to pay values were used along with mill abatement costs to derive a total cost of pollution. Results indicate that the current effluent limit of 0.022 parts per quadrillion for the Mead mill is not pareto optimal; it places an undue burden upon the mill at a cost that society is unwilling to pay.

ACKNOWLEDGEMENTS

Phew! The acknowledgement page. The thesis committee agrees, friends and family are elated, and there may be time on the horizon to read a novel. I would not be able to write an acknowledgement page if it were not for the support, suggestions and criticisms provided by my circle of friends. The encouragement I received and the fortitude I desired, emanated from those with whom I share space: my circle of friends. There are a few within this circle that deserve more gratitude than this page can provide. However, this page, along with a heartfelt thank you, will have to suffice. Eckhart Dersch, thank you for inspiring me to look critically at existing policy in an effort to derive creative answers to societal problems. Darrell King, thank you for your patience and for demonstrating to me on a regular basis that everything is truly connected to everything else. Tom Edens, you were there from inception to publication; thank you for your insight, oversight, and daily support. And, to Andria Moore Ditschman, your critique of this thesis was invaluable. Without your love, support, and critical mind, I'd probably be a bum, or at least less one masters degree - thank you.

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CHAPTER ONE: INTRODUCTION

1.1 *The Policy Making Environment*

Regulating toxic substances is similar to spending a day at a three ring circus. In one ring, scientific professionals measure, analyze and conjecture truth and justice in an attempt to explain the risks associated with the toxins in people's daily lives. At the opposite end, in a dimly lit ring, federal and state regulatory agencies juggle platitudes from industry, environmental interest groups, and the scientific community such as "The discharges contribute to a pollution that leads to birth defects, cancer, respiratory problems and death" (Port Huron *Times Herald*, 8 April 1990), "What we are resisting is the attempt to impose discharge limits that are unrealistically low" (Onstream, 1989), and "Cabbage and broccoli contain a chemical whose breakdown products behave in the body in much the same way as dioxin, one of the most feared industrial contaminants" (University of California, 1990).

In the center ring, the main attraction, surrounded by high intensity spotlights, are the ace reporters who excite, bemuse, and befuddle the unsuspecting audience with explosive headlines, "Paper Mill Dioxin Pose Threat, EPA: Eating fish from downstream raises cancer risk," (Port Huron *Times Herald*, 1 May 1990) colorful placards reading, "Dioxins: Dancing with Death," (Port Huron *Times Herald*, 8 April 1990) and flaming editorials, "Dioxin: Oops Never Mind" (*Detroit News*, 10 June 1990).

This is the policy making environment in which government agency personnel must develop policies to regulate toxic substances. Risk managers[1] base the creation of policy on science, public perception and political climate. At any time during the policy making process any one of these three factors may be weighted differently, with the resulting policy having very real impacts. Risk managers must have information concerning the magnitude of these impacts if they are to develop and implement policies that maximize the health, welfare, and safety of society.

This research develops a policy analysis model that can be used to examine the impacts of regulating toxic substances in surface water. The model is rooted in pollution cost theory, which accounts for the costs to industry of abating pollution as well as the costs society incurs from exposure to pollution. **First**, using the flow rate of a river and the concentration and discharge rate of an industrial effluent, an amount of toxin in fish is calculated. **Second**, estimates of damages suffered by a population from consuming toxin tainted fish are made. **Third**, estimates are made of the private costs associated with decreasing or eliminating the toxin in the industrial effluent. **Finally**, the damages to a population and the costs incurred by a polluting firm are compared in an effort to evaluate one particular impact: total cost to society.

This policy analysis model is applied to a particular regulatory situation in Michigan which involves the toxic substance 2,3,7,8-TCDD and the Mead Corporation's kraft pulp mill in Escanaba. The total cost to society of the dioxin

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[1] The term risk manager refers to the regulatory agency personnel ~~which~~ who develop and implement rules and regulations in response to legislative action. In developing rules and regulations risk managers attempt to minimize risks in an effort to protect the health, welfare and safety of society.

regulations developed by the Michigan Department of Natural Resources (MDNR), Michigan Department of Public Health, and U.S. Food and Drug Administration are evaluated.

1.2 The Environmental Concern of Dioxin

There has been significant debate over the actual risks that dioxin poses to human health and the environment. As the scientific community continues to assess the risks, public perception of dioxin as one of the most carcinogenic substances known to humankind prevails. Until the health risks of dioxin are more fully understood, public perception of risk will be a dominant factor in shaping federal and state policy. Governmental agencies can ill afford to risk public health, welfare and safety, and as a result will err conservatively in policy development.

Dioxin is the unintended side effect of a number of industrial activities and is also found naturally in the environment. Dioxin generically refers to a family of 75 similarly related compounds, polychlorinated dibenzo-p-dioxins, of which 2,3,7,8-TCDD is one. A class of related compounds, polychlorinated dibenzo-furans (furans), are generally found in close association with dioxin, which, although they share similar chemical characteristics, are less toxic than dioxins. This research is devoted exclusively to the study of 2,3,7,8-TCDD (referred to in this study as dioxin).

In the absence of human health data on the effects of dioxin exposure, the results of animal tests are extrapolated to give some indication of potential risks to human health. A number of toxicological studies have been conducted to assess the impacts of dioxin on animals. Results of these studies indicate a variety of adverse health effects, including the occurrence of cancer (Kociba et al. 1976, Kociba et al. 1978, Murray et al., 1979, Allen et al., 1977), on a number of animal species at various doses. Kociba et al. (1978) reported various cancers of the liver in female rats at extremely low doses of dioxin, 0.01 microgram per kilogram (ug/kg). On the basis of these and other studies, current federal and state regulation of dioxin is based on the assumption that dioxin is carcinogenic. Whether or not dioxin is actually carcinogenic in humans is widely debated. While the debate continues, regulatory agencies have taken the conservative position of presuming dioxin to cause cancer in humans. This presumption creates a policy environment based on imperfect information which can result in significant resource expenditures by industry to meet a standard that provides an uncertain level of protection to society.

Because of dioxin's intense toxicity there is concern for exposure at very small doses. Scientific instrumentation has developed to the extent that toxic substances can now be measured at extremely low concentrations. Dioxin has been found in the parts per trillion (ppt) range in fish, and in the parts per quadrillion (ppq) range in pulp mill effluent. Current Michigan Department of Natural Resource regulations require the discharge of dioxin from a new pulp mill to be below 0.01 ppq level, which is below current scientific measurement capabilities (presently limited to the 3-4 ppq range). Table 1.1 puts these measurements in perspective; they have been adapted from comparisons made by Warren B. Crummett of the Dow Chemical

Company (Kagel).

Table 1.1 Comparison of Trace Concentration Units

Unit	1 part per trillion	1 part per quadrillion
Length	1 inch/16,000,000 miles	1 inch/16,000,000,000 miles
Time	1 second/320 centuries	1 second/320 millenniums
Money	$.01/$10,000,000,000	$.01/$10,000,000,000
Weight	1 pinch salt/10,000 potato chips	1 pinch salt/10,000,000 potato chips
Action	1 bogey/3,500,000,000 golf tournaments	1 bogey in 3,500,000,000,000 golf tournaments
Quality	1 bad apple per 2,000,000,000 barrels	1 bad apple per 2,000,000,000,000 barrels
Rate	1 dented fender per 10,000,000 car lifetimes	1 dented fender per 10,000,000,000 car lifetimes

There are two primary properties that can increase the hazard potential of dioxin to humans and the environment: persistence and bioaccumulation. Dioxins are generally resistent to biological breakdown and can persist in the environment for years. Dioxins are also lipid (fat) soluble and tend to be accumulated by living organisms.

The bioaccumulation property of dioxin poses a potential threat to Great Lakes anglers who consume their catch. Fish bioaccumulate dioxin, magnifying the concentration in water from parts per quadrillion to parts per trillion in their flesh. This increased dioxin concentration makes the consumption of sport fish a higher risk to the human population than that of exposure to the skin, or the drinking of dioxin tainted surface water.

1.3 Dioxin in the Great Lakes

A number of studies have detected dioxin throughout the Great Lakes Basin. Kaczmar et al. (1985) reported detectable residues of dioxin in bottom feeding fish ranging from 17 to 586 nanogram per kilogram (a ng/kg is equivalent to a ppt) in many Michigan watersheds. Analyses conducted on fish from Lake Ontario, Lake Erie, and the Hudson River (Smith et al., 1983) and Lake Huron (Stalling et al. 1983) indicated dioxin in a variety of fish species with concentrations ranging from non-detectable (at 3.2 ng/kg) to 107 ng/kg.

A number of analyses have been conducted on Michigan rivers receiving dioxin laden discharge from industry. Results of a 1988 analyses conducted on the Menominee River downstream from Champion Paper Company's Quinnesec pulp and paper mill indicated the presence of dioxin in redhorse sucker, smallmouth bass, northern pike, and walleye in the range of non-detectable (at 0.11 ng/kg) to 1.97 ng/kg (MDNR, 1988a). A 1988 sampling of walleye from the Tittabawassee River at Midland near Dow Chemical Company, confirmed that dioxin was present, ranging from 1.3 to 5.61 ng/kg (MDNR, 1988b). The results of a 1989 analysis of fish in the Escanaba River near the Mead Corporation's Escanaba pulp and paper mill identified northern pike, white sucker and smallmouth bass with detectable residues of dioxin ranging from 2.86 to 23.4 ng/kg (MDPH, 1989).

The flushing time of the Great Lakes, particularly the deep Upper Great Lakes, plays an important part in characterizing the potential harm from persistent toxic substances. The flushing time to remove fifty percent of a conservative material, such as dioxin, from the Great Lakes ranges from 120 years for Lake Superior, 50 years for Lake Michigan and Lake Huron, approximately 7 to 10 years for Lake Ontario, and 2.5 years for Lake Erie, (Bennett, 1978, Rainey, 1967, Sly, 1967). Long flushing times increase the amount of time a material stays in the lakes which increases the chances for the material to be bioaccumulated in fish.

1.4 Risk Management Approach to Regulating Toxic Substances

The regulation of toxic substances occurs at the federal, state, and local level. These regulations are manifested in a variety of forms. There are federal laws that affect the development, use, storage and disposal of toxic substances and the protection of resources from the disposal of these substances. Examples of these laws include the Federal Insecticide, Fungicide, and Rodenticide Act of 1972, Safe Drinking Water Act of 1974, Toxic Substances Control Act of 1976, Clean Water Act of 1972, and the Resource Conservation and Recovery Act of 1976. States promulgate rules as a result of state and federal legislation. Michigan's Water Quality Standards are promulgated as rules (Part 4 of the General Rules of the Water Resources Commission) under the Water Resources Commission Act, P.A. 245, of 1929 as amended. Local ordinances can also play a role in regulating toxic substances through the siting of chemical production facilities. The primary process used by both federal and state governments in regulating toxic substances in surface water is risk management.

Risk management agencies use a risk management approach to protect the public health and environment from toxic substances such as dioxin. Risk management refers to an optimal balance between uncertain benefits and uncertain costs (Haimes, 1990). According to Haimes, risk is the measurement of the probability and severity of adverse effects. Probability refers to the likelihood that an event will occur and severity is a measure of the magnitude of the event's effects. In the case of dioxin, risk includes the likelihood of a human to contract cancer as a result of being exposed to the chemical.

Risk management is the second part of a two part process that also includes risk assessment. Risk assessment is defined by the U.S. National Academy of Sciences (1983) as:

> ...the scientific activity of evaluating the toxic properties of a chemical and the conditions of human exposure to it in order both to ascertain the likelihood that exposed humans will be adversely affected and to characterize the nature of the effects they experience.

Wentz (1989) points out that "risk assessment techniques include environmental impact assessment, systems analysis, cost-benefit analysis and probability analysis," and explains that "risk assessment is really based upon environmental impact assessment in that it quantifies the potential hazards of economic development and technological change."

In developing protection policies based on risk assessment and risk management, risk managers must address four questions:

1. What can go wrong?
2. What is the likelihood that it will go wrong?
3. What are the consequences?

4. What can be done (Haimes, 1990)?

Besides risk, policies must also address the issue of safety. Measuring risk is an empirical, quantitative, scientific activity, while judging safety is a normative, qualitative, political exercise. Judging safety is judging the acceptability of the risks (Haimes, 1990).

While risk assessment and risk management are independent activities, they are often linked by risk managers to provide a system for devising risk based protection policies (Figure 1.1).

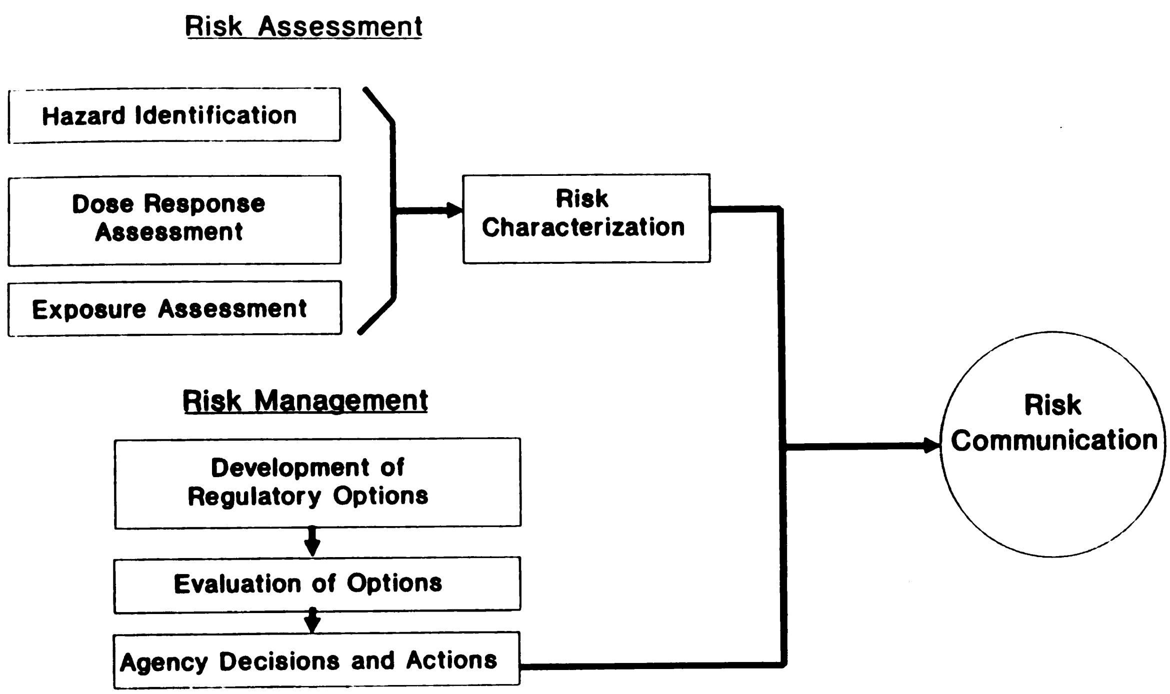

Figure 1.1 The Risk Assessment/Risk Management Process[2]

[2] Adapted from Bedford et al., 1990 and the National Academy of Science, 1983.

Risk assessment includes four steps:

1. Hazard Identification: The gathering of information to determine whether a particular chemical is or is not causally linked to particular health effects.

2. Dose Response Assessment: The determination of the relation between the magnitude of exposure and the probability of occurrence of the proposed health effects.

3. Exposure Assessment: The estimation of the number of people which will be exposed and the characteristics of the exposure before or after application of regulatory controls.

4. Risk Characterization: The integration of hazard identification, dose response assessment, and exposure assessment to describe the nature and often the magnitude of human risk (Pollock et al., 1989).

After the results of risk assessment have been clearly articulated risk managers apply risk management techniques to the decision making process. Risk management includes three steps (Bedford et al. 1990):

1. Development of regulatory options.

2. Evaluation of public health, economic, social, and political consequences of regulatory options.

3. Consequent agency decisions and actions.

An important distinction between risk assessment and risk management is that, ideally, risk assessment consists of objective, quantifiable determinations. Risk management generally involves a multitude of unquantifiable factors including perceptual, economic, cultural, and political influences (Wentz, 1989). Risk Communication is a separate component shared by both processes. It refers to the communication of relevant information to pertinent audiences.

Bedford et al. (1990) suggest that risk communication is the most important element in the risk assessment/management process. It is the element that either "convinces the public that the system is working and that their health is being protected or leads to distrust of the message and the involved parties." For risk communication to be effective it is necessary for the agencies involved to deliver the same message to the same audience. Bedford et al. states, "it is important that the results of the risk assessment process be as uniform as is reasonably possible given the different purposes for its use within individual state agencies as well as balance between agencies." The concept of uniformity in risk assessment methods can also be expanded to include consistency between states as well as between federal and state agencies.

The current sophistication in measurement and the techniques used to determine the effects of toxic substances on certain species are activities pursued in the realm of scientific inquiry. However, the utilization of these data for risk management and safety judgement is done outside the realm of science in the political arena. It is in the political arena that federal and state agencies are left to deal with the question of what is a safe level of exposure, or "how safe is safe?"

The protection polices developed by agencies do not directly answer the question of "how safe is safe?" rather they provide a range of risks. Agencies use mathematical models to "estimate the upper boundary (95 percent) on risk of increased incidence of cancer over background cancer rates for a population exposed to certain concentrations of a chemical over a lifetime of exposure under assumed set of conditions (MDNR, 1984)." The result of this cancer risk assessment is generally expressed in terms of additional cases of cancer in a given number of individuals. For example, the U.S. Environmental Protection Agency (EPA) bases its protection policies on risk assessments relating risks to **one excess case of cancer per one million** exposed population. The Michigan Department of Natural Resources and the Michigan Department of Public Health both use measures of risk relative to **one excess case of cancer per 100,000** exposed population. Risk managers can compare the risks associated with a certain toxic chemical to risks in people's lives.

On a daily basis people are faced with numerous risks both unavoidable, such as being struck by lightening and being in an automobile accident, and avoidable, including skiing, swimming, and hunting. By evaluating the range of avoidable and unavoidable risks, a risk manager can choose a limit that relates the risk associated with being exposed to a toxic chemical that provides some margin of safety that exceeds the majority of risks that people face.

1.5 Michigan Dioxin Policy

The Clean Water Act of 1972 (33 U.S.C. 1251 et seq.) specifies a number of mandates to achieve its rigorous goal of maintaining the integrity of the Nation's waters. The Act calls for the elimination of pollution discharges into navigable waters and declares a national policy "that the discharge of toxic pollutants in toxic amounts be prohibited." In the development of the Act a number of non regulatory "market" mechanisms, including tax-subsidy approaches and pollution certificates, were proposed to control pollution. However, in the end, Congress adopted a regulatory approach which directly addresses the quantity of pollution discharged (Goldfarb, 1988).

The Act provides for the development of water quality-based effluent limits and technology-based limits to control pollution. According to Goldfarb, the Act's principal control mechanism "is uniform national technology-based effluent limitations, progressively tightened until a 'zero discharge' goal is reached." As an interim step, until these technology-based effluent limitations are developed, water quality-based effluent limits are used by states to control the amount of toxic substances entering surface waters. Federally authorized state agencies generally use a risk management approach in developing state water quality-based effluent limits (referred to as effluent limits).

The Michigan Department of Natural Resources (MDNR) uses risk management to formulate policies to protect the population from the potential adverse health effects of exposure to dioxin contaminated surface water. The MDNR develops effluent limits as part of an EPA authorized state National Pollutant Discharge Elimination System (NPDES) program. These limits act as warnings that no discharge will be tolerated if it disrupts the integrity of a body of water (Goldfarb, 1988). The MDNR established an effluent limit of 0.01 parts per quadrillion (ppq) for new discharges of dioxin into Great Lakes tributaries. The current NPDES permit for the Escanaba Mead pulp and paper mill[3] is 0.022 ppq dioxin for discharges to

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[3] There are 104 bleach kraft mills in the U.S. Each mill has its own specific process configuration, however, the mills generally share a number of similar characteristics such as the use of a chlorine based bleaching process and kraft pulping technology.

the Escanaba River.

The Department of Public Health (MDPH) uses risk management to develop sport fish consumption advisories and corresponding health advisory triggers to inform the public of the risks associated with eating sport fish burdened with toxic substances. The MDPH has set 10 ppt as the health trigger for dioxin in fish. If a body of water has been identified as having fish with a body burden of 10 ppt or greater of dioxin, an advisory is issued warning individuals not to eat the contaminated species. The question that must be addressed is what relationship exists, if any, between water quality based effluent limits and health advisory triggers?

Both the MDNR and MDPH use risk management in developing dioxin regulations. However, the differences in an agency's application of risk management techniques, in the development of effluent limits or health triggers, may have significant effects on social welfare when they are implemented. Combs et al. (1989) state:

> . . .subjectivity is a factor in the interpretation of the data upon which the standard is based. Two standard setting bodies, using the same toxicological information, and equally qualified personnel to interpret that information, may produce numerical standards that are markedly different. This subjectivity in the interpretation of the data has led to many questions about the appropriateness of various numerical standards and to the belief by many that the numbers represent little more than "black magic."

Although the MDPH health trigger is not a numerical standard, but rather a

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The Mead Corporation's Escanaba Mill is representative of the characteristics found in the majority of the U.S. bleach kraft mills.

mechanism for communicating risk, it is an integral part of Michigan's policy to control human exposure to dioxin. The MDNR's effluent limit is the target the discharging firm must meet, while the health trigger is a value that indicates the level at which a fish can be burdened by a toxic substance and still be safe to eat. Having two agencies independently formulate dioxin policy can cause miscommunication, provide for inconsistencies, and raise serious questions concerning the effectiveness of these policies in protecting human health.

The term effectiveness, when used in the context of gauging policies that protect human health, refers to whether or not a policy is protecting a population to a given level of risk, or in some cases, a range of risks. The risk level defines the region in which agencies have judged exposure to be safe.

One inconsistency between agency responses is their cancer potency factors. Both agencies use the linearized multistage model[4] for extrapolating animal data to humans, an assumed risk of one excess case of cancer per 100,000 exposed population, and the same animal study (Kociba et al. 1978). However, because of different risk assessment assesment assumptions they derive potencies that are significantly different. The MDNR uses a potency factor of 1.51×10^5 mg/kg/day and the MDPH uses a factor of 3.57×10^4 mg/kg/day. Because the potency value is critical to determining the cancer risk of a toxic substance, this magnitude of difference in the

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[4] The linearized multistage model is used to fit animal laboratory data which was generated in a high dose range to a dose response curve in order to predict responses to a particular carcinogen at low doses. The model assumes that there is a risk of cancer being developed at any dose.

factor alone will have a significant effect on the safety margin of a particular protection policy. Other inconsistencies between regulatory responses to dioxin control are identified in Chapter 3.

1.6 Study Objectives

The desirable approach to the assessment and management of any particular chemical includes the analysis of all relevant information (Bedford et al., 1990). Bedford et al. suggest that ideally this evaluation would be conducted by a panel of experts composed of representatives from the disciplines of medicine, toxicology, ecology, sociology, economics, and other relevant fields. However, such a panel would require tremendous expenses in terms of money, time, and effort, all of which are in limited supply in state and federal agencies.

In the absence of such a panel, agency personnel are left with limited information on which to base the development of toxic substance policy. To assist risk managers in making decisions, a policy analysis model based on biological and economic data is developed which provides information on the exposure and associated risks of a toxic substance as well as the associated costs.

A model is merely an abstraction of reality. To gain utility from a policy analysis model, several factors must be addressed which, when combined, lead to an outcome which the policy was designed to effect. The first key factor that must be addressed by the policy analysis model is a firm's choice of **abatement** methods. For example, an effluent limit for a toxic substance is developed in order to prevent the further contamination of a water resource from a particular contamination source. The effluent limit adopted by the risk manager is determined to be at a level that protects the health, welfare and safety of a particular population. This effluent limit sends a message to the source that it will face regulatory action if it does not comply with the limit. The source, usually an industrial firm, in turn adopts technologies in order to decrease the concentration of the toxic substance in the effluent to the prescribed level. Until the source is in compliance, and even after it reaches the effluent limit, the toxic substance will be released at some level into the environment.

Each firm is faced with a set of choices in determining which abatement technology to adopt. These choices are limited by a number of constraints including the cost and effectiveness of the technology. A firm will generally seek to just meet the effluent limit using the least cost technology. The effectiveness of the technology will determine the amount of toxic substance that enters a water body.

The **fate** of the toxic substance is the second key factor that must be addressed. Once the toxic substance is in the aquatic environment it may adsorb to particulate matter and immediately settle on the bottom of the water body or it may be transported some distance before it settles; it may also be consumed by aquatic organisms. The substance could also dissolve in the water or volatilize into the atmosphere.

If the toxic substance is incorporated into fish tissue then the fate of the contaminated fish must be identified. If the fish is eaten by predatory species such as herons, bears or humans, the third factor in the model is to identify the **effects** on the species which consume the contaminated fish. If the consumption of contaminated fish causes harm, a fourth factor is to determine the **costs** associated with this harm. Each of these factors must be examined within the policy analysis model if a complete picture of the effectiveness of the effluent limit is to be developed.

The policy model developed in this research is based on the economic theory of social welfare maximization which states that the most desirable condition for any society is maximum social well-being (welfare) at a minimum cost[5]. When applied to the problem of assessing the impacts of toxic substances on public health, the key component of the model is the amount of a toxic substance that ends up in fish tissue.

There are three primary factors governing the amount of toxins in fish tissue: effluent concentration of a toxic substance, rate in which effluent enters a water body, and rate of flow of the water body. Other ancillary factors will be discussed in Chapter 2. Once established, the amount of the contaminant in fish can be used to identify potential exposure to a specific population. This exposure can then be used to characterize the risk of contracting cancer for the population.

Economic valuing techniques are applied to a population's risk of contracting cancer in an effort to determine a damage cost for dioxin exposure. Economists have recently begun to quantify what individuals would be willing to pay for reducing their risk of death. Although the risk of death is one (everybody will die) there are

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[5] Maximum social well-being is defined as a state "in which society is as well off as it can possibly be, given its resource base, its productive technology, and the tastes and preferences of its members" (Randall, 1987).

activities which, if undertaken, have been statistically shown to provide a greater chance of risk related death than other activities. For example, based on a fifty year period a fire fighter has a 32 in 1,000 chance of dying on the job, while a service or government worker has only a 40 in 10,000 chance of dying on the job in the same period (Clark et al., 1987). The "value of life", as stated by Blomquist (1979), "is based on changing the probability of survival by a small amount." Because risk is not traded in markets economists use various methods to determine what people are willing to pay to reduce their risk of dying from specific avoidable behaviors.

Economists estimate a willingness to pay value to indicate the change in well-being that would result from changing the risk of death related to specific activities. They derive this estimate by measuring "how much of other goods and services a person is willing to give up to get a reduction in the risk of death (Fisher et al., 1989)." This concept of valuing the risk of death from avoidable behavior is critical to the development of this policy model. A more detailed discussion will be provided in Chapter 4.

By associating willingness to pay values with a population's risk of contracting cancer, the implied costs that the population incurs due to the exposure of a toxic substance can be calculated. These costs are referred to as "damage costs". In this study, the damage costs are derived by applying values (found in the literature) that people are willing to pay for reducing their risk of dying from specific activities to the potential risk of death, from contracting cancer resulting from eating dioxin burdened fish, faced by the Delta County sport fish eating population. Costs can also be calculated to reflect what a discharging firm incurs to control the release of the toxic substance to a regulated level. These costs are called "abatement costs."

This policy model is used to evaluate both current and potential policies in order to determine whether or not the pollution control level maximizes social welfare and minimizes the costs to society--usually referred to as **Pareto optimality**[6]. This model takes the earlier explained concept of effectiveness a step further by incorporating the constraints of maximum protection at a minimum cost. The water quality based effluent limits and the health advisories are developed to provide an adequate margin of protection to society without much concern to the costs involved in achieving the protection. This model adds potential damage costs and abatement costs to the protection equation and extends the evaluation of whether or not a policy is protecting a population to a given level of risk to include the costs imposed on society of achieving a particular level of risk.

This study will attempt to determine whether or not the inconsistencies in applying risk assessment/management to the development of standards and health triggers by Michigan regulatory agencies provides a toxic substance policy that is economically optimal (in the Pareto sense). A policy analysis model is developed and applied to determine whether or not the application of the Michigan Department of

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[6] This concept of maximum welfare at a minimum cost is often referred by economists as achieving a Pareto optimal solution. Named for the Italian economist Vilfredo Pareto (1848-1923), the concept refers to a solution in which no one individual can be made better off without necessarily making some other individual worse off. The term Pareto efficiency is also used to describe such an allocation as "efficient if conditions cannot be made unambiguously better (Nicholson, 1985)."

Natural Resource's 0.022 ppq dioxin effluent limit for Mead's Escanaba kraft pulp mill and a Michigan Department of Public Health dioxin health trigger of 10 ppt in fish for the sport fish eating population of Delta County leads to an efficient (Pareto optimal) allocation of resources. The researchable question for this study is: **do the private costs to the Mead Corporation's Escanaba kraft pulp mill, incurred as a result of the Michigan Department of Natural Resource's dioxin effluent limit, exceed the benefits of the reduced risk of contracting cancer, which are based on MDPH and MDNR risk management approaches, received by the Delta County sport fish eating population?**

The objective of this thesis is to develop a policy analysis model that can be used to evaluate toxic substance regulations in Michigan, by identifying the private costs to industry and the benefits to society of decreased risk to adverse effects of toxic contaminated surface water, and determining a range of Pareto optimal solutions. A critical component of this study lies in translating a quantity of a regulated effluent into a measurable quantity in fish in order to evaluate whether the MDNR effluent limit provides the margin of safety required by the MDPH health trigger without unnecessarily burdening the discharger. The U.S. Food and Drug Administration risk management approach to dioxin regulation will also be evaluated with this policy analysis model in order to compare the compatibility of federal and state approaches to regulating dioxin.

CHAPTER TWO: DIOXIN CONTAMINATION

Dioxin has been at the forefront of the public's interest since the early 1970s discoveries of dioxin contamination in New York's infamous "Love Canal" and at Times Beach, Missouri. Since its discovery, the compound has been at the center of policy debates between citizens and regulators, regulators and industry, and amongst various regulatory agencies. It has also been the subject of intense scientific scrutiny, especially the 2,3,7,8 TCDD. And, on a regular basis has been a prominent feature in the developed world's newspapers.

Through their investigations, scientists have identified a number of sources, both natural and human based, of dioxin. The fate and transport of the chemical, along with its chemical characteristics, is now fairly well understood in the scientific community. As a result, industry is developing process changes to reduce the flow of dioxin from industrial activities into the environment. However, even after significant resource expenditures and countless hours of research, one key piece of information remains uncertain: the effects of dioxin on wildlife and human health.

This chapter provides a limited literature review in an effort to provide a brief summary of information concerning, the sources, chemical characteristics, and health effects associated with dioxin. The information will provide a foundation for understanding the development of dioxin policy in the United States.

2.1 Sources of Dioxin Contamination

Dioxins are by-products unintentionally created in the manufacturing of other chemicals. Regulatory concern for dioxin originated from the 1970s detections of dioxin in the herbicide 2,4,5-T. Other sources identified in the 1970s included the manufacturing of 2,4,5-trichlorophenol (2,4,5-TCP) and hexachlorophene. The discovery of 2,4,5-T in waste oil still bottoms used in horse arenas in Times Beach, Missouri and the leaking of wastes from earlier chemical production, including 2,4,5-T, disposed of in the "Love Canal" in New York, provided the impetus for federal and state regulatory policies for the compound.

In the late 1970s, reports surfaced of dioxin being released from combustion sources, particularly municipal waste incinerators (Barnes, 1985). Dioxin is now associated with metallurgical processes such as smelting, the manufacture of pulp and paper and car exhausts (Rappe, 1988).

2.2 Environmental Characteristics of Dioxin

Specific polychlorinated dioxins are defined by the number of chlorine atoms attached to the basic molecules, and by the position of the chlorine molecules. The 2,3,7,8 TCDD molecule is identified by its four chlorines, and is considered the most toxic (Figure 2.1) (Rappe, 1988 p.137).

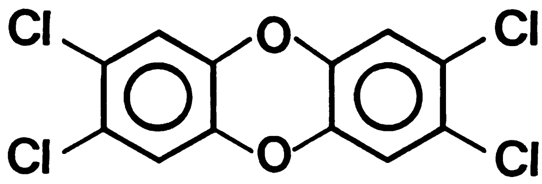

Figure 2.1 The 2,3,7,8-TCDD molecule.

Dioxin is a colorless crystalline solid at room temperature. It is nearly insoluble in water and tends to travel on particles or accumulate in sediments and organisms (Wentz, 1989). The compound binds strongly with organic carbon and sediments which decreases opportunities for the compound to volatilize to the atmosphere, to be degraded by the sun, or react with water. Once the compound enters an aquatic ecosystem there is very little chance of it exiting.

Bioaccumulation Because of its persistent nature, dioxin is available to be bioaccumulated by fish. Bioaccumulation is the process by which an organism accumulates a substance as a result of ingestion of water and food in which the substance is dissolved or to which the substance is bound. Dioxin is also highly soluble in fat which increase its opportunities to accumulating in the fatty tissue of fish. A number of studies have shown the potential for fish to bioaccumulate dioxin (Metcalf and Liu, 1973; Isenee and Jones, 1975; and Tsushimoto et al., 1982). Dioxin uptake in fish varies significantly between species of fish and the organs within a fish (Keuhl et al. 1987, Muir et al. 1985). Body burdens (an amount of toxic substance incorporated in fish tissue) of dioxin in fish result from dioxin concentrations in several sources including river water, organic carbon consumed directly by the organism either passively or actively, and food; and by several species-specific parameters including: uptake, assimilation and feeding rates, depuration, and growth (Anderson et al. 1990 p.8).

Bioaccumulation factors (BAF) and bioconcentration factors (BCF) are unitless ratios of toxic substance concentration in water to the concentration of the toxic substance in fish. Bioconcentration refers to the process by which a dissolved substance can be taken up by an organism directly from water. The type of data and its availability generally determines the method for estimating bioaccumulation or bioconcentration factors.

It has been suggested that food chain models utilizing site-specific data with their inherent kinetic properties are probably the best means of estimating body burdens (Anderson et al. 1990 p.18). In the absence of food chain models, Anderson et al. (1990) suggested utilizing site-specific data for a kinetic approach as the next best method. Using a mean dioxin concentration from the analysis of twenty-two fish (northern pike, smallmouth bass, and white sucker) of 10.69 ppt and an Escanaba River dioxin concentration of 1.48 ppq, Anderson et al. calculated a site specific BAF for dioxin of 7,238 (see Appendix A).

The BCF utilized by the MDNR is standardized to reflect the value for fresh fish tissue having a lipid content of 9.6%, and is preferably determined using standardized laboratory tests. If bioconcentration factors are not available from laboratory studies, field data may be used to determine a BCF. In the absence of field data MDNR guidelines require the BCF be calculated using the following equation:

$$\log BCF_c = 0.847 \log Kow - 0.628 \text{ (MDNR, 1985)}$$

where:	log Kow	=	the log (base 10) of the ratio of the octanol to water equilibrium concentrations of a compound.
	BCF_c	=	calculated bioconcentration factor from log Kow or other regression equations.

The current laboratory derived BCF for dioxin is 51,600 for developing water quality based effluent limits for dioxin in Michigan (Taft, 1990).

An EPA laboratory determination of lake trout dioxin bioaccumulation kinetics specific to Lake Ontario fish exposure conditions concluded that 140,000 is a reasonable BAF estimate (Cook, 1990). These three estimates of a BCF and BAFs are a representative sample of the variability that exists in determining the potential for fish to accumulate dioxin. The EPA (1990b) used similar BCFs of 5,000 and 50,000 in a recently published risk assessment study of dioxin contaminated receiving waters from U.S. chlorine-bleaching pulp and paper mills.

Health effects There have been a number of accidental human exposures to dioxin. These exposures have generally been workers who were accidently exposed to dioxin during the production or handling of the 2.4.5-trichlorophenoxy acetic acid (2,4,5-T) and products made from this chemical, or through the use of other herbicides contaminated with dioxin. Studies of exposed individuals are at times contradictory and are often inconclusive.

For example, a comparison study of 1,261 Agent Orange (a herbicide containing the dioxin contaminated 2,4,5-T and 2,4-D used to defoliate jungle flora during the Vietnam War) exposed personnel and 19,101 non exposed personnel resulted in no statistical difference between cumulative mortality (Wolfe et al. 1989). However, a Vietnamese study derived the tentative conclusion that the difference in the infant mortality rates between the villages sprayed with agent orange and the non-sprayed villages suggests that there may be increased health risk to infants consuming dioxin-contaminated mother's milk (Dai et al. 1989).

Bonsor et al. (1989) summarize the rampant uncertainty associated with current dioxin epidemiological studies,

> (1) People who lived in a trailer park at Times Beach, Missouri, where [dioxin] contaminated oil was used for dust control, show serious impairment of the body's immune system, which has the function of protecting from infectious agents. The effect has been noted in many studies with animals, and is associated with a loss of lymph tissue. Therefore it was surprising that the impairment in Times Beach people was not accompanied by increased morbidity or mortality, and has not been documented in other human studies. (2) An association between increased soft-tissue cancer and degree of exposure to herbicides was shown in Swedish workers. The results cannot be directly attributed to PCDDs because of the great mixture of chemicals included in the exposures. (3) Liver damage, as measured by various tests of liver enzyme function, was seen in at least 3 locations among the workers who showed chloracne, and was also documented following the Seveso explosion, and among Americans who had sprayed agent orange. Liver damage also shows up in most sublethal studies with laboratory animals. (4) Damage to the nervous system has been evident in several of the more severe exposures of humans, mostly in the peripheral nerves, with loss of sensation. For each of these items, there were other studies which failed to find such effects.

The following four deficiencies are found in most if not all of the current epidemiology studies making it difficult to derive a definitive conclusion on health effects and the cancer risk of dioxin to humans: (1) lack of sufficiently measured exposure, (2) lack of sufficient time between exposure and the study for disease development, (3) a population too small for one to expect to find cases of soft tissue sarcoma, and (4) possible lack of contamination of the commercial product with dioxin (CDC, 1983 p.3).

In the absence of concrete human health data animal studies are used to make extrapolations of adverse human health effects. The toxicity of a substance is traditionally measured through the use of a bioassay. In a bioassay, a single dose of a measured amount of a toxic substance is administered to rats or other species to determine how many animals die. The dose at which 50 percent of the animals die is considered as the LD50 (lethal dose). An oral LD50 is derived by dosing the animal by delivering the material to the stomach. The oral LD50 of dioxin varies significantly among species, from 0.6-2 ug/kg in guinea pigs, and 44 ug/kg in rats to about 5 mg/kg in hamsters (CDC, 1983 p.5). In spite of this range, among different tested animals, dioxin is still considered extremely toxic (CDC, 1983).

Because of its accumulative property, after repeated dosing, dioxin is stored in adipose tissue and to some extent, in the liver and other organs. Lifetime studies conducted on rats and mice have concluded that dioxin affects reproduction in female animals, depresses the cell-mediated immune response, is toxic to the liver, and causes cancer (CDC, 1983). Through the evaluation of animal bioassays, the EPA

(1984) independently concluded that several rodent studies establish dioxin as an animal carcinogen in multiple species and organs and is probably carcinogenic in humans.

The MDNR, in developing its regulatory response to toxic substances, assumes that all animal carcinogens are human carcinogens. The MDNR assumes the following:

> since every known human carcinogen, with the exemption of arsenic, has also been found to be carcinogenic in animals, prudent policy is to accept the use of such data, rather then wait for proof of human carcinogenicity (MDNR, 1984 p.27).

In the Kociba et al. (1978) study animals were given dioxin in the doses of 0.001, 0.01, and 0.1 ug/kg/day. The animals in the highest dose group exhibited various cancers of the liver in 11/49 female rats compared to 1/86 in the control group. At the 0.01 ug/kg dose, hyperplasia of the liver and lung was observed. The lowest dose group observed no adverse effects and was considered the no-observable-adverse-effect-level (NOAEL[7]). The Kociba et al. (1978) study is the foundation for quantitative risk assessments for dioxin made by the EPA, FDA, MDPH, and the MDNR.

2.3 *The Pulp and Paper Industry as a Source of Dioxin Contamination*

After finding dioxin in native fish collected downstream from a number of pulp and paper mills, the EPA and the paper industry undertook a study in 1986 to

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[7] The NOAEL refers to the highest level of toxicant that results in no observable adverse effects to exposed test organisms (MDNR, 1985).

determine the occurrence and fate of dioxins and related furans in five bleached kraft mills. Results of the EPA/Paper Industry Cooperative Dioxin Screening Study, released in 1988, indicated that dioxin is formed as trace contaminants during the bleaching of kraft hardwood and softwood pulps with chlorine and chlorine derivatives. The study also indicated that dioxin was found in treated wastewater effluent from three of five of the kraft mills at levels ranging from 0.015 to 0.12 ppt (USEPA, 1988a).

Kraft is both the Swedish and German word for strong. It refers to a particular pulping process in which wood is separated into its individual fibers by cooking wood chips under pressure and elevated temperature in a digester with strong alkali, Figure 2.3 (Smook, 1982). The lignin and non-fibrous material are recovered as black liquor at a 96 to 99.5 percent recovery rate. The remaining black liquor becomes part of the mill effluent and can negatively impact the downstream aquatic environment (Bonsor et al., 1989). The efficiency and reliability of the black liquor recovery system is directly related to all effluent parameters except those related to chlorinated organics such as dioxin (Bonsor et al., 1989).

The majority of the pulp is then bleached by chlorine and related chemicals (Figure 2.3), and dried for sale or used on site to make paper. Traditional bleaching processes cause up to 7 percent of the weight of the pulp to be discharged in the form of a wide variety of compounds, including organochlorines. A minute amount of the total organochlorine discharge consists of dioxins (Bonsor et al., 1989).

The Pulp and Paper Research Institute in Canada's (PAPRICAN) 1988 laboratory studies concluded that a "boundary line" of dioxin formation depends upon the proportion of chlorine and chlorine dioxide used and the amount of bleach chemicals added (Fales, 1988). Non-chlorinated contaminants, especially in defoamer made from recycled oil, were identified as a second major potential source of dioxin (Fales, 1988). New defoamers without dioxin precursors are now on the market making this a fairly negligible source of dioxin in current pulping operations.

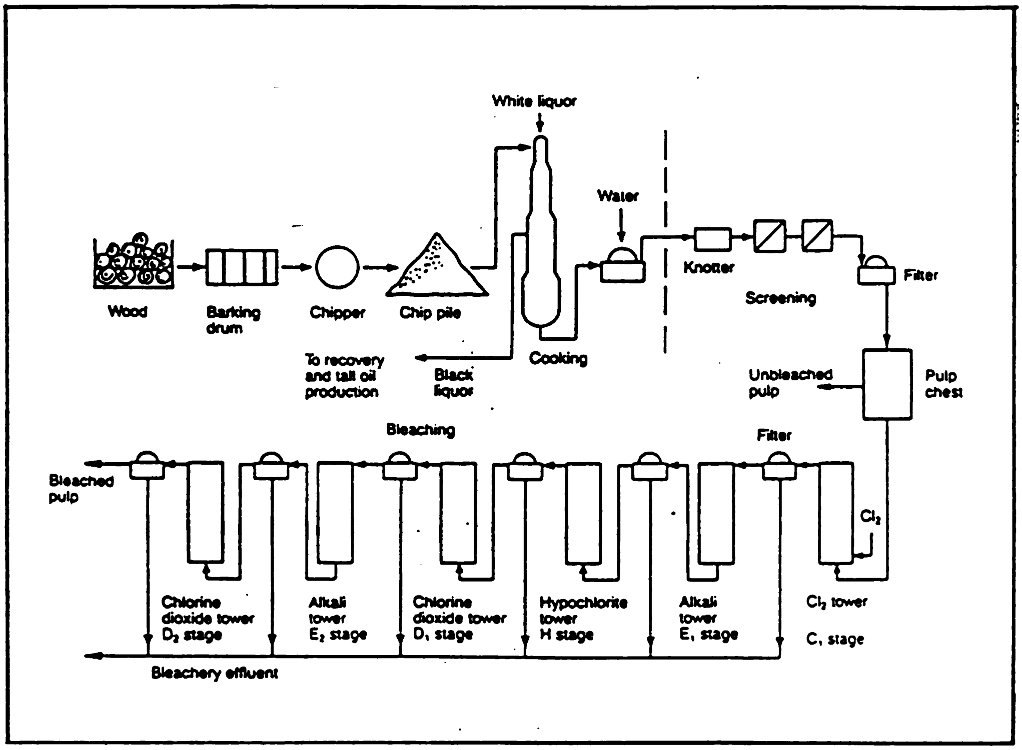

Figure 2.3 Kraft pulp operation with a conventional bleach plant (USEPA, 1990a).

To reduce chlorine use the industry is examining a number of options. The substitution of chlorine dioxide for molecular chlorine appears to be the most promising approach for existing mills. A second option is the substitution of peroxide as a final polishing stage where added brightness is desired. Oxygen delignification is an option for new mills or existing mills with adequate chemical recovery capacity. Other measures such as improved pitch control, brownstock washing, improved process control for good uniformity, and kappa factor control[8] are effective measures which have generally been incorporated into current pulp mill processes (USEPA, 1990a).

The pulp and paper industry is examining several available and emerging technologies to reduce dioxin formation in both the pulping and bleaching stages. Technologies currently available for minimizing dioxin contamination through pulping process changes include: extended delignification, oxygen delignification, polysulfide cooking, and improved pulp washing. Current bleaching process technology changes include: chlorine dioxide substitution, oxygen extraction, Monox-L substitution, control of chemical dosage, improved mixing, split chlorine addition/pH control, and monitoring of the chlorine multiple (USEPA, 1990a)[9]. Three wastewater treatment technologies have shown some effectiveness in eliminating dioxin, these include ultrafiltration, chemically assisted clarification, and enhanced photooxidation, however, they are not widely used.

The Michigan Department of Commerce (MDC) has been marketing the state as an ideal site for pulp and paper investments (MDC, 1982). MDC maintains that

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[8] A kappa factor is a measure of lignin in pulp, according to a standard laboratory procedure.

[9] See USEPA 1990a for a comprehensive treatment of available and emerging technology for decreasing and eliminating dioxin formation in pulp and paper production.

Michigan can provide the required forest resources, freshwater, large land area and accessibility to markets for the potential products. Bleached kraft pulp, sanitary paper products, and printing/writing papers have been identified as the best use for the forest resource (MDC, 1982).

Despite the current dioxin regulations pulp and paper mills continue to investigate pulp and paper mill investment opportunities in Michigan. This is exemplified by James River Corporation's recent analysis concerning the suitability for siting a pulp and paper mill on Michigan's Keweenaw Peninsula. Although, James River ultimately decided against siting a mill on the Keweenaw, the potential exists for future pulp and paper mill development in Michigan.

Because of Michigan's attractiveness to pulp mill development and the ever present need of increased employment and tax opportunities it is critically important that state regulations be objectively examined to ensure that the health, welfare and safety of the people of Michigan is preserved. The use of the policy analysis model developed in Chapter 4 is one tool that is available to assist state regulators in determining what pollution control level will maximize social welfare and minimize the costs to society. However, before the model is presented a brief examination of the current institutional setting for dioxin policy is necessary. The following chapter will address federal and state responses to dioxin contamination as well as illustrate some of the inconsistencies within Michigan's dioxin policy.

CHAPTER THREE: INSTITUTIONAL SETTING FOR DIOXIN POLICY

Policy is a course of action adopted by governments to make decisions and influence the behavior of firms and individuals (Morris, 1979). Policies are generally made in response to a perceived or real threat to society, such as exposure to pollution. The policy making process is one marked by perpetual evolution; as policy is developed and implemented it is continually assessed and reformulated. The dynamic nature of society forces policy to be receptive to change. This constantly changing nature of environmental policy is exemplified by the recent passage of the 1990 Clean Air Act amendments which strengthened the 1977 amendments to the 1970 Clean Air Act.

Environmental policy is often differentiated by resource, (air, water, land) with various agreements, laws and rules developed to address specific threats to the quality of the resource. Pollutants that threaten human health or the aquatic environment at relatively low concentrations are generally referred to as toxic substances (Wentz, 1989). Three primary directives exist for restoring and protecting the Great Lakes from toxic substances: (1) the Great Lakes Water Quality Agreement; (2) the Federal Clean Water Act, and equivalent state laws; and (3) the Great Lakes Toxic Substance Control Agreement. These agreements encompass international, federal and state jurisdictions.

In the U.S., the Environmental Protection Agency and the Food and Drug Administration (FDA) of the U.S. Department of Health and Human Services have primary jurisdiction for enforcing international and federal policy for protecting the population from exposure to toxic substances, such as dioxin, in surface water. Great Lakes States also enforce international policy, in the form of the Great Lakes Toxic Substance Control Agreement, as well as implement state toxic substance regulations.

3.1 International Response to Toxic Substances in the Great Lakes

The Great Lakes Water Quality Agreement (GLWQA), signed in 1972, revised in 1978 and amended in 1987, is an international commitment signed by the U.S. and Canada, in cooperation with Ontario and the eight Great Lakes states, "to restore and maintain the chemical, physical and biological integrity of the waters of the Great Lakes Basin ecosystem (IJC, 1989)." Article 2 of the agreement, commits Canada and the U.S. to a policy requiring, that the discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated (EPA, 1989).

The Great Lakes Toxic Substances Control Agreement, signed by the eight Great Lakes Governors in 1986 and agreed to by Ontario and Quebec in 1988, commits the states to actions congruent with the GLWQA. Specifically, Principle IV states:

> The signatory States commit to continue reducing toxics in the Great Lakes Basin to the maximum extent possible. Such actions shall be consistent with the Federal Clean Water Act goal of prohibiting the discharge of toxic pollutants in toxic amounts, as well as the Great Lakes Water Quality Agreements's aim to "virtually eliminate" the discharge of all persistent toxic substances.

The governors further agreed that the permitting process is the "best means now available" to regulatory agencies for controlling the release of toxic substances. The Agreement also states that "discharges, emissions or releases of toxic substances will be controlled by a regulatory permit process in order to reduce or eliminate the negative effects of toxics on human health and the environment."

These international policies provide specific goals and objectives for controlling the release of toxic substance. To achieve these goals agencies need to implement and enforce federal and state protection policies.

3.2 Federal Response to Dioxin Contamination

The Federal Clean Water Act of 1972 (33 U.S.C. 1251 et seq.) is the primary water pollution control law in the United States. Section 101 refers to the elimination of pollution discharges as a specific goal:

> The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. In order to achieve this objective, it is hereby declared that, consistent with the provisions of this Act,
>
> > (1) it is the national goal that the discharge of pollutants into navigable waters be eliminated by 1985;
> >
> > (2) it is the national goal that wherever attainable, an interim goal of water quality provides for the protection and propagation of fish, shellfish, and wildlife, and provides for recreation in and on the water be achieved by July 1, 1983;
> >
> > (3) it is the national policy that the discharge of toxic pollutants in toxic amounts be prohibited;

In an attempt to achieve these rigorous goals, the act "combines two approaches to water pollution control: a water quality-based approach and a technology-based approach" (Goldfarb, 1988 p. 167).

Water quality standards provide the foundation for water quality-based pollution control, which up until 1972 characterized U.S. water pollution control policy. Water quality standard are defined by Goldfarb as having two parts:

(1) a designation of the desired use for a given body of water, and

(2) the water quality criteria appropriate for that use.

The water quality criteria "are specific levels of water quality that, if not exceeded, are expected to render a body of water suitable for its designated use." In order to control the discharge of particular substances from an industrial firm, water quality standards are translated into water quality-based effluent limitations. These effluent limitations are "restrictions on quantities, rates, and concentrations in waste water discharges measured at the discharger's outfall pipe" (Goldfarb, 1988).

Although water pollution control policy was traditionally based on the water quality-based approach, it has been generally deemed a failure due to the following eight deficiencies identified by Goldfarb:

(1) There is not yet an adequate scientific basis for tying water quality criteria to designated uses.

(2) Assigning wasteload allocations to discharges based on mathematical models is still an uncertain enterprise because of the relatively primitive nature of even the best advanced water quality models.

(3) Modeling and wasteload allocation difficulties are compounded by the concept of "mixing zones." A mixing zone is an area around a discharge point in which a discharger is permitted to mix its wastes without liability for violating water quality standards.

(4) Even if waterbodies could be modeled precisely there would be thorny problems of distributional equity in attempting to allocate wasteloads.

(5) The variability of water quality-based effluent limitations is also a major obstacle to enforcement.

(6) Because water quality-based effluent limitations are so difficult to set and enforce, there are many waterbodies or segments of waterbodies where state agencies have not established them, especially for toxic pollutants.

(7) Many people consider the water quality-based approach to be morally intolerable. It assumes that, to some extent,"pollution is the price of progress."

(8) The bioassay is a highly useful tool for determining the toxicity of mixed waste streams, but it has limitations with regard to water pollution control in general. Bioassays are insensitive to long-term effects, bioaccumulative effects, and synergistic or antagonistic effects of multiple discharges.

In 1972, Congress redirected U.S. water pollution control policy to include uniform national technology-based effluent limitations which are to be "progressively tightened until a 'zero discharge' goal is reached" (Goldfarb, 1988). The technology-based approach is focused on preventing the causes of water pollution rather than relying on a tolerable level of pollution. According to Goldfarb, the current CWA debate "now involves whether further water quality improvement is worth the cost of installing expensive control technology, and whether these more sophisticated control mechanisms are necessary to restore or maintain desired waterbody uses."

While the move to water pollution policy is towards the prevention oriented technology-based approach, until these limits are developed, water quality standards will remain the primary state control mechanism for water pollution. The National Pollutant Discharge Elimination System (NPDES) is the program in which states and regional EPA offices translate effluent limitations into enforceable permit conditions.

An NPDES permit contains three parts: effluent limitations and monitoring requirements, monitoring and reporting, and compliance schedules. In general, each regulated pollutant in a permit has effluent limitations expressed in terms of load and concentration with each pollutant having a maximum daily discharge limitation and an average monthly discharge limitation (MDNR, 1989c). For example, the Mead Escanaba pulp mill's NPDES permit requires a monthly average of 0.022 ppq dioxin, however, it does not contain a daily maximum for dioxin. The permit also specifies that for monitoring purposes samples must be made twice monthly using a 24 hour composite effluent sample (MDNR, 1989c).

Reasserting the goals of both the 1972 CWA and the GLWQA, section 118 of the 1987 CWA amendments states that the U.S. should "seek to attain the goals embodied in the Great Lakes Water Quality Agreement of 1978 with particular emphasis on goals related to toxic substances." In Section 118(c)(1)(E) of the CWA, Congress specifies the EPA as the lead agency to coordinate its actions with other federal, state and local authorities to ensure their input and support in achieving the objectives of the GLWQA (EPA, 1989a). Section 304(a) of the CWA requires the U.S. EPA to establish criteria which enable states to adopt water quality-based effluent standards, anti-degradation policies[10], and implementation procedures necessary to achieve the goals of the CWA in the Great Lakes (EPA, 1989a).

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[10] The "restore and maintain" language of section 101 of the CWA provides a national goal that not only requires the clean up of polluted waters but also forestalls the degradation (referred to as anti-degradation) of current high-quality waters (Goldfarb, 1988 p. 174).

Discharge under the NPDES must meet the more stringent of either water quality-based effluent standards or technology based limitations. Water quality-based effluent limits are derived by states to meet state water quality standards. The EPA is responsible for developing treatment based standards (technology-based approach). The agency is expected to have proposed best available, economically achievable technology limits by 1993, with final regulations by 1995 (USEPA, 1990b). These effluent guidelines will focus on process changes designed to prevent pollution from initially occurring (USEPA, 1990b).

The NPDES program requires all dischargers, industrial and municipal, to obtain a discharge permit. The permit is "either a temporary privilege to use a waterbody for waste disposal until improved pollution control technology is developed or, where an ambient based variance is available, a warning that discharges that disrupt the integrity of the water body are unacceptable" (Goldfarb, 1988, p. 208). The program is administered by either an EPA regional office or by a state that has received EPA permission to issue permits. The CWA sets provisions for the U.S. EPA to delegate a NPDES program to a state, provided it possess the resources and statutory authority to implement it.

Environmental Protection Agency In 1983, the EPA issued its "National Dioxin Strategy," which provided a systematic framework for investigating the nature of dioxin contamination throughout the U.S.[11] This strategy was a first attempt at comprehensively collecting information to assess the risks posed by dioxin in the environment and to subsequently minimize (manage) any risks to human health or the environment.

The strategy consisted of seven tiers of activity focusing on known and suspected sources of dioxin contamination (Table 3.1). The first part of the strategy dealt with production facilities of 2,4,5-T or its derivatives. The second part formed the "National Dioxin Study," which included sampling air, water, soil and fish and selected pesticide formulators, combustion sources, sites of commercial pesticide use, and chemical manufacturing sites (Barnes, 1985).

Among the results from the National Dioxin Study, dioxin was identified in native fish collected downstream from pulp and paper mills. The subsequent finding of dioxin in bleached kraft pulp and paper mill wastewater sludge lead to the development of a detailed process evaluation study conducted by the EPA and the paper industry (EPA, 1988a). The findings of the cooperative study confirmed that bleach kraft pulp mills were a source of dioxin contamination of surface waters.

[11] See Van Strum and Merrell for a comprehensive overview of early dioxin regulatory issues.

Table 3.1 An overview of the U.S. EPA National Dioxin Strategy[12]

Tier 1	2,4,5-Trichlorophenol (2,4,5, TCP) production sites
Tier 1A	Waste sites associated with Tier 1 sites
Tier 2	2,4,5-TCP used as a precursor
Tier 2A	Waste sites associated with Tier 2 sites
Tier 3	Formulators/Blenders of 2,4,5-TCP and derivatives
Tier 3A	Waste sites associated with Tier 3 sites
Tier 4	Combustion Sources
Tier 5	Present/past use sites
Tier 6	Other manufacturing facilities where poor quality control might result in formation of dioxin
Tier 7	"Background" sites

In response to these findings the EPA established an agency goal to eliminate the presence of dioxin in discharges from pulp and paper mills to U.S. waters (EPA, 1988b). In support of this goal the EPA developed an interim strategy for the regulation of dioxin discharges from pulp and paper mills. The strategy consists of:

(1) aggressive action to fully implement or, where necessary, to develop State water quality standards for dioxin applicable to water bodies where mills using chlorine bleach processes are discharging;

(2) collection of data on each of the 104 affected mills, including dioxin levels in their pulp, effluent and sludge;

(3) detailed technical evaluation of wastewater treatment technologies and/or in-process changes to reduce or eliminate the presence of dioxin in wastewater discharges; and

[12] Adapted from Barnes, 1985.

(4) issuance of NPDES permits that regulate and require monitoring for dioxin, examine effluent toxicity and provide for monitoring to tighten controls consistent with the final strategy and requirements of the CWA (EPA, 1988b).

In 1989, the EPA Region 5 Office, which has jurisdiction over the Great Lakes States, developed a detailed approach for the regulation of pulp and paper mill dioxin discharges as a follow up to the interim strategy. This approach was proffered to states as a framework for setting water quality and technology based limits in paper mill effluent. The major elements of the approach include:

(1) Placement in all bleaching mill permits of Best Management Practices requirements, dioxin control plans, and interim limits for dioxin designed to allow flexibility from mill to mill, yet require steady progress toward the lowest possible levels of dioxin discharge. These provisions would not take effect unless "triggered" by existing or future confirmation of dioxin at the mills.

(2) Placement of water quality based effluent limits for dioxin in permits for all bleached kraft mills and all other bleaching mills where dioxin is found. Compliance required by June 1992 if listed on the CWA 304 (l) list. Non detection of dioxin with good quality assurance would be defined as compliance.

(3) Monitoring requirements for wastewater, sludge and fish tissue (USEPA, 1989b).

Independent of the National Dioxin Study, EPA undertook risk assessment/management activities to assess the health risks associated with dioxin and develop a regulatory response (USEPA, 1985). Based on long-term animal studies (Kociba et al., 1978; NTP, 1982a; NTP, 1982b), EPA concluded that dioxin should be regarded as a probable human carcinogen (USEPA, 1985). In making this determination the agency used a linearized multistage model to estimate human carcinogenic risk from dioxin.

The EPA model assumed a linear dose response between dioxin and cancer, suggesting that any exposure to dioxin potentially poses some level of risk of contracting cancer. The model is exponential "approaching 100% at high doses, with a shape at low doses that is described by a polynomial function" (Anderson et al., 1990). This statistical calculation identifies an upper bound below which one can be 95% certain the actual dose-response curve will fall. "The slope of this upper 95% bound of the dose-response curve is called the cancer potency factor and has units of (mg/kg/day)" (Anderson et al., 1990).

Using female rat liver data from Kociba et al. (1978) and the linearized multistage model, EPA developed an upper bound carcinogenic potency factor for dioxin of 1.56×10^5 (mg/kg/day). In 1984, the agency published an Ambient Water Quality Criteria for dioxin of 0.013 ppq, under its CWA authority (USEPA 1984). In developing this criteria, EPA assumed the carcinogenic potency factor of 1.56×10^5 (mg/kg/day), a one excess case of cancer per one million exposed population, a dose of 2.88×10^{-10} (mg/kg/day), a bioconcentration factor of 5,000, and a 6.5 g/day consumption of fish by a 70 kilogram individual.

This criteria was offered as a model to assist states in the development of water quality-based effluent limitations for dioxin. While the EPA has primary jurisdiction over protecting the quality of U.S. waters and is responsible for developing water quality criteria, the FDA has responsibility for administering laws that ensure the purity and safety of food, such as commercial fish.

Food and Drug Administration The FDA first developed contaminant action levels in the late sixties and early seventies to regulate interstate commerce of fish. These action levels have since been used by a number of Great Lakes states to establish sport fish consumption advisories (Clark et al., 1987).

State agencies have jurisdiction over sport fisheries. The FDA consumption advisory is provided to state health departments as additional information that can be used in determining state health advisories. It is the philosophy of the FDA that the degree of control necessary to protect the sport fish consuming public "is best determined on a local basis by local authorities" (Hile, 1985). An FDA advisory provides states with several options including: the option to close a fishery completely, advise people to limit their consumption of fish from a fishery, or take actions entirely different from those described in the FDA's advisory (Hile, 1985).

Starting in 1980, the FDA initiated bilateral scientific consultations with the Canadian Health Protection Branch to share and evaluate the information available to both countries concerning dioxin. A joint laboratory effort by the agencies was undertaken to survey the extent of dioxin contamination of fish in the Great Lakes.

In deriving consumption advice, the FDA relied on a risk assessment/management approach that included the laboratory results of dioxin residues in fish, fish consumption data, analytical variability and toxicity studies. An extrapolation from animal to human using the same rodent data from the 2-year chronic feeding study as the EPA, provided the basis of the risk based advice (Kociba et al., 1978).

The FDA animal-to-human extrapolation of the no-observable-adverse effect level (NOAEL) for dioxin exposure from the rodent data indicated an intake of 1 ng/kg body wt/day as the no effect level, or based on a 70 kg individual, a total daily intake of 70 ng as the level in which no adverse effect is identified. Based on 36.8 g/day consumption of a fish (which is significantly higher than the EPA, MDNR and MDPH 6.5 g/day consumption value) containing average dioxin residue levels of 25 ppt, the total daily intake of dioxin would be 0.92 ng or 13 picogram per kilogram (pg/kg) body weight per day which is less than 1/70th of the no-effect level, less than 1/700th of the lowest-effect level, and less than 1/7000th of the carcinogenic level (Cordel, 1981 p.386).

The use of the NOAEL combined with a safety factor in calculating an acceptable daily intake for carcinogens assumes the existence of a threshold. At the time the FDA derived these initial health risks, carcinogenesis was generally believed to have a linear dose-response relationship and not a threshold. In response to criticism over the initial calculations the FDA recalculated the dioxin cancer risk using extrapolation models (MDPH, 1986). With this information the FDA concluded that there did not appear to be cause for concern for fish distributed in interstate commerce (FDA, 1981). Recent evidence now indicates that dioxin's mechanism of carcinogenesis does have a threshold (CanTox, 1989). The FDA currently basis their health risk advice on the linearized multistage extrapolation model which is based on the linear dose-response relationship.

Based on the extrapolation model, the FDA recommended advice to Great

Lakes States having a problem concerning consumption of dioxin contaminated fish by anglers and consumers is as follows:

> if the TCDD levels found in fish average less than 25 ppt, FDA believes that there is little cause for concern. On the other hand, if the average values exceed 50 ppt, the State should seriously consider more stringent methods to limit the taking of fish from these areas. For those values between 25 and 50 ppt, sport fishermen who generally consume fish only a few times a year, should restrict their intake to no more than one meal a week. Permanent residents of these areas who might consume the fish over the entire year, should restrict their intake to no more than 1-2 times a month (FDA, 1981).

This advisory is similar to the EPA's water quality criteria; they both provide information to state agencies. The states are the front line forces for implementing toxic substance policy. They have primary jurisdiction over their natural resources and are generally charged by their constitution to protect the health, welfare, and safety of the public, which includes the protection of natural resources.

3.3 Michigan Response to Dioxin Contamination

In Michigan, there are two bleached kraft mills discharging effluent to Great Lakes tributaries and one mill discharging to a municipal system. The Champion Corporation located in Quinnesec, Michigan discharges to the Menominee River which empties into Lake Michigan. The Mead Corporation located in Escanaba discharges to the Escanaba River which is also tributary to Lake Michigan. The Scott Paper Company discharges into the Muskegon municipal system. Dioxins and furans have been detected at levels of concern in effluent, sludge and fish captured adjacent to the Champion and Mead mills (IJC, 1989). Analytical results of the *U.S. EPA/Paper Industry Cooperative Dioxin Study* indicated Champion mill effluent contained 9.0 ppq of dioxin and that dioxin was not detected at 17 ppq[13] for the Mead effluent (Staniec, 1989).

Michigan policy to protect human life from the potential adverse effects of dioxin in surface waters was established in the late 1970s, in response to the Dow Chemical Company's discharge of dioxin-laden effluent to the Tittabawasee River. Both the Michigan Department of Natural Resources (MDNR) and the Department of Public Health (MDPH) developed independent regulatory responses to this contamination.

<u>Department of Natural Resources</u> The MDNR is statutorily and constitutionally charged with responsibility for the control of the discharge of pollutants into the air, soils, and waters of the state, and the protection of natural resources of the state from pollution, impairment or destruction. In response to dioxin contamination of the Tittabawasee River from Dow Chemical Company, the MDNR revised Rule 57 of the Michigan Water Quality Standards *(Mich. Admin. Code. r.323.1057).*

Rule 57 is considered a narrative water quality standard which contrasts to a numerical rule which creates absolute values specified for a list of toxic substances. As required by the Michigan Constitution, Rule 57 is an attempt at balancing natural resource protection and the maintenance of a viable economy. The philosophy behind

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[13] The dioxin effluent analysis for the Mead Escanaba mill indicated a 17.0 ppq ND (non detect) which indicates that no dioxin was found above 17.0 ppq (which was the lowest limit of the analysis). Dioxin may have been present below 17.0 ppq.

the development of the rule is best characterized by the following quote from an MDNR (1984) support document:

> If we wish to continue to enjoy our current lifestyle, we must accept chemicals as part of our daily lives, accept some level of risk associated with these chemicals, and expect some additional cost of living associated with improved treatment of wastes to remove chemicals. Most chemicals, when manufactured or used under the appropriate conditions, can be controlled so that they represent little risk of adverse impacts on human health or the environment. The goal of the proposed regulation is to assure that discharge to toxic substances is properly regulated and controlled.

The rule consists of two subrules (see Appendix B). Subrule (1) is a general statement prohibiting levels of toxic substances in the waters of the state that are harmful to human health and the environment.

> Toxic substances shall not be present in the waters of the state at levels which are or may become injurious to the public health, safety, or welfare; plant and animal life; or the designated uses of those waters. Allowable levels of toxic substances shall be determined by the commission [Natural Resources Commission] using appropriate scientific data *(Mich. Admin. Code. r.323.1057(1))*.

Subrule (2) outlines the method of developing allowable toxicant levels in the waters of the state applicable to point source discharges. Rule 57(2) guidelines detail procedures for calculating levels of toxic substances necessary to protect aquatic life, wildlife, and public health from threshold effects of toxic substances; and toxic substance concentrations which provide an acceptable degree of protection to public health from cancer (MDNR, 1984).

Rule 57(2) establishes a maximum concentration of a substance to protect humans from adverse effects resulting from contact with or ingestion of surface waters and from ingestion of fish taken from surface waters. The subrule places an upper boundary of one excess case of cancer per 100,000 exposed population for carcinogens not determined to cause cancer by a threshold mechanism.

In developing Rule 57 the MDNR convened an expert committee to advise staff on appropriate methodology. The Rule 57 Advisory Committee used the commonly accepted risks presented in Tables 3.2 and 3.3 to derive the Rule 57 risk level.

TABLE 3.2 Risks of activities used in the development of Rule 57 (MDNR, 1984).

Everyday Risks Living in the United States	Time to Accumulate a 1 in 100,000 Risk of Death	Average Annual Risk per Capita	Extrapolated to Risk/70 yr lifetime
Motor vehicle accident	15 days	2×10^{4}	1.4×10^{2}
Falls	60 days	6×10^{5}	4.2×10^{3}
Drowning	100 days	4×10^{5}	2.8×10^{3}
Fires	130 days	3×10^{5}	2.0×10^{3}
Firearms	360 days	1×10^{5}	7.0×10^{4}
Electrocution	20 months	5×10^{6}	3.5×10^{4}
Tornados	200 months	6×10^{7}	4.0×10^{5}
Floods	200 months	6×10^{7}	4.0×10^{5}
Lightening	20 years	5×10^{7}	3.5×10^{5}
Animal bite or sting	40 years	2×10^{7}	1.4×10^{5}
OCCUPATIONAL RISKS			
General			
manufacturing	45 days	8×10^{5}	5.6×10^{3}
trade	70 days	5×10^{5}	3.5×10^{3}
service/government	35 days	1×10^{4}	7.0×10^{3}
transport/public utilities	10 days	4×10^{4}	3.0×10^{2}
agriculture	150 hours	6×10^{4}	4.0×10^{2}
construction	140 hours	6×10^{4}	
mining/quarrying	90 hours	1×10^{3}	4.0×10^{2}
Specific			7.0×10^{2}
coal mining (accidents)	140 hours	6×10^{4}	
police duty	15 days	2×10^{4}	3.0×10^{2}
railroad employment	15 days	2×10^{4}	1.4×10^{2}
fire fighting	110 hours	8×10^{4}	1.4×10^{2}

Table 3.3 One in a million cancer risks used in the development of Rule 57 (MDNR, 1984).

Source of Risk	
Cosmic Rays	one transcontinental round trip by air; living 1.5 months in Colorado compared to New York; camping at 15,000 feet for 6 days compared to sea level
Other radiation	20 days of sea level natural background radiation; 2.5 months in masonry rather than wood building; 1/7 of a chest X ray
Eating and drinking	40 diet soda (saccharin) 6 pounds of peanut butter (aflatoxin) 180 pints of milk (aflatoxin) 200 gallons of drinking water from Miami or New Orleans 90 pounds of broiled steak (cancer risk only)
Smoking	2 cigarettes

The committee "felt that the risk associated with exposure to these chemicals in ambient water should generally be below that of common everyday risks and recommended that an estimated risk level of 10^{-5} (1 in 100,000) be used as the upper boundary on risk for establishing allowable levels of carcinogens in the waters of the state applicable to point discharges" (MDNR, 1984).

The rule requires that a point source discharge not develop an estimated risk to public health greater than 1 in 100,000 above background (the level of existing or dioxin associated with "natural" sources in the environment) in the surface water after mixing with an allowable receiving stream as specified by rule.

> The DNR staff feels that the actual risk to the public health associated with exposure to these chemicals [carcinogenic substances] in most surface water of the state under these conditions, will be considerably less than 1 in 100,000 and will be well below that of common everyday risks since the background rate of a person contacting [sic] cancer is 1 in 3 (MDNR, 1984).

The concentration, established by Rule 57, is used in calculating water quality based effluent limits to control the discharge of toxic substances in accordance with the State's National Pollutant Discharge Elimination System (NPDES) authority. The Rule 57 concentration is calculated using the formula for estimating excess lifetime cancer risk (risk = potency x dose).

The MDNR derived a cancer potency factor for dioxin from the same female rat liver data (Kociba et al., 1978) used by the EPA and the FDA. MDNR justification for the use of this data was, "because the study quality is unsurpassed and because the data yielded the highest potency value (MDNR, 1989a)." Using the multistage model (Global 79) to estimate the upper bounds of risk at low doses, the MDNR derived the potency of dioxin of 1.51×10^5 mg/kg/day (MDNR, 1989a). This potency value is then used in calculating a Rule 57(2) value of 1.4×10^{-5} ng/l using the following formula (see Appendix C for calculations):

$$C = \frac{D \times W_h}{WC + (F \times BCF)}$$

where: C = Concentration of carcinogen (mg/l)

D = Dose[14] (6.62×10^{-5} ng/kg/day)

W_h = Weight based on a 70 kg individual[15]

[14] MDNR, 1989a

[15] The Rule 57 Advisory Committee recommended the 70 kg value since it has been widely accepted in the scientific community for dealing with diversified populations of people. The EPA uses this number in the development of water quality criteria (MDNR, 1984).

WC = 0.01 l/day for surface water and 2 l/day for drinking water[16]

F = Fish consumption[17] (0.0065 kg/day)

BCF = Bioconcentration factor (51,600)

The Rule 57(2) value is then used to calculate a monthly average water quality based effluent limit (WQBEL) using the following relationship:

$$WQBEL = \frac{V((1/4\ QR) + QE) - CRQR}{QE}$$

where: V = Rule 57 (2) value (1.4×10^{-5} ng/l)

QE = Outfall design maximum flow (mgd)

QR = 95% exceedance flow for river[18] (mgd)

CR = Ambient river dioxin concentration (zero assumed)

The effluent limit formula is applied to individual industrial and municipal discharges which require NPDES permits. The values used in the development of the effluent

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16 The 0.01 l/day value for surface waters not protected for drinking water is to account for incidental exposure such as absorption through skin or ingestion of small quantities while swimming (MDNR, 1984). The value of 2.0 liters for surface waters protected as a drinking water source is recommended by the EPA for establishing drinking water standards (MDNR, 1984).

17 The 0.0065 kg of fish per day is also used by the EPA. It is based on average national fish consumption, including marine and shell fish. An estimate of consumption of inland fish by Michigan anglers was calculated at 0.0040 kg/day, however, MDNR decided to use the larger EPA number "because it was calculated on better data and was slightly more conservative" (MDNR, 1984).

18 "The 95 percent exceedance flow is the flow which is exceeded in the river 95 percent of the time" (MDNR, 1984).

limit will vary based on river flow characteristics and maximum discharge rate for each discharge source. The water quality based effluent limit for the Mead Escanaba mill is 0.022 ppq.

Department of Public Health The MDPH has the responsibility of protecting public health and in that capacity to provide the public consumption advice related to sport-caught fish. This is primarily a risk communication function rather than a regulatory mandate. The MDPH provides health advisory information in a booklet which is distributed to anglers who obtain a fishing license. The agency provides the advice, however, it is up to individual fisherpersons to comply. The MDPH does not police Michigan lakes and streams to ensure that fisherpersons are complying with the advice, however, they do monitor areas of contamination in an effort to maintain timely advisories. Fish consumption advisories are based on tissue concentration of contaminants in species and size classes of fish in relation to some trigger level (Foran and VanderPloeg, 1989). When tissue concentrations exceed a health advisory trigger, consumption advise ranging from restrict consumption for certain groups, such as pregnant women and children, to do-not-eat is issued.

Although U.S. Food and Drug Administration or U.S. Environmental Protection Agency enforcement guidelines exist for some contaminants, the MDPH has historically established specific sport fish consumption advisories for Michigan anglers. The MDPH uses a risk assessment/management approach in developing health advisory triggers. The MDPH's selection of an "acceptable contaminant concentration" is an evolving process which is guided by the following factors: fish consumption patterns, contaminant level trends, vulnerable population, history, choice of risk models and adoption of various assumptions used in mathematical extrapolations (MDPH, 1986).

In 1986, the MDPH's Center for Environmental Health Services selected 10 part per trillion (ppt) as a trigger level for establishing an advisory for dioxin contaminated fish in the Tittabawasee River. The advisory, including similar conservative assumptions, was latter extended to include other Great Lakes tributaries. The MDPH dioxin risk assessment, like that of the EPA, FDA, and MDNR, is based on the Kociba et al. (1978) female rat liver data. The MDPH also used a multistage model for carcinogenesis, because it is "generally regarded as the most biologically defensible of the low dose extrapolation models (MDPH, 1986 p.6)."

The MDPH risk modeling process included the following conservative exposure assumptions:

1. That the level of TCDD contamination would remain constant at the present level for the lifetime of the fish consumers.

2. That persons consume uncooked skin-on fillets for a lifetime and that all of their fish come from the Tittabawasee River (MDPH, 1986 p.10).

The uncooked skin-on fillet significantly increases the conservative nature of their health advisory trigger. Stachiw et al. (1988) demonstrated that restructured carp fillets lost between 35 and 67 percent (with an average of 54.6 percent) of dioxin by cooking the fish in a manner which allows the fish oils to drip away from the edible portion of the fish. Dioxin may also be reduced by trimming the fatty areas of the fillet prior to cooking (MDPH, 1986).

The MDPH used the Center for Disease Control (CDC) risk ranges derived for sport fish collected in the Tittabawasee River (Table 3.4) and associated doses in deriving their health advisory trigger. The CDC ranges were based on a one excess case of cancer per 100,000 exposed population and calculated using a cancer potency factor of 3.57 x 10^4 mg/kg/day derived from a multistage model (MDPH, 1986). Through their risk assessment process the MDPH concluded that "TCDD concentrations at or below 10 ppt would result in an insignificant increased cancer risk to the Michigan sport-fishing community (MDPH, 1986 p.10)."

Table 3.4 Evaluation of sport fish caught native to the Tittabawasee River.[1]

Number	Size Length (inches)	Range Weight (pounds)	Number Tested	2,3,7,8 TCDD Quantitation (parts per trillion) Range	Mean	95% C.I.
White Bass	9.6 - 13.8	0.4 - 1.1	13	5.7 -15.0	8.0	4.24< X <11.76
Crappie	7.9 - 10.4	0.2 - 0.6	9	2.8 - 4.5	3.9	3.02< X <4.78
Walleye	18.1 - 27.6	2.0 - 6.9	14	2.5 - 14.0	5.28	3.36< X <6.64
Smallmouth Bass	14.6 - 15.4	1.6 - 1.8	3	2.8 - 6.4	-	
Pike	21.3 - 28.0	2.0 - 4.3	3	6.1 - 15.0	-	
All species	-	-	26[2]	-	6.76	5.12< X <8.4[3]

1 MDPH, 1986

2 14 walleye, 1 composite of 3 crappie, 1 composite of 3 white bass, 3 pike and 3 smallmouth bass

3 Assuming the samples analyzed are representative of fish of these species in the Tittabawasee River, the mean 2378 TCDD concentration in part per trillion would fall within this confidence interval 95% of the time.

3.4 Inconsistencies in Michigan's Dioxin Policy

The risk assessment/management process is employed by a number of regulatory agencies for a variety of regulatory programs. The purpose behind individual regulatory programs influences the assumptions used in the risk assessment/management process. The Michigan Environmental Council has identified three purposes for which risk assessments might be conducted (Bedford et al., 1990):

1. preventative purposes--where the purpose of the assessment is to develop controls on pollution sources that will prevent future harm;

2. corrective purposes--where the purpose of the assessment is to determine the appropriate response by either a responsible party or government agencies to an existing environmental exposure; and

3. communication purposes--where the purpose is to provide potentially exposed individuals with usable information concerning the hazards associated with toxic chemicals.

A water quality based effluent limit is an example of a preventative based regulatory program, whereas, a health advisory trigger is communication based. The effluent limit is a level that is prescribed to a discharging firm, and in effect states, "that at a certain level the toxic substance in your effluent will provide no harm to human health or the environment." Similarly, the health advisory trigger communicates to the angler that fish below a certain level are safe to eat. Because an effluent limit is issued on a three year cycle, the limit must be conservative enough to provide for risk and uncertainty over a three year period. In contrast to the prudent effluent limit, a health advisory trigger is based on the best currently available data and can be readily adjusted to account for new information.

Both of these regulatory activities encompass a substantial degree of uncertainty. Uncertainty exists among the epidemiology studies which have been used as a basis for assuming dioxin is carcinogenic in humans, as well as in interpreting which tumors to count and how to count them. Uncertainty exists in the "acceptable" risk level that has been assumed to provide society with an "adequate" margin of safety. There is uncertainty in the determination of how much fish an individual actually eats. Risk managers are faced with uncertainty at nearly every stage of the risk assessment/management process, yet it is still a valuable tool in protecting the health, welfare, and safety of society as long as the purposes are well defined and the assumptions are justified.

Table 3.5 illustrates some specific differences between EPA, FDA, MDNR, and MDPH risk assessments for dioxin. Each agency relies on a cancer potency factor for dioxin which is based on one particular rat study, Kociba et al. (1978), and all use a multistage model. However, they derive different cancer potency factors. The cancer potency factor is the foundation for the risk assessment of dioxin. A difference in magnitude as exhibited between the environmental agencies, EPA and MDNR, and the public health agencies, FDA and MDPH, can create a significant gap in the safety margin provided by the risk management process. The average margin of safety provided by the environmental agencies is 4.55×10^{-5} compared to the 3.0×10^{-4} risk level of the public health agencies.

Table 3.5 State and federal agency dioxin potency derivations (MDPH, 1986).

Agency	Study Used for Extrapolation	Tumor Type	Model	Potency (mg/kg/day)	10^{-5} Risk (pg/person/day)
EPA	Kociba	Liver Lung Nasal	Multistage	1.56×10^{5}	4.5
MDNR	Kociba	Liver	Multistage	1.51×10^{5}	4.6
CDC/MDPH	Kociba	Liver	Multistage	3.57×10^{4}	20.0
FDA	Kociba	Liver	Multistage	1.75×10^{4}	40.0

One significant difference between the MDPH and FDA values and the MDNR and EPA values is the surface area species conversion factor used by MDNR and EPA in their risk assessments. Both the EPA and MDNR assume different species are equally sensitive to the effects of dioxin if they absorb the same dose per unit body of surface area (Anderson et al., 1990). As a result, the EPA and MDNR extrapolate the rat data on the basis of body surface area. The MDPH believes the factor, which multiplies the risk by approximately 5.4, is difficult to justify and basis its extrapolation on a body weight scaling factor (MDPH, 1986). Another discrepancy in the risk assessment of dioxin is EPA's inclusion of nasal and lung tumors which have the potential to over estimate cancer risk (MDPH, 1986).

While the program purposes of the MDNR effluent limit and the MDPH health advisory trigger are different, combined, they form a policy with the specific purpose of protecting Michigan citizens from the adverse effects of dioxin exposure. To answer the researchable question presented in Chapter 1, two initial inquiries must first be addressed. The first question, is: **does the level of dioxin permitted into the environment, by water quality-based effluent limits, when bioaccumulated by fish, provide the same margin of safety as the MDPH health advisory triggers?** The policy analysis model presented in the next chapter will provide insight into the effectiveness of the Michigan policy as well as pose the second question which concerns the costs of a policy.

CHAPTER FOUR: ECONOMIC CONCEPTS FOR EVALUATING PERSISTENT TOXIC SUBSTANCE POLICY

Persistent toxic substance policy has often relied on regulations that are based primarily on risk assessment and on the notion of some acceptable risk (e.g. one excess case of cancer per one million exposed individuals or one excess case of cancer per one hundred thousand exposed individuals) with little regard for the actual costs involved. The science of economics provides the risk manager with a number of tools which can add the dimension of personal values to the policy development process. As risk managers debate the issue of "how safe is safe?" economic analysis can provide a means of measuring an individual's acceptance of risk. This chapter will provide a discussion of how economics can be used to quantify levels of acceptable risks and how they can be used to evaluate the human impacts of dioxin policy decisions.

4.1 Economics as a Means to Analyze Policy

Economics is the study of how individuals and society make choices (Nicholson, 1985). Individuals express preferences by placing value, often in monetary terms,[19] on objects of choice. Because individuals exhibit different tastes

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[19] Three basic value relationships which influence policy are identified in the literature: values expressed by individual preferences; public preference value which is expressed through social norms; and functional physical ecosystem value. Individual preferences are assigned values in terms of willingness to pay and willingness to accept compensation, public preferences are held values which are aimed at influencing individual preferences, and physical ecosystem

and preferences, any object of choice, often referred to as a good (which implicitly includes services as well), may have a number of assigned values. For example, the choice to develop a pulp mill may be perceived as beneficial to those who are seeking employment. However, the development may seem detrimental to those who fear ~~the~~ it will have a negative impact on the environment. Those individuals who are seeking employment will place a higher value on the pulp mill and favor the decision to develop the mill. The individuals who are fearful that a pulp mill will cause environmental degradation will place a lower value on the pulp mill and oppose the development decision.

<u>The Concept of Value</u> Economic values are determined by: (1) individual demand for an object, (2) a seller's ability to supply the object, and (3) the technical capacity to produce the object (Talhelm, 1990). Demand expresses an individual's willingness to pay to buy an object, while supply expresses willingness to accept payment for selling an object. Figure 4.1 illustrates this concept.

The demand function is an expression of an individual's demand (which includes factors influencing demand such as preferences, price, and budget) for a good. It shows the maximum quantity individuals would be willing to buy at each given price. The supply function expresses the seller's preferences (which includes the seller's ability to produce goods from various inputs) for accepting compensation

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value is a non-preference value that is measured in natural sciences (Pearce and Turner, 1990).

for a good, and illustrates the minimum price at which a seller is willing to sell a quantity of the good. Where demand and supply intersect (A) a particular price (b) and quantity sold (c) is observed in the market (Randall, 1987).

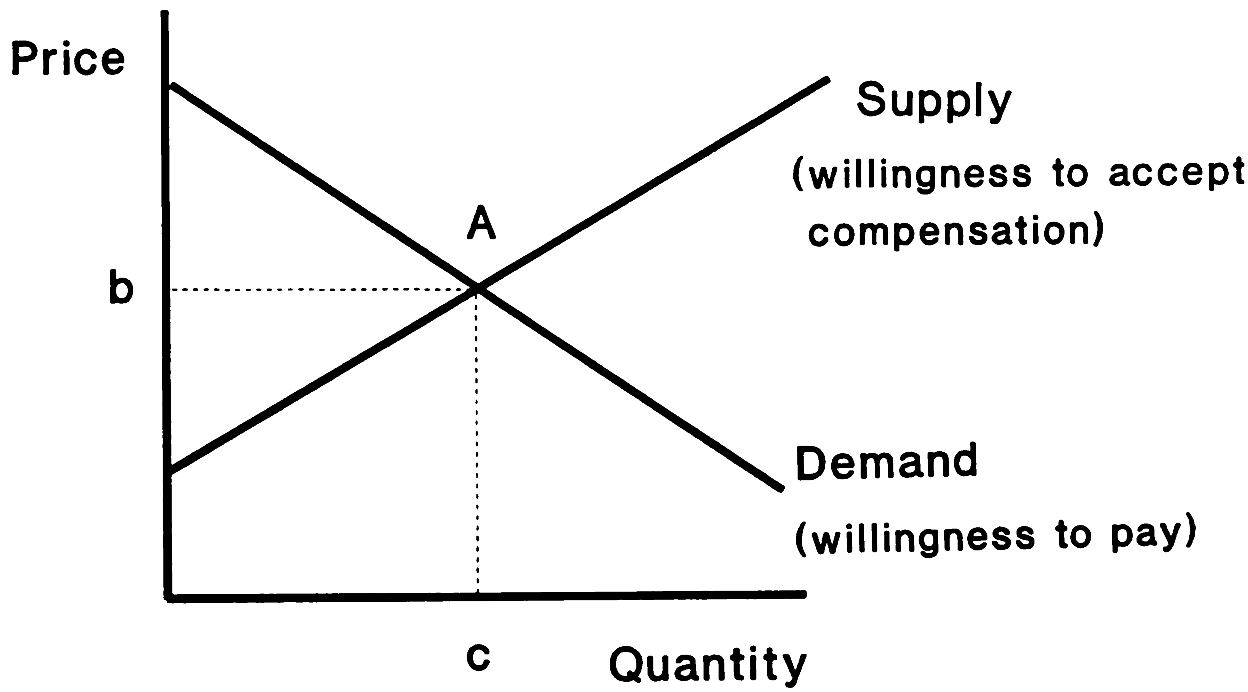

Figure 4.1 Market diagram - supply and demand as determinants of economic value.

In the neoclassical sense, the market defines a set of economic laws which govern economic activity. In the market individuals are thought to maximize their utility. The amount of personal utility yielded determines the economic value of marketable commodities, unpriced environmental goods and services, or sympathy for posterity (Pearce and Turner, 1990).

Maximum Social Wellbeing Welfare economics is based on the concept that individual preferences are revealed by the choices they make, and "efficiency and consistency of choice reflect rational behaviour" (Pearce and Turner, 1990). Pearce and Turner state that "'the basic theorem of welfare economics' seeks to legitimise rational behaviour as being socially desirable and also to justify some government intervention to improve the conditions under which individuals make choices.[20]" At the heart of welfare economics is the theory of social welfare maximization at a minimum cost. Randall (1987) defines maximum social well being as a "condition in which society is as well off as it can possibly be, given its resource base, its productive technology, and the tastes and preferences of its members."

The Pareto criterion is used as a measure of maximum social wellbeing. The criterion, named for the Italian economist Vilfredo Pareto, refers to a Pareto optimal solution as one in which no one individual can be made better off without necessarily making some other individual worse off. The term Pareto efficiency is often used to describe an allocation as "efficient if conditions cannot be made unambiguously better" (Nicholson, 1985).

The materials balance approach is one market model of environmental

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[20] There is much debate among economists concerning the actual mechanism of individual human behavior. Neoclassical economists accept the 'rational and egotistic person' as the model of human behavior. Other economists support the humanistic paradigm which rejects the 'rational person' and accepts a behavioral psychology approach emphasizing a "hierarchy of needs in place of a flat plane of suitable wants" (Pearce and Turner, 1990).

management adopted by economists to measure Pareto efficiency.[21] This approach assumes an economic optimum (Pareto efficient) level of pollution can be defined, given certain assumptions. The level of pollution at which the costs of abating the pollution are equal to the costs of the damage caused by the pollution, is often referred to as the "economic optimum level of pollution" (Freeman et al., 1973; Randall, 1987; Pearce and Turner, 1990). However, Pearce and Turner point out that due to deficiencies in data the optimum situation is not a practical policy objective. They state that "instead society sets 'acceptable' levels of ambient environmental quality, and policy instruments [such as effluent limits and health advisory triggers] are directed at these standards. The analytical task is to seek out the least-cost policy package sufficient to meet acceptable ambient quality standards."

4.2 *Using the Concept of Pareto Optimal Solution to Evaluate Policy*

A variety of criteria have been developed to identify the "least cost policy package." Bro et al. (1987) suggest that a rational response to controlling public exposure to toxic substances is to consider the magnitude of the threat relative to the costs and benefits of pursuing corrective action or otherwise avoiding risks. The

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[21] The property rights approach is another widely used market model. According to Pearce and Turner, (1990 p. 17) in the market model, "environmental pollution is a form of market failure, usually because of the over-exploitation of resources held in common property or not owned at all. The market fails therefore when property rights are inadequately specified or are not controlled by those who can benefit personally by putting the resources to their most highly valued use."

costs of abating dioxin contamination are primarily the private costs a firm incurs through process changes. These costs are generally capital costs associated with adopting new abatement process equipment, operational costs associated with changing a process requirement such as adding a specific chemical to the process, or a combination of both. The benefits of dioxin abatement are primarily social in nature, realized in terms of decreased risk to society from adverse effects associated with swimming in, or drinking, or eating fish from surface waters.

In general, economists view zero discharge as a near impossible pollution abatement goal. They argue that the total prohibition of emissions would eliminate the production of a significant amount of necessary goods as well as luxuries (Dewees et al, 1975 p. 2). They criticize policy goals for not accounting for total or marginal benefits and costs. Randall (1987 p.372) has suggested that the 1972 Clean Water Act, with its target of zero discharge of pollutants into the nation's waterways by 1985, is an extreme example of an "economically unrealistic" and inflexible goal for water pollution abatement.

Following traditional abatement theory, the primary question addressed by environmental economists then becomes not whether to allow pollution but how much pollution to allow (Dewees et al., 1975 p.2). In a society that must meet its needs from limited resources, the answer lies in the distribution of those resources among competing needs.

The search for the optimum pollution level is often defined in terms of costs or benefits. Dewees et al. (1975) list the following objectives for environmental policies that can be used to evaluate alternative policy choices: Pareto efficiency, abatement efficiency, administrative efficiency, promotion of technological progress, and the distribution of control costs among polluters.

The concept of maximizing social welfare refers to achieving a pollution control level such that any further control would impose abatement costs greater than savings in pollution damage or welfare benefits that would result (Dewees et al, 1975 p.16). Pareto efficiency is achieved at the point at which no person could be made better off by more or less investment in pollution control without making others worse off.

According to Dewees et al. (1975) the empirical determination of optimal pollution control levels is difficult to achieve and the search for abatement efficiency frequently replaces the search for social efficiency. Abatement efficiency takes the environmental quality standard or goal as given and examines only the cost of meeting that goal.

Administrative efficiency is the search to achieve a given level of control at the least possible administrative cost. This objective is sometimes viewed as striking a balance between the costs of abatement, the benefits of reduced emissions, and the costs of administering a program (Dewees et al., 1975 p. 16).

The promotion of technological progress is a fourth objective. If control costs can be reduced by new technology then it is important that policies foster more rapid technological progress. A final objective deals with the distribution of control costs among polluters and of the benefits received by those exposed to the effects of pollution or its control. Abatement efficiency stresses the minimization of total costs. Depending on specific operational configurations, procedures and costs, under this criteria, firms producing similar products might suffer extreme variations in abatement costs or percentages of abatement.

Dewees et al. (1975) suggest that one problem implicit in numerous environmental policy considerations, but not explicitly addressed in their criteria, is that of uncertainty. They point out that the information about costs of pollution control or consequences of continued emissions is not well documented and suggest that policy must be made without a definite understanding of the comparative consequences for human health or economic growth of alternative policies (Dewees et al, 1975 p. 17). The policy analysis model developed in Chapter 5 addresses this information deficit by incorporating the costs associated with policy decisions into the policy decision making process.

The policy analysis model is built upon the fundamental pollution control model which determines a Pareto optimal solution (Freeman et al. 1973). Although in reality an actual optimal solution is impossible, a theoretical optimal solution can provide valuable information concerning the Pareto efficiency of a policy. The pollution control model as described by Freeman et al. (1973) encompasses the materials balance approach to environmental management. This fundamental benefit-cost analytic approach is a traditional choice among economists in determining the economically efficient level of persistent toxic substances (Moore, 1984).

The concept of zero discharge, as advocated by the U.S. Clean Water Act and the Great Lakes Water Quality Agreement, is an example of setting an acceptable level of ambient environmental quality. Rather than a policy endpoint, zero discharge is a goal designed to promote technological progress. Pearce and Turner (1990) suggest that zero discharge can only be a goal, rather than an actual endpoint, stating that the laws of thermodynamics suggest that a nonpolluting product can not exist.[22] They state that in order to achieve zero pollution there would have to be zero economic activity. Therefore, in the absence of zero discharge an optimal level of pollution is sought to maximize social wellbeing.

The pollution control model is often referred to as a cost minimization model[23] because economic theory considers social welfare to be maximized when the total cost of pollution is minimized (Dewees et al., 1975, Freeman et al., 1973). Figure 4.2 illustrates this concept. The curve sloping upward to the left from Q_1 represents the total cost of decreasing human risks from a persistent toxic substance such as dioxin, and is labeled "abatement costs." Abatement costs are those costs that a firm incurs to control the release of a regulated toxic substance. The curve sloping upward to the right from Q_3 represents the total cost of increasing human risks from dioxin, and is labeled "damage costs." Damage costs are the costs associated with "adverse impacts on human health, outdoor recreation and aesthetic opportunities,

[22] The second law of thermodynamics implies that "any system and its surroundings as whole spontaneously tend towards increasing randomness or disorder" (Miller, 1982).

[23] It is this concept of cost minimization, whether it is referred to as the pollution control model or the cost minimization model, that is the foundation for the policy analysis model developed in this paper.

ecosystem productivity, and industrial productivity" (Moore, 1984).

The total cost of pollution is the sum of the damage and abatement costs, shown by the heavy line. Q_2 indicates the minimum of this total cost curve and is labeled the optimum level of pollution (Freeman et al., 1973; Randall, 1987; Pearce and Turner, 1990). In this paper optimality is used as a guide in determining the efficiency of existing policy, illustrating a range of values and not one specified "economically optimal" level of pollution.

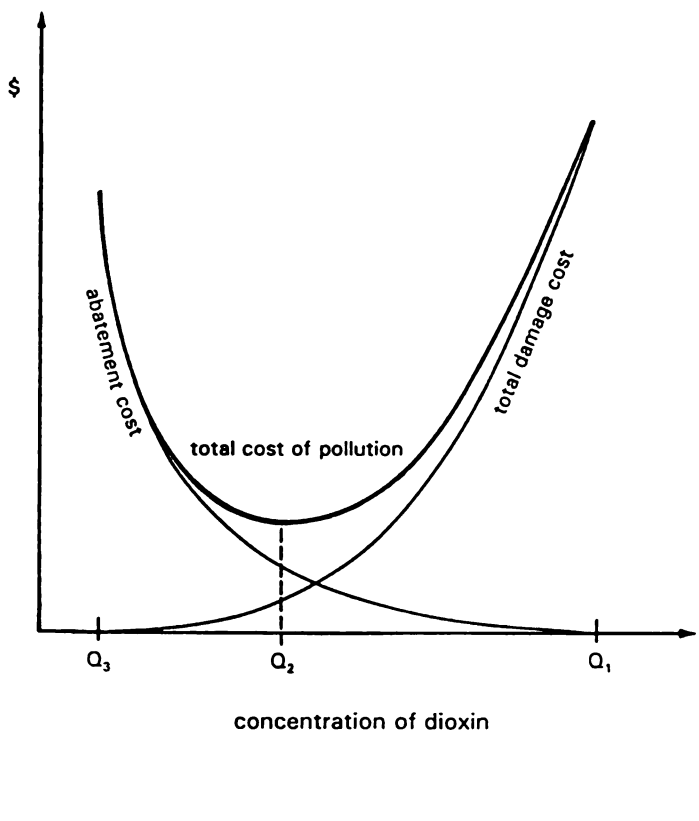

Figure 4.2 The optimum level of pollution.

This optimum level of pollution, Q_2, is not static. A technological innovation could be discovered that could drastically increase abatement efficiency, shifting the abatement cost curve to the left thereby indicating a new optimal level of pollution, Q_4 (Figure 4.3). Similarly, if new epidemiological data indicated that a toxic substance which was once thought to be characterized by a non threshold mechanism was found to actual have a threshold, the damage curve would shift to the right and a new optimal level of pollution would be identified, Q_5 (Figure 4.4).

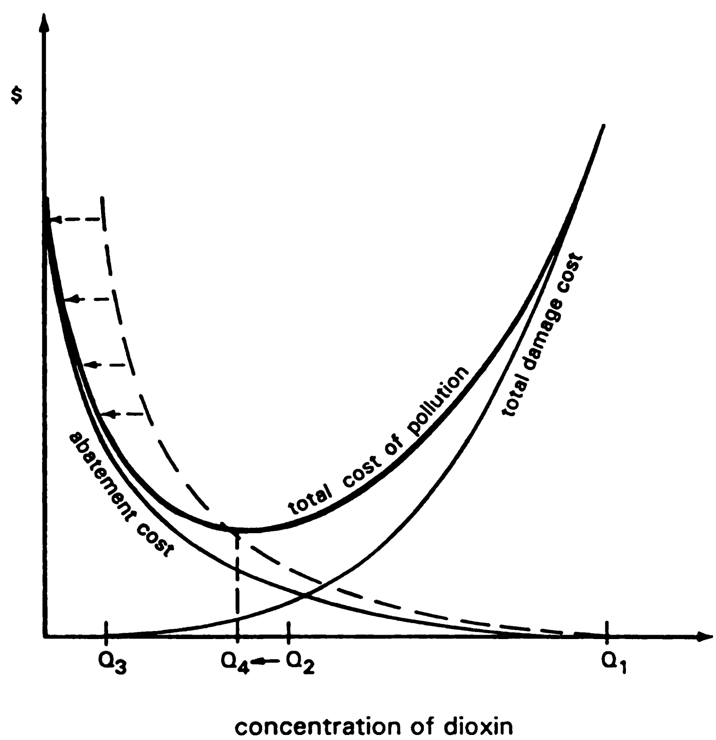

Figure 4.3 The optimal level of pollution after technological innovation.

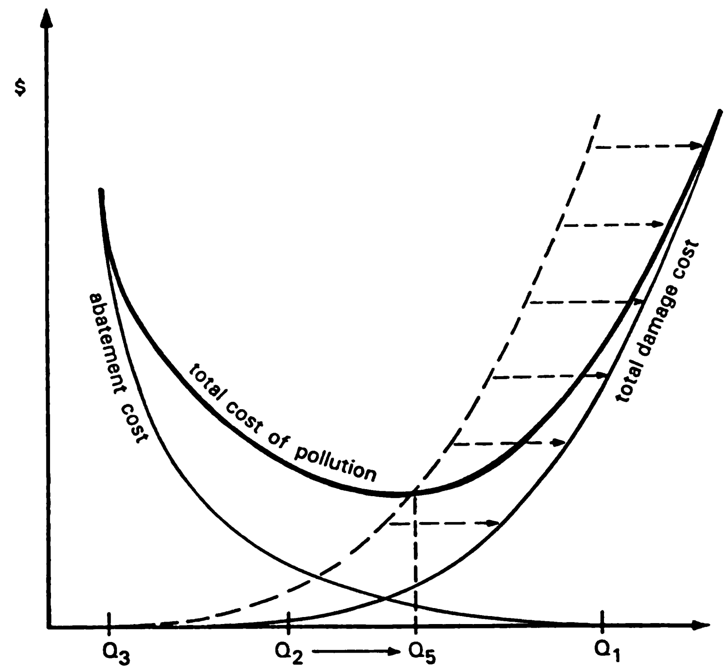

Figure 4.4 The optimal level of pollution after new epidemiological evidence indicates a toxic substance characterized by a threshold.

4.3 Estimating Damage Caused By Persistent Toxic Substances

Depending on the concentration in effluent discharge, persistent toxic substances can cause substantial damage to the environment. If released in large enough quantity and high enough concentration, toxic substances may prove to be acutely toxic resulting in immediate severe damage to aquatic organisms. However, if a toxic substance, such as dioxin, is released at a very low concentration the environmental damage is less certain.

Due to dioxin's persistent nature small amounts tend to accumulate in the environment. If the substance is taken up by an organism it will bioaccumulate in its tissue. As other organisms prey upon the contaminated organism, the dioxin undergoes biomagnification as it is cycled up the food chain. As a result, the release of a minute amount of dioxin at a level below any health concern can be magnified to a quantity above levels deemed to be safe, such as the MDPH's 10 ppt health advisory trigger.

Because deriving abatement costs is a relatively straight forward exercise which consists of valuing the application of a particular pollution control technology, the critical component of a useful policy analysis model lies in deriving damage cost. Hufschmidt et al. (1989) provide a simplified schematic for understanding the steps in deriving a point estimate of the damage cost caused by the discharge of a toxic substance (Figure 4.5).

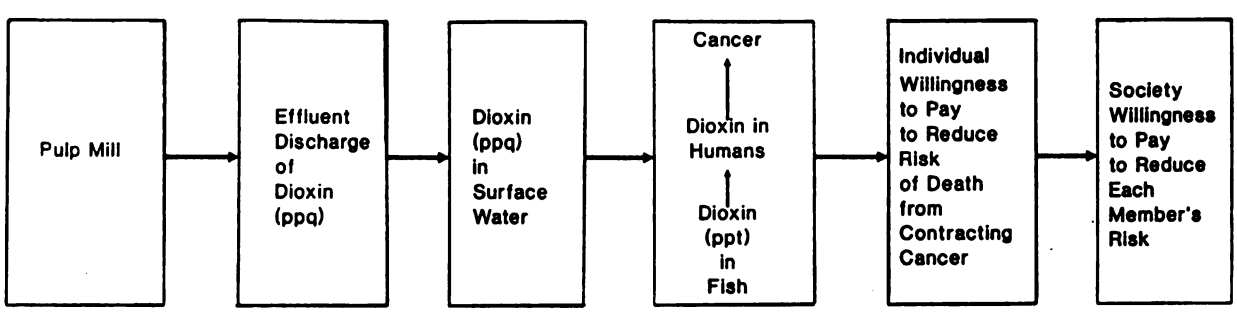

Figure 4.5 Estimation of social damage due to the release of emissions from an economic activity (Hufschmidt et al, 1989).

The economic activity in this study has been identified as pulp production which contributes an effluent discharge of dioxin into surface water. The primary chemical characteristics that affect the fate and transport of dioxin in the environment are persistence and bioaccumulation. The actual health effects on individuals and aquatic organisms are uncertain, however, regulatory consensus has identified dioxin as carcinogenic to mammals.

In addressing the researchable question the first inquiry (described in Chapter 3) to be addressed by the policy analysis model is: does the level of dioxin permitted into the environment, by water quality-based effluent limits, when bioaccumulated by fish, provide the same margin of safety as the MDPH health advisory triggers? However, the answer to this inquiry presents only one half of the answer to the researchable question. Assuming that over a period of time some level of dioxin (to be determined by a regulatory agency) will cause cancer in exposed organisms, to answer the question completely and fully evaluate Michigan's dioxin policy a second inquiry must be addressed by the policy model: **what is the value of the damage caused when organisms are exposed to dioxin in the environment?**

<ins>Willingness to Accept Values for Wildlife Damage</ins> The majority of environmental goods and services fall outside the boundaries of traditional markets. Angling is an example of such an environmental good. Anglers do not normally pay anyone for the privilege to extract wild trout from streams, nor pay for the actual fish (Talhelm,

1990).[24] Talhelm points out that "the private market does not make available angling for wild trout at a going market price." While trout fishing may not have specific market costs it certainly does posses some value or anglers would not pursue the activity. There are also transportation and other costs which are not normally accounted for in the market. In the absence of defined markets for environmental goods and services, economists have relied on non-market valuation techniques to place values on recreation, the existence of wildlife, aesthetics, and other environmental amenities.

The three primary tools for estimating non-market values are: (1) the travel cost and (2) hedonic valuation methods which derive willingness to pay and willingness to accept from "careful observations of how users exchange the cost of use for the amount of use," and (3) contingent valuation which "carefully asks people how much they would pay or accept if they had to, as if there were a market" (Talhelm, 1990).

A significant difference between contingent valuation and market valuation is the resulting willingness to pay and willingness to accept values. In defined markets willingness to pay always equals willingness to accept, whereas, in contingent valuation an individual's willingness to accept may be substantially greater than

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[24] The term "pay" here refers to transactions in the market for the cost of fishing on state water bodies. It does not refer to the regulatory costs of obtaining a permit which provides permission to capture fish in state waterbodies.

willingness to pay.[25]

One simplified attempt to value the damage dioxin exposure has on wildlife is to ask people what they would be willing to pay to ensure the existence of the quantity of each species currently living in an affected area; or, what they would be willing to accept for the loss of each individual animal. Given that dioxin is carcinogenic to various species, one assumption a willingness to pay/accept study could hold would be that a specific amount of dioxin in a river over a period of time would cause death to those species currently existing in the ecosystem. A census of the species and the amount of individual animals would be taken and the values provided by the respondents would be multiplied by the quantity of each species. Talhelm suggests that a corrective factor of four be applied when using willingness to pay to provide a value comparable to one derived using willingness to accept.

The following is an example of how the willingness to pay/accept concept could be used to provide an estimate of wildlife damage from dioxin in the Escanaba River. A simplified estimate of fish eating birds and mammals existing near the Mead Corporation's Escanaba pulp mill, on the Escanaba River, is provided in Table 4.1. Similarly, an estimate of fish living in the Escanaba River near the Mead pulp mill is provided in Table 4.2

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[25] Economists have found that when people are randomly asked to sell a possession their willingness to accept cash for the item is about four times greater than their willingness to pay for the same item (Talhelm, 1990).

Table 4.1 Gross estimate of fish eating birds and mammals near the Escanaba pulp mill on the Escanaba River (Aartila, 1990).

Species	Estimated Quantity
Brown Bear	1
Raccoon	10
Muskrat	15
Opossum	10
Great Blue Heron	12
Green Heron	6
Eagles	8
Herring/Ring Billed Gulls	9,000
Mergansers	50

Table 4.2 Gross estimate of the quantity of fish in the Escanaba River downstream from the Mead Escanaba pulp mill (Wheelan, 1990).

Species	Estimated Quantity	Estimated Weight (lbs)
Smallmouth	85	7.5
Rock Bass	140	7.5
Walleye	18	15.9
Northern Pike	14	4.7
Bluegill	31	0.7
Yellow Perch	41	1.0
Forage fish	3,031	57.0

In his 1990 study, *Recommended Values for Computing Fair Restitution to the Citizens of Minnesota for Fish and Wildlife Illegally Killed, Injured or Possessed,* Talhelm applied contingent valuation techniques to derive willingness to accept values for fish and wildlife. Applying these values to the estimated numbers of fish, birds, and mammals provides a gross assessment of the value of the estimated fish and wildlife populations in or near the Escanaba River in the vicinity of the Mead pulp mill (see Table 4.3).

This \$102,519 value is an estimate provided merely to illustrate the complexities involved in valuing fish and wildlife populations. This example clearly neglects to account for the persistent nature of dioxin and the potential for future harm to wildlife in the area. It fails to account for transport of the compound to other areas within the Great Lakes Basin and any resulting negative impacts. The population count is merely an educated guess and by no means an accurate census. The value in this example, although certainly underestimating wildlife damage, does provide a comparison for potential human damage. To provide a more accurate assessment of wildlife damage values from dioxin an actual willingness to pay/accept study would need to be undertaken in the affected area.

Table 4.3 Gross estimated willingness to accept values for fish and wildlife in the vicinity of the Mead Escanaba pulp mill.[26]

Species	Quantity	Total Pounds	Base Value ($)	Total Value ($)
Brown Bear	1	-	400.00	400.00
Raccoon	10	-	30.00	300.00
Muskrat	15	-	30.00	450.00
Opossum	10	-	10.00	100.00
Great Blue Heron	12	-	100.00	1,200.00
Green Heron	6	-	100.00	600.00
Eagles	8	-	500.00	4,000.00
Herring/ Ring Billed Gulls	9,000	-	10.00	90,000.00
Mergansers	50	-	40.00	2,000.00
Smallmouth (Black Bass)	85	7.5	20.00	1,700.00
Rock Bass	140	7.5	3.00	420.00
Walleye	18	15.9	30.00	540.00
Northern Pike	14	4.7	30.00	420.00
Bluegills	31	0.7	5.00	155.00
Yellow Perch	41	1.0	5.00	205.00
Forage fish	3,031	57.0	.50/lb	29.00
Total Value				102,519.00

Willingness to Pay Values for Reducing Risk of Death Economists point out that "in a world of scarcity difficult decisions concerning tradeoffs between health and other desirables are unavoidable," and suggest that "essential to efficient provision of

26 Base values taken from Talhelm (1990), wildlife population estimates provided by Aartila (1990) and fish population estimates provided by Wheelan (1990).

safety, and the environment is correct valuation of risks to human health" (Berger et al., 1984). To evaluate policies that reduce the risks individuals experience in their daily lives economists must first determine a "value of life." Blomquist (1979) suggests that the "value of life" is based on "changing the probability of survival by a small amount." Economists have adopted the "willingness to pay" framework in their attempt to place value on life and risk reduction (Blomquist, 1979; Smith and Desvousges, 1987; and Fisher et al., 1989).

Economists are quick to point out that although the risk of death is one (everybody will die) there are activities which, if undertaken, have been statistically shown to provide a greater chance of non natural death than other activities. These are the types of statistics the MDNR Rule 57 committee used in their determination of 1 in 100,000 acceptable risk level (refer back to Tables 3.2 and 3.3). For example, based on a 70 year working lifetime, MDNR Table 3.2 indicates a farmer has a 4 in 100 chance of dying on the job, while a government worker has 7 in 100 chance of dying on the job in the same period (MDNR, 1984).

According to Fisher et al. (1989), "a willingness-to-pay estimate values the change in well-being that would result from changing the risk of death; it is measured by how much of other goods and services a person is willing to give up to get that reduction in the risk of death." Because risk is not directly traded in traditional markets, economists rely on willingness to pay studies to place value on risk. Three techniques generally used are: (1) wage-risk studies, (2) contingent market studies, and (3) consumer market studies. Fisher et al. (1989) define the techniques as follows:

> Wage-risk studies estimate the wage premium associated with greater risks of death on the job. The contingent valuation approach poses a hypothetical market situation to survey respondents who are asked about their willingness to pay for alternative levels of safety. [And] consumer market studies examine the observable tradeoffs people make between risks and benefits in their consumption decisions.

These willingness to pay studies focus primarily on avoidable or voluntary risks. Since voluntary risks provide options, whether or not to take the more risky job for example, values can be readily obtained through wage-risk or contingent valuation studies. Individual willingness-to-pay values can be summed in an effort to determine what a group would be willing to pay for reducing each member's risk by a small amount. The value a group is willing to pay to reduce a members risk is referred to as the value of a statistical life (Fisher et al., 1989).[27]

The following example using data from Delta County[28] will illustrate this concept. If each of the 8,242 fishing license holders in Delta County were willing to pay $20 for a reduction in risk from 3 deaths per 8,242 to 1 death per 8,242, the total willingness to pay would be $164,840 ($20 x 8,242 people) and the value per statistical life would be $82,420 (with two lives saved - the value for each life is $82,420, which when summed equals the total willingness to pay: $164,840).

The concept of reducing the risk of death from avoidable behavior can be

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[27] For clarification purposes, the **value of a statistical life** is the value a group is **willing to pay** to reduce a members risk. Both of the bolded terms refer to social damage and will be used interchangeably.

[28] The Mead pulp mill in Escanaba is located in Delta County, Michigan.

extended, using the fundamental risk formula: cancer risk = potency x dose, to determine the damage costs associated with human exposure to dioxin. First, a dose is derived by assuming a given population (for this research the Delta County licensed fishing population will be used) is exposed to a quantity of toxic substance, through eating contaminated sport fish.

Second, multiplying this dose by a cancer potency factor provides the level of risk in which the Delta County licensed fishing population may contract cancer. This risk will be directly related to the amount of toxic substance released in the environment. As more toxic substance is released fish will bioaccumulate it, thereby increasing the dose. If individuals continue to eat the fish, their risk of contracting cancer will similarly increase.

The third and final step is to apply a value of a statistical life to the risk of contracting cancer. This results in a damage cost directly related to risk: as risk increases the value of a statistical life, otherwise known as the societal willingness to pay to reduce risk, increases.

The concept of willingness to pay for reducing risk of death is the fundamental component in determining damage costs in the policy analysis model. In Chapter 5, within the context of the Michigan dioxin regulatory environment, this concept of damage cost will be added to abatement costs in a cost minimization model in order to illustrate the design and application of the policy analysis model.

CHAPTER 5: DESIGN AND APPLICATION OF THE POLICY ANALYSIS MODEL

The policy analysis model employs the concept of achieving a Pareto optimal solution through the use of a cost minimization model to evaluate policy. The model is based on the flow of a toxic substance from a point source into the environment. The key components of the model include: (1) the resulting damage costs from the release and (2) the abatement costs associated with the technology employed to minimize the release. These costs are summed and provide a total cost of pollution for any particular quantity of toxic substance release. The minimum total cost indicates the optimum level of pollution (in the Pareto sense), see Figure 4.2. The model is developed using a Lotus 123 spreadsheet. The development and application of the model will be illustrated using Michigan's dual agency approach to dioxin regulation, the Mead Corporation's pulp and paper mill in Escanaba, Michigan, and the Delta County Michigan registered fishing population.

5.1 Study Site

The Escanaba River, located in Michigan's Upper Peninsula (Figure 5.1), is currently the only identified stream with fish exceeding the MDPH health advisory trigger of 10 ppt for dioxin. Table 5.1 illustrates the results of a Michigan Department of Public Health fish monitoring program on the Escanaba River. The number of fish sampled from the Escanaba River on October 4, 1989 with dioxin concentrations are listed; a positive sign indicates a concentration above the 10 ppt

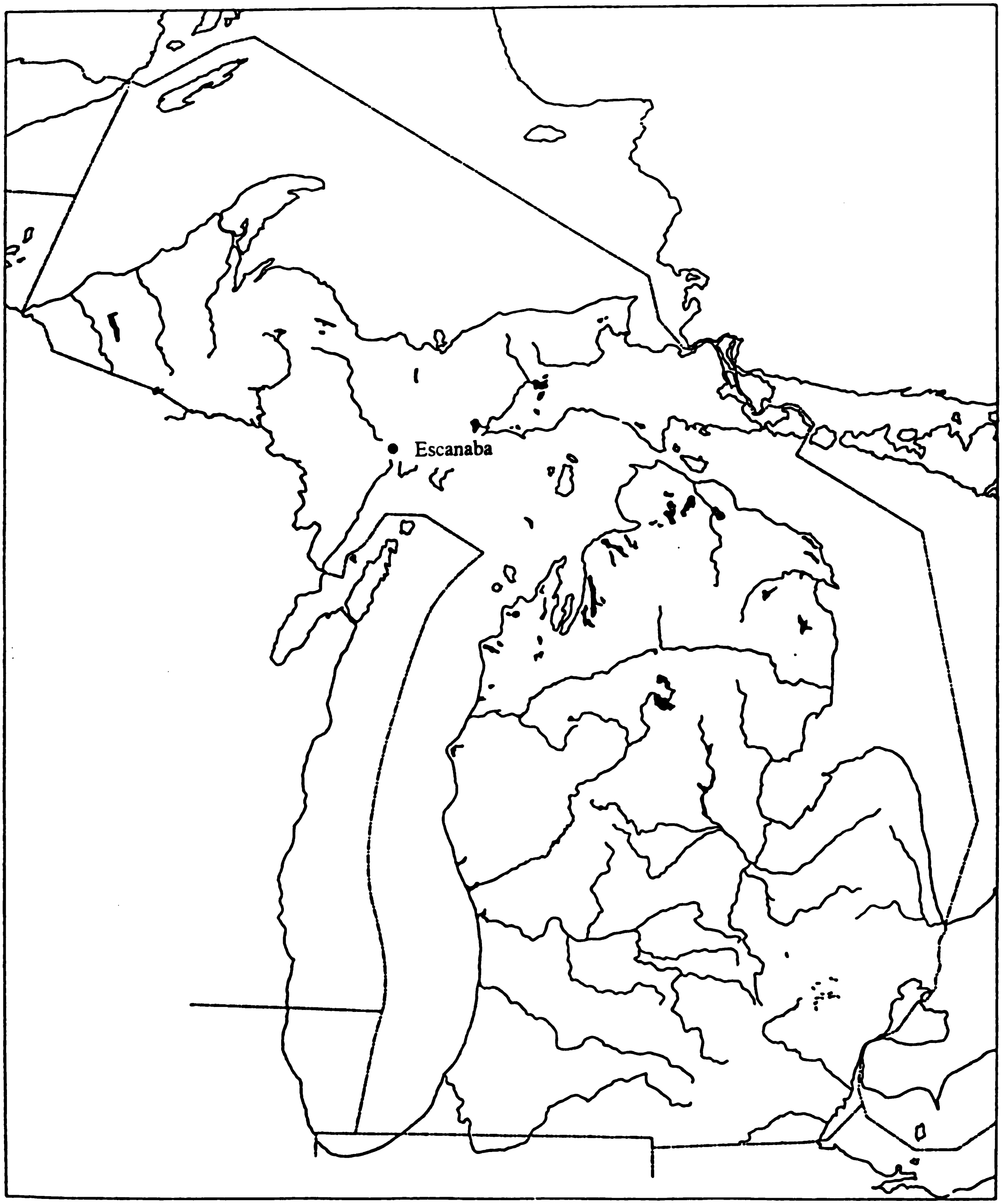

Figure 5.1 Escanaba and the Escanaba River.

Table 5.1 Dioxin concentration in fish collected from the Escanaba River on October 4, 1988[29]

Species	Length (inches)	Weight (lbs.)	Dioxin concentration (ppt)	MDPH health advisory trigger
Northern Pike	29.1	6.1	3.31	-
Northern Pike	29.9	6.3	23.4	+
Northern Pike	30.1	5.7	10.2	+
Northern Pike	-	5.7	12.0	+
Northern Pike	27.6	5.0	13.6	+
Northern Pike	28.5	5.2	24.4	+
Northern Pike	26.0	4.0	7.15	-
Northern Pike	26.2	3.7	4.9	-
Northern Pike	26.4	4.6	9.81	-
Northern Pike	24.0	3.3	2.86	-
Northern Pike	22.4	2.5	6.62	-
White Sucker	18.5	3.7	8.44	-
White Sucker	18.1	3.0	8.29	-
White Sucker	21.9	4.4	17.6	+
White Sucker	20.7	3.7	9.06	-
White Sucker	19.1	3.0	13.4	+
White Sucker	18.9	2.9	15.3	+
White Sucker	19.5	3.1	12.4	+
White Sucker	20.5	3.9	8.8	-
White Sucker	19.7	3.5	8.55	-
White Sucker	22.0	4.1	9.61	-
Smallmouth Bass	15.7	2.0	5.51	
Average dioxin concentration			10.69	+

[29] MDPH, 1989

MDPH health advisory trigger.

Of the fish sampled in the Escanaba River, 43 percent were above the current MDPH health advisory trigger for dioxin. The source of dioxin has been traced to the wastewater effluent from the Mead Corporation pulp and paper mill in Escanaba, located near the mouth of the Escanaba River in Delta County (Figure 5.1). Mead's 1990 effluent dioxin levels were in the 7-8 ppq range which is significantly above the MDNR's water quality based effluent limit of 0.022 ppq.

A MDNR survey indicated that the Escanaba River supplies a good fishery for bass, northern pike, smelt, and walleye both at the Mead site and downstream (Long, 1973). Above the Mead site the Escanaba River provides a trout fishery. There are two dams at the site which virtually cut off the migration of fish upstream from the site (Long, 1973).

The Delta County population was 38,800 in 1985 (Verway, 1987). A review of fishing license data from 1986-1989 indicates a year round average fishing population of 8,242 based on resident and senior fishing licenses only (Appendix D). This number gives an indication of the anglers in Delta County. For the purposes of this research it is assumed that these anglers fish in the Escanaba River at or below the Mead pulp mill and consume their fish. This assumption does not take into consideration that a number of anglers release their catch or share their catch with friends and family. Non-resident and daily permits were not included in the average fishing population because they represent a limited exposure for the angler to dioxin in fish.

River access is a factor which contributes to the conservative nature of this value. The only access to the stretch of river were dioxin contaminated fish have been identified is by way of Mead property. Although access to the public is available, it is not generally taken advantage of. As a result, it is highly unlikely that 8,242 Delta County anglers will fish the stretch of river with contaminated fish and catch a contaminated fish. While this value may be conservative, it provides a value to illustrate potential cancer risk. It can certainly be adjusted to reflect a number of fishing circumstances.

The Mead mill is integrated; containing both pulp and paper production processes. The mill produces book publishing paper. For the last ten years the mill has been producing 60% hardwood and 40% softwood pulp. Utilizing the kraft pulping process the mill averages 1000 tons/day when producing hardwood pulp and 850 tons/day for softwood pulp.

The mill uses a standard five stage bleaching sequence, CEDED (Abbott, 1990a):

1. chlorination (C) where the pulp is subjected to a reaction with elemental chlorine in acidic medium;
2. alkaline extraction (E) where the pulp is subjected to a dissolution of reaction products with NaOH;
3. chlorine dioxide (D) where the pulp is subjected to a reaction with ClO_2 in acidic medium;
4. alkaline extraction; and
5. chlorine dioxide (Smook, 1982).

A four year National Pollutant Discharge Elimination System (NPDES) permit, issued to Mead Corporation on March 29, 1990, set a dioxin discharge limitation of 0.022 ppq from June 1, 1992 until permit expiration in 1994. **This permit level is less than the current detection technology which is around 3 ppq for dioxin.** Although the dioxin limit is 0.022 ppq, until measuring capabilities allow for detection limits to be accurately measured, the MDNR permit indicates any discharge of dioxin at or above the current level of detection is considered by the MDNR (1989c) to be a specific violation of the permit. In effect, there are two dioxin limits, (1) a goal of 0.022 ppq and (2) an actual limit which corresponds with the level of detection. As long as dioxin effluent levels are below detection it is impossible to determine whether it is in fact below 0.022 ppq.

The permit included the special condition of requiring Mead Corporation to submit a Dioxin Minimization Program. The program is intended to show that the mill is proceeding towards compliance with the final effluent limitations for dioxin and towards the "goal of eliminating all detectable levels of 2,3,7,8-TCDD in any wastewater stream discharged to the wastewater collection facility at this facility [the pulp mill] (MDNR, 1989c)." The Dioxin Minimization ~~Plan~~ Program is required to include the following (MDNR, 1989c):

1. A review of all potential 2,3,7,8-TCDD sources, and provision for an annual update of this review.

2. Wastewater treatment or process modifications, currently underway and/or proposed, intended to minimize chlorine usage and reduce the formation and discharge of 2,3,7,8-TCDD, including but not limited to increased substitution of chlorine dioxide for chlorine, and the use of defoamers which contain reduced concentrations of precursors which could form 2,3,7,8-TCDD; along with a proposed timetable for implementation.

3. Wastewater treatment modifications incorporating the recommendations for total suspended solids minimization contained in the Preliminary Report on the USEPA Bench Scale Wastewater Treatability Study: Pulp and Paper Mill Discharges of 2,3,7,8-TCDD and 2,3,7,8-TCDF / Proposed Interim Control Measures / Interim NPDES Permit Strategy, October 1988, along with a proposed timetable for implementation.

4. Any additional measures necessary to proceed towards compliance with final effluent limitations for 2,3,7,8-TCDD and towards the goal of eliminating all detectable sources of 2,3,7,8-TCDD into the wastewater collection system, along with a proposed timetable for implementation.

5. Provision for a quarterly monitoring program to acquire data for 2,3,7,8-TCDD at the following indicated locations: individual process wastewater lines, influent to wastewater treatment facility, and sludge.

The permit also requires Mead to collect ten northern pike and white sucker downstream from the wastewater outfall during the months between August and October. The standard edible portions of each individual fish will be analyzed for 2,3,7,8-TCDD using an analytical detection limit of 1 ppt for fish tissue (MDNR, 1989c).

A 1988 analyses of the mill wastewater treatment influent sources, indicated that 94 percent of the dioxin input into the wastewater treatment system is associated with the kraft mill bleach plant effluent (Abbott, 1990b). Figure 5.2 illustrates dioxin discharges, based on a 24 hour composite sample, from March 1987 through June 1990. The variability in dioxin concentration from March, 1987 to September, 1989 has not been accounted for by mill staff. Components of the Dioxin Minimization Program were instituted after September, 1989.

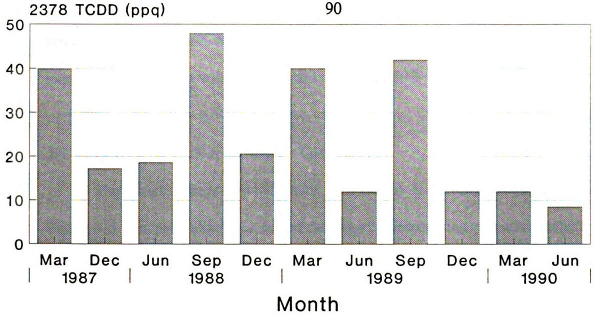

Figure 5.2 Mead Dioxin Discharges from March 1987 - June 1990.

Mead submitted a draft Dioxin Minimization Program to the MDNR in March, 1990 (Appendix E). The program includes the actual and potential implementation of the following four technologies to limit the mill's discharge of dioxin: changing to a purified oil based defoamer, chlorine dioxide substitution in the bleaching stage, the addition of a peroxide extraction stage to its bleaching sequence; and adding oxygen delignification.

The mill switched to a purified oil based defoamer after September, 1989 which decreased dioxin discharge from the 40 ppq range to 12 ppq without any significant added costs (Figure 5.3). Adding chlorine substitution in the bleaching stage and implementing a new chip screening process decreased dioxin levels to below 8.5 ppq (this was the non detect level) in June of 1990 (Figure 5.3) (Abbott, 1990a). Future process changes may include the addition of a peroxide extraction stage to the bleaching sequence with an estimated 50% dioxin reduction, and the addition of oxygen delignification with an estimated additional 50% reduction in dioxin.

5.2 Developing a Dioxin Damage Cost Function

The social damage cost schematic provided by Hufschmidt et al. (1989), Figure 4.5, has been altered to reflect the steps in determining potential damage costs resulting from dioxin discharge from the Mead pulp mill (Figure 5.3). While the model is designed to be applicable to point sources discharging persistent toxic substances into surface waters in general, the Mead pulp mill in Escanaba is used to illustrate model components.

There are two specific types of potential damage caused by the release of dioxin into the environment: (1) damage to wildlife populations (including birds, mammals, fish, etc.), and (2) damage to human populations. While dioxin has been detected in a variety of species of wildlife, (Young et al., 1987, Elliott et al., 1989) the actual effects on species' health is still under investigation. The $102,519 value, derived in Chapter 4 from the simplified attempt to value dioxin damage to certain species of fish, mammals, and birds living in the vicinity of the Mead, provides only a gross estimate of potential wildlife damage costs.

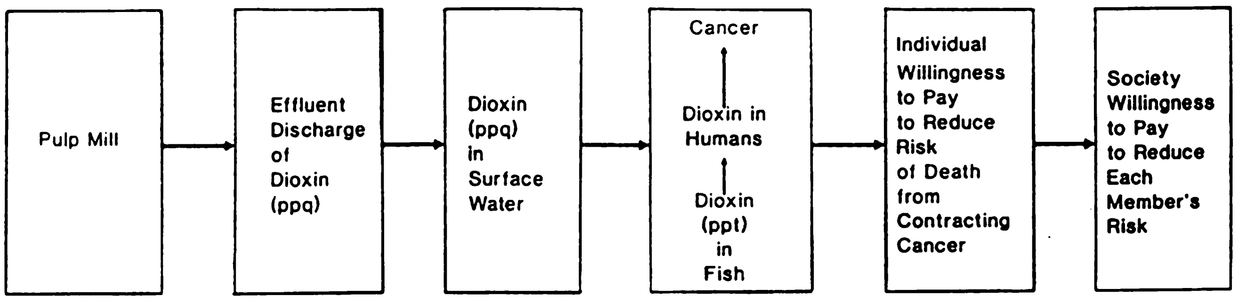

Figure 5.3 Estimation of social damage cost function due to the release of dioxin from the Mead pulp mill.

Although a significant amount of uncertainty exists in determining the actual damage to animal life and human populations, the Michigan dual agency dioxin regulatory framework specifically addresses the protection of human health.[30] The effects of dioxin on animal life are no less important than the effects on human health, and clearly more research is needed to define these effects. However due to the lack of any reasonable species census and the limited number of willingness to accept/pay studies concerning wildlife values, this study is specifically concerned with human exposure to dioxin from the ingestion of dioxin contaminated fish. The gross estimate

[30] The MDNR Rule 57 states that "Toxic substances shall not be present in the waters of the state at levels which are or may become injurious to the public health, safety, or welfare; plant and animal life. . ." The MDPH health advisory trigger is designed to provide information on the human health risks of consuming contaminated fish. Separately, the MDNR and the MDPH have their specific mandates as discussed in Chapter 3. Combined, the MDNR water quality based effluent limits and the MDPH health advisory triggers formulate state policy designed specifically to protect public health.

of animal damage from dioxin exposure is relatively small and is essentially included in the study by default as a result of the magnitude and ranges of the willingness to pay values for reducing risk of death.

Figure 5.3 illustrates the sequential development of the damage cost function. The Mead pulp and paper mill in Escanaba has been identified as the "economic activity" discharging effluent containing a ppq concentration of dioxin into the Escanaba River. One pathway available to dioxin in the river is uptake by aquatic organisms.[31] Assuming that 100% of the dioxin dissolved and adsorbed to suspended solids is bioavailable to fish a potential dosage relating dioxin in the effluent to dioxin in humans can be determined[32]. Once a human dose of dioxin resulting from the effluent is determined, a risk of cancer can be projected. Applying willingness to pay values for reducing risk from avoidable behavior to the projected cancer risks (as illustrated in Chapter 4) will provide the basis for estimating a damage cost function.

A series of six equations are used to develop the damage cost function. The following sequence will be taken for each equation to illustrate their use in developing the damage cost function : (1) the equation will be described, (2) listed, and (3) an example of the use of the equation will be provided.

Equations 1 and 2 (combined) provide the foundation from which the damage

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[31] Other pathways available to dioxin include immediate settling on the river bottom, being transported some distance from the source and then settling, and being consumed by aquatic organisms which are consequently consumed by predatory species other than humans.

[32] Considering the various pathways available to dioxin in a river system, assuming 100% bioavailability to fish is rather conservative.

cost function is developed. They transform the concentration of dioxin in the effluent discharge into a level of dioxin in fish. Equation 1 converts projected dioxin effluent levels into a river water concentration of dioxin in parts per quadrillion (ppq).

(Equation 1) Z = Ec x Ef x 1/(Rf + Ef)

where:

Z = river water concentration of dioxin (ppq)

Ec = effluent concentration (ppq)

Ef = effluent flow (mgd)

Rf = 95% exceedance flow for Escanaba River (mgd)

(Example 1) Z = Ec x Ef x 1/(Rf + Ef)

where:

Z = river water concentration of dioxin (ppq)
Ec = effluent concentration = 10 ppq
Ef = effluent flow = 36.6 mgd
Rf = 95% exceedance flow for Escanaba River = 122.8 mgd

Z = 10 ppq x 36.6 mgd x 1/(122.8 mgd + 36.6 mgd) = 2.296 ppq

Equation 2 converts the river water concentration of dioxin into a fish body burden of dioxin using a factor or a bioaccumulation factor (BCF and BAF respectively). The river water concentration of dioxin from Equation 1 is multiplied by a BCF or BAF. The resulting value is then divided by a conversion factor of 1000 which converts the value to ng/kg.

As identified in Chapter 3, the Anderson et al. (1990) site specific

As identified in Chapter 3, the Anderson et al. (1990) site specific bioaccumulation factor of 7,238, the MDNR factor of 51,600 (Taft, 1990), and the bioaccumulation factor of 140,000 derived by Cook (1990) are used to provide a range of potential dioxin concentrations in fish. These three factors are representative of the differences and ranges for species and encompass all pathway variations reported in the literature.[33]

(Equation 2) $Y = Z \times b/1000$

where:

Y = fish body burden of dioxin (ng/kg, which is equivalent to ppt)

Z = river water concentration of dioxin (ppq)

b = BCF or BAF

(Example 2) $Y = Z \times b/1000$

where:

Y = fish body burden of dioxin (ppt)
Z = river water concentration of dioxin = 2.296 ppq
b = BCF = 51,600

Y = 2.296 ppq x 51,600 x 1 ng/1000 pg = 118.5 ng/kg

The amount of dioxin in fish from Equation 2 provides a means for comparing MDNR water quality based effluent limits and MDPH health advisory

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[33] The EPA (1990b) used similar BCFs of 5,000 and 50,000 l/kg in their risk assessment study of dioxin contaminated receiving water from chlorine-bleaching pulp and paper mills.

triggers. Using the MDNR water quality based effluent limit of 0.022 ppq as the effluent concentration (Ec) in Equation 1, will result in a river water concentration of dioxin in compliance with the Mead mill's NPDES permit. This river water concentration can then be used in Equation 2 to determine the fish body burden of dioxin based on each of the /bioaccumulation factors. The resulting fish dioxin body burdens can then be compared with the MDPH 10 ppt health advisory to determine if the MDNR water quality based effluent limit is protecting human health to the margin of safety identified by MDPH. The results of this comparison are presented in Chapter 6.

Once converted to a body burden of dioxin in fish, a human dose of dioxin based on the consumption of contaminated fish can be derived. Equation 3 assumes human consumption of 6.5 grams/day of fish by a 70 kg human.[34] This calculation also employs the relatively conservative assumption of 100% bioavailability of dioxin to humans.[35]

(Equation 3) $D = (Y \times F_g)/W$

where: D = dose (mg/kg/day)

Y = fish body burden of dioxin (ng/kg)

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[34] As identified in Chapter 3, these assumptions are used by the MDNR in developing water quality based effluent limits and the EPA in developing water quality criteria.

[35] Boyer (1989) concluded that 85-95% absorption can be expected of dioxin bioavailability in humans from the ingestion of fatty or oily foods. EPA (1990) assumed 95% bioavailability for their pulp mill risk assessment study.

F_g = fish consumption (g/day)

W = weight (kg)

(**Example 3**) $D = (Y \times F_g)/W$

where:

D = dose (mg/kg/day)
Y = fish body burden of dioxin = 118.5 ng/kg
F_g = fish consumption = 6.5 g/day
W = weight = 70 kg person

D = (118.5 ng/kg x 6.5 g/day)/70 kg = 1.10×10^{-8} mg/kg/day

The dose value derived from Equation 3 can then be inserted into the fundamental risk formula: risk = dose x potency. In Equation 4, the resulting doses are each multiplied by the cancer potencies of either MDNR (1.51×10^5), MDPH (3.57×10^4), or FDA (1.75×10^4), to determine a predicted upper limit of excess lifetime cancer risk[36]. The actual risk could be lower than this upper bound estimate.

(Equation 4) $P = D \times X$

where:

P = cancer risk (incidence of cancer per exposed population)

D = dose (mg/kg/day)

X = potency (mg/kg/day^{-1})

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[36] Because the difference between the EPA and MDNR cancer potency factors is 0.05, (EPA - 1.56×10^5, MDNR 1.51×10^5) the MDNR cancer potency factor is used to represent the potential cancer risks of both of the environmental agencies.

(Example 4) $P = D \times X$

where:

$P =$ cancer risk (incidence of cancer per exposed population)
$D =$ dose $= 1.10 \times 10^{-8}$ mg/kg/day
$X =$ potency $= 1.51 \times 10^{5}$ mg/kg/day^{-1}

$P =$ 1.10×10^{-8} mg/kg/day $\times$ 1.51×10^{5} mg/kg/day^{-1} $= 1.66 \times 10^{-3} = 1.66$ excess cases of cancer per 1000 exposed individuals[37]

Multiplying the risk estimate from Equation 4 by the Delta County, Michigan sport fish eating population results in an estimate of the excess lifetime cancer risk for the population (Equation 5).

(Equation 5) $F_g = P \times F_p$

where:

$F_g =$ risk of contracting cancer of the Delta County sport fish consuming population

$P =$ cancer risk (incidence of cancer per exposed population)

$F_p =$ Delta County sport fish consuming population (number of individuals)

(Example 5) $F_g = P \times F_p$

where:

$F_g =$ risk of the Delta County fish consuming population
$P =$ cancer risk $= 1.65 \times 10^{-3} = 1.65$ excess cases of cancer per 1000 exposed individuals
$F_p =$ Delta County fish consuming population (8,242)

[37] 1.65 cases per cancer is misleading since one either has cancer or does not have cancer, however it is merely one value in the development of the total damage cost function.

$F_g = 1.66 \times 10^{-3} \times 8{,}242 = 13.6$ excess cases of cancer per 8,242 Delta County sport fish consumers

Through the use of these five equations, a relationship between the amount of dioxin discharged from the Mead pulp mill and the incidence of cancer among the Delta County sport fish eating population is developed. Changes in effluent discharges and cancer risk incidence are directly related (this relationship reflects the total damage cost curve in Figure 4.2). To complete the damage cost function economic values are applied to each risk of contracting cancer faced by the Delta County sport fish consuming population (derived using Equation 5).

Equation 6 multiplies a value of statistical life (also referred to as the society's willingness to pay to reduce each members risk of death from avoidable behavior) by the Delta County sport fish consuming population's risk of contracting cancer, which is represented by the ratio of the population's risk of contracting cancer to the total Delta County sport fish consuming population (8,242). To derive an equalized willingness to pay value, the resulting value is divided by the mean risk level of the sample used to derive the initial statistical value life.

In the absence of any Delta County willingness to pay studies to determine a population-specific statistical value of life, estimates from the literature are used. A review of this literature identified a number of studies.[38] Three studies have been selected which represent a range of judgmental best estimates for the marginal

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[38] Fisher et al. (1989) provide an excellent summary of early estimates of values of reducing the risk of avoidable death.

willingness to pay and mean risk levels for reducing the risk of death from avoidable behavior. These include: Olsen (1981), Gegax et al. (1985), and Blomquist (1979). Fisher et al. (1989) reviewed each of these studies and determined a judgmental best estimate for the value of a statistical life for each. These values are adjusted to 1990 dollars (see Appendix F) and are used in Equation 6.

Olsen (1981) examined the wage differentials received by workers on hazardous jobs. He concluded that "compared to nonunion workers, union members received substantially higher fatal accident premiums." Olsen suggests that these increased premiums indicate that union members collectively place a higher value on life than nonunion workers. The judgmental best value for a statistical life for the Olsen (1981) study is $6.8 million, which is based on a mean risk level for the sample of 1×10^{-4} (one excess case of cancer per 10,000 individuals).

The Gegax et al. (1985) wage-risk study used a "mail study to collect information on annual labor earnings, the perceived risk of fatal accidents at work, the individual's human capital, work environment, and personal characteristics" (Fisher et al., 1989). The study provided a statistical value of life of $1.36 million for union blue collar workers based on a mean risk level for the sample of 10.1×10^{-4} (10.1 excess cases of cancer per 10,000 individuals).

Blomquist (1979) studied the "typical individual's value of a small change in the probability of his survival." The statistical value of life of $518,624 was determined through the analysis of automobile seat-belt use. This value is based on a mean risk level for the sample of 3×10^{-4} (3 excess cases of cancer per 10,000 individuals).

(Equation 6) $C_d = (WTP \times (F_g/8{,}242))/(S_r)$

where:

C_d = damage cost ($)

F_g = risk of the Delta County fish consuming population (excess cases of cancer per exposed population)

WTP = society's willingness to pay to reduce each members risk of death from avoidable behavior ($)

S_r = mean risk level of sample (excess case if cancer per sample)

(Example 6) $C_d = (WTP \times (F_g/8{,}242))/(S_r)$

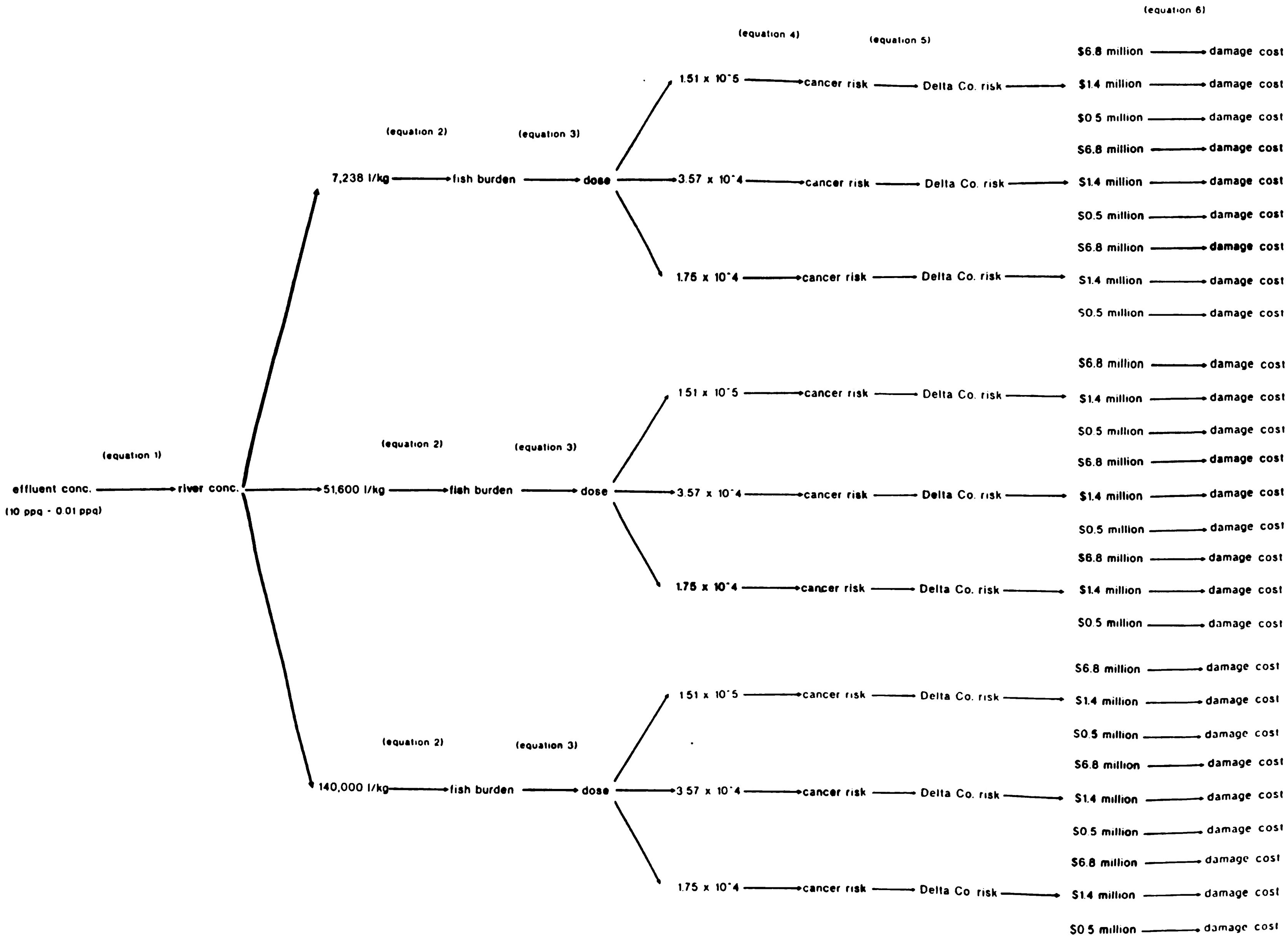
where:

C_d = damage cost ($)
F_g = risk of the Delta County fish consuming population = 13.6/8,242 (13.6 excess cases of cancer per 8,242 Delta County sport fish consumers)
WTP = society's willingness to pay to reduce each members risk of death from avoidable behavior = $6,801,622
S_r = mean risk level of sample = 1×10^{-4}

C_d = ($6,801,622 x (13.6/8,242))/0.0001 = $112,232,549

A separate damage cost curve is developed for the twenty-seven combinations of bioconcentration/bioaccumulation factors (7,2368, 51,600, and 140,000), cancer potency factors (1.51 x 10^5, 3.57 x 10^4, and 1.75 x 10^4) and values of statistical life ($6,801,622 million, $1,360,323, $518,624). Figure 5.4 expands the conceptual diagram shown earlier (Figure 5.3) by adding the variables for each equation used in the development of a damage cost curve. The damage cost functions are based on a range of effluent concentrations of 10 - 0.01 ppq. Each effluent concentration in the range provides one point, for a total of 30 points, on each of twenty-seven damage cost functions.

Figure 5.4 Deriving damage costs for the release of dioxin from the Mead pulp mill.



5.3 Developing an Abatement Cost Function

The abatement cost function is related directly to the costs of the technologies employed to reduce the concentration of dioxin in mill effluent. Each of the four technologies outlined in Mead's Dioxin Minimization Program has a corresponding cost. As these technologies are added to the pulp bleaching process, abatement costs increase and dioxin in the effluent decreases.

There were no significant costs associated with Mead's switch to a purified oil based defoamer. However, the remaining technologies did have significant capital costs. The capital cost of adding chlorine substitution in the bleaching stage was $4.1 million and the new chip screening process cost $12.8 million for a combined cost of $16,900,000 (Abbott, 1990a). If implemented, the addition of a peroxide extraction stage to the bleaching sequence would have an estimated cost of $250,000, and the addition of oxygen delignification would have an estimated cost of $140 million. In deriving an abatement cost it is assumed that both peroxide extraction and oxygen delignification will be implemented.

The total cost for dioxin abatement is the sum of the depreciated capital cost and the depreciated operating cost. The depreciated operating cost is calculated based on the following assumptions (Hoppe, 1990):

1. Hardwood pulp price = $600/air dry metric ton of pulp (admt),
2. A 5% profit margin,
3. A 30% tax margin,
4. 15% for overhead costs,

5. No local property taxes, and

6. 15 years for straight line depreciation.

Operating costs are back calculated from the hardwood pulp price using the percentages for profit margin, tax margin and the overhead costs:

Operating costs = ((($600/admt x 95%) x 70%) x 85%) = $339.15/admt

The mill produces 1000 tons of hardwood pulp a day. Converting this value to air dry metric tons and multiplying by 365 days will provide the annual hardwood pulp production in air dry metric tons:

Hardwood pulp production = 1000 tons/day x .907 admt/ton x 365 days = 331,055 admt/yr

The hardwood pulp production multiplied by the operating costs divided by a 15 year straight line depreciation will provide a depreciated operating cost (Hoppe 1990):

Depreciated operating costs = (331,055 admt/yr x $339.15/admt)/15 yrs = $7,485,153.55

Table 5.2 illustrates the total cost per year for the three technologies. Table 5.3 provides the cumulative per day equivalent abatement costs and the associated dioxin effluent concentration. The dioxin effluent concentration for the addition of peroxide extraction stage and oxygen delignification is projected based on a 50% reduction for each added technology.

Table 5.2 Mead abatement processes, capital costs, depreciated capital and operating costs, and total costs.

Abatement Process	Present Capital Cost ($)	Depreciated Capital Cost/yr ($)	Depreciated Operating Cost/yr ($)	Total Cost/yr ($)
ClO_2 substitution Chip screening	16,900,000	1,126,667	7,481,843	8,608,510
Extraction stage	250,000	16,667	7,481,843	7,498,510
Oxygen delignification	140,000,000	9,333,333	7,481,843	16,815,176

Table 5.3 Mead Abatement Technologies, Cumulative Per Day Costs, and Resulting Dioxin Discharges

Abatement Technology	Cost $/day	Dioxin Discharge (ppq)
ClO_2 substitution Chip screening	23,585	7.5
Extraction stage	44,129	3.5
Oxygen delignification	90,198	1.5

Figure 5.5 is a plot of the per day abatement costs and the corresponding dioxin discharges. The following power function for a dollar per day equivalent dioxin abatement value can be fitted to total abatement costs in Table 5.3 (r^2 = 1.00):

$$\$/\text{day} = 126125\ (\text{dioxin concentration})^{-.83}$$

Using this equation, an abatement cost point is calculated for the 10 - 0.01 ppq range of dioxin concentrations. When combined, these points suggest a total abatement cost curve that extends beyond the current abatement range (Figure 5.6) and resembles the hypothesized abatement cost curve illustrated earlier in Figure 4.2.

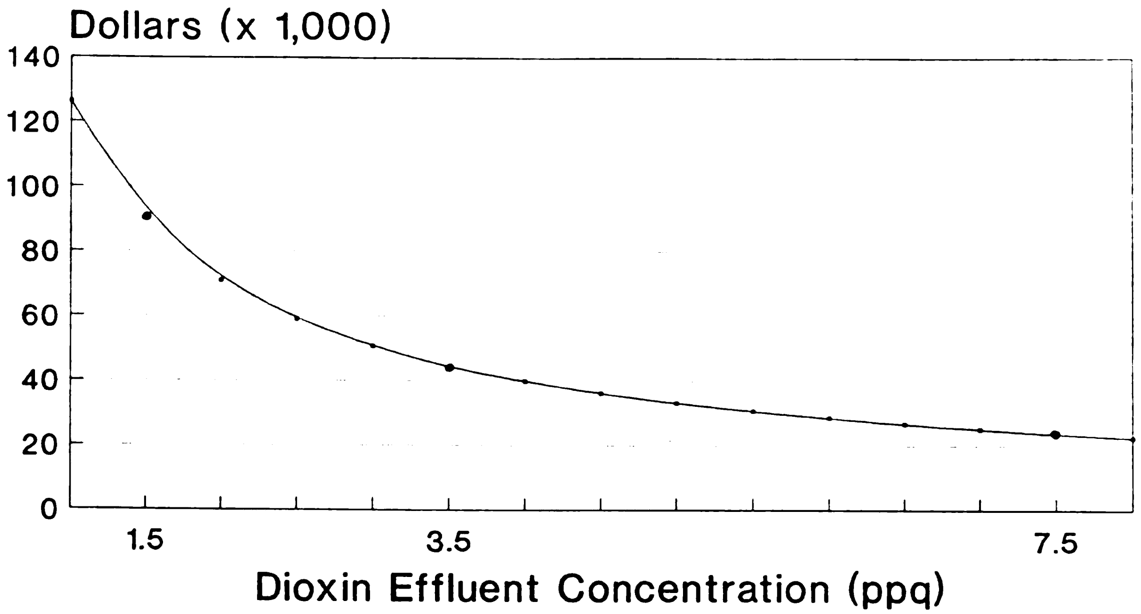


Figure 5.5 Per day Mead abatement costs and corresponding dioxin discharges.

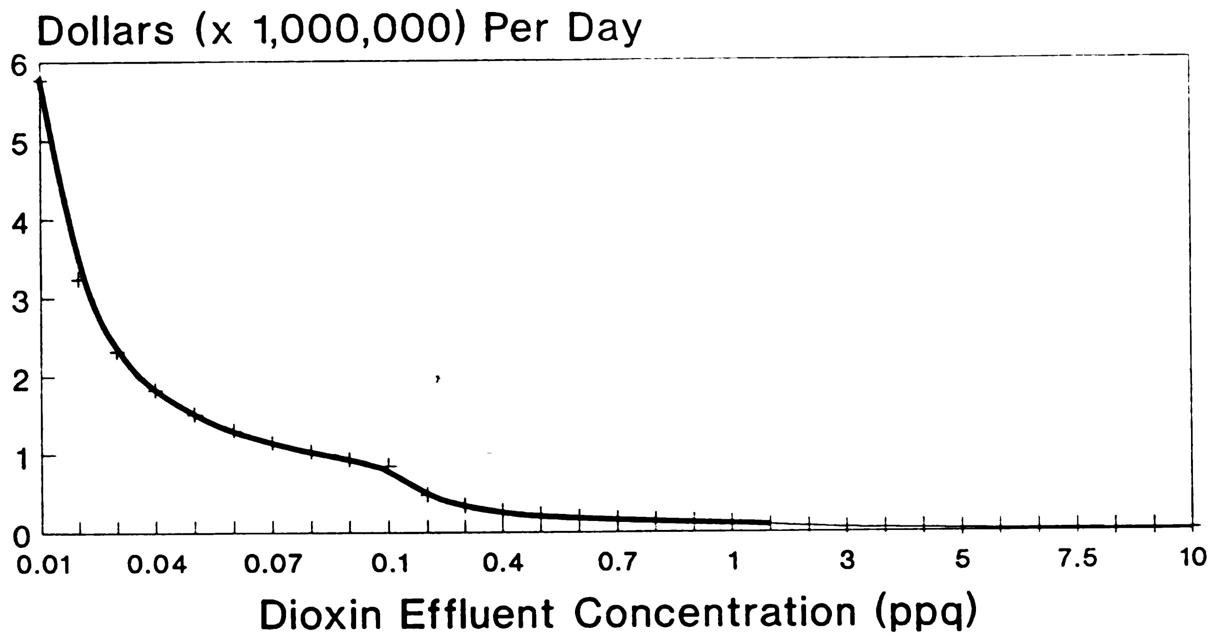


Figure 5.6 The Mead abatement cost curve extended and corresponding dioxin discharges.

The abatement cost curve for the Mead mill is added to each of the twenty-seven damage cost functions to derive twenty-seven separate total costs of pollution. The minimum of each of these total cost functions provides twenty-seven separate optimum levels of pollution (in the Pareto sense). A comparison of the range of "optimal levels of pollution" provides a means for determining whether or not the application of the MDNR's 0.022 ppq dioxin effluent limit for Mead's Escanaba kraft pulp mill and a MDPH dioxin health trigger of 10 ppt in fish for the sport fish consuming population of Delta County leads to an efficient (Pareto optimal) allocation of resources. The results of this comparison and discussion are presented in Chapter 6.

CHAPTER SIX: RESULTS AND DISCUSSION

The policy analysis model uses the concept of cost minimization to determine a Pareto optimal level of pollution (dioxin discharge), which has been described as the level that maximizes social wellbeing and minimizes costs. In the absence of a true optimal level of pollution, Pearce and Turner (1990) suggest, "the analytical task is to seek out the least-cost policy package sufficient to meet acceptable quality standards." Michigan dioxin policy, as applied to the Mead pulp mill in Escanaba, has two acceptable standards which both must be met: (1) an MDNR water quality based effluent limit for dioxin which is 0.022 for the Mead mill in Escanaba[39], and (2) a MDPH health advisory trigger for dioxin in fish which is 10 ppt for fish in the Escanaba River.

Based on the set of assumptions for the policy analysis model presented in Chapter 5, the "least cost policy package" (referred to in this research as the Pareto optimal dioxin discharge level) for Mead Corporation's Escanaba kraft pulp mill has been derived. An attempt will then be made to determine whether or not the "policy package" matches the current standards of Michigan's dual agency dioxin policy. If the policy package matches the standards of Michigan's dioxin policy, then the Michigan policy will be deemed Pareto optimal. To determine whether such a match exists the issue of dual agency coherence was addressed: Does the level of dioxin

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[39] As pointed out in Chapter 5, this limit is at present purely hypothetical as current detection levels with best available technology range between 1 and 4 ppq.

permitted into the environment, by MDNR's water quality-based effluent limit, when bioaccumulated by fish, provides the same margin of safety as the MDPH health advisory trigger? Identifying the value of the damage caused when humans are exposed to dioxin in sport fish is a key component in making this determination.

To determine the Pareto optimal dioxin discharge level for the Mead mill, the policy analysis model is used to evaluate the 27 separate policy scenarios which encompass combinations of three different bioconcentration/bioaccumulation factors (7,238, 51,600, and 140,000), three different cancer potency factors (1.51×10^5, 3.57×10^4, and 1.75×10^4) and three values of societal willingness to pay to reduce a members risk of death from avoidable behavior ($6,801,622 million, $1,360,323, $518,624). Although the primary purpose of this research is to evaluate Michigan dioxin policy, a secondary purpose is to compare FDA's dioxin fish advisory development to the development and application of Michigan's dioxin policy. Therefore, the FDA's dioxin in fish consumption advisory along with the agency's risk assessment assumptions, is included in the 27 policy analysis scenarios[40].

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[40] A further option of including a range of consumption levels was not taken due to timing constraints. However, EPA used a range of consumption levels in their pulp mill dioxin risk study (USEPA, 1990b).

6.1 Results

Each of the 27 policy scenario's include an abatement cost curve, a damage cost curve, and a total cost of pollution curve (similar to those illustrated by Figure 4.2). The series of Figures 6.1-6.3, graphically represent the logarithms of curves for the policy scenario that includes a bioconcentration factor of 51,600 and the willingness to pay value of \$6,801,622 (\$6.8 million). Each figure depicts the curves based on a different cancer potency factor. Figure 6.1 illustrates the abatement cost, damage cost, and total cost using the MDPH cancer potency of 3.57×10^4. Figure 6.2 illustrates the abatement cost, damage cost and total cost using the MDNR cancer potency factor of 1.51×10^5, and Figure 6.3 illustrates the abatement cost, damage cost and total cost using the FDA cancer potency factor of 1.75×10^4. At the minimum of the total cost curve on each of the figures, a line has been drawn to indicate the Pareto optimal solution (the point indicated on the x-axis by the line is representative of Q_2 in Figure 4.2). The Pareto optimal level of dioxin discharge (the level of dioxin discharge which maximizes social wellbeing and minimizes costs under the specified set of assumptions) indicated by Figures 6.1-6.3 is: 0.2 ppq for MDPH, 0.08 ppq for MDNR, and 0.3 ppq for FDA.

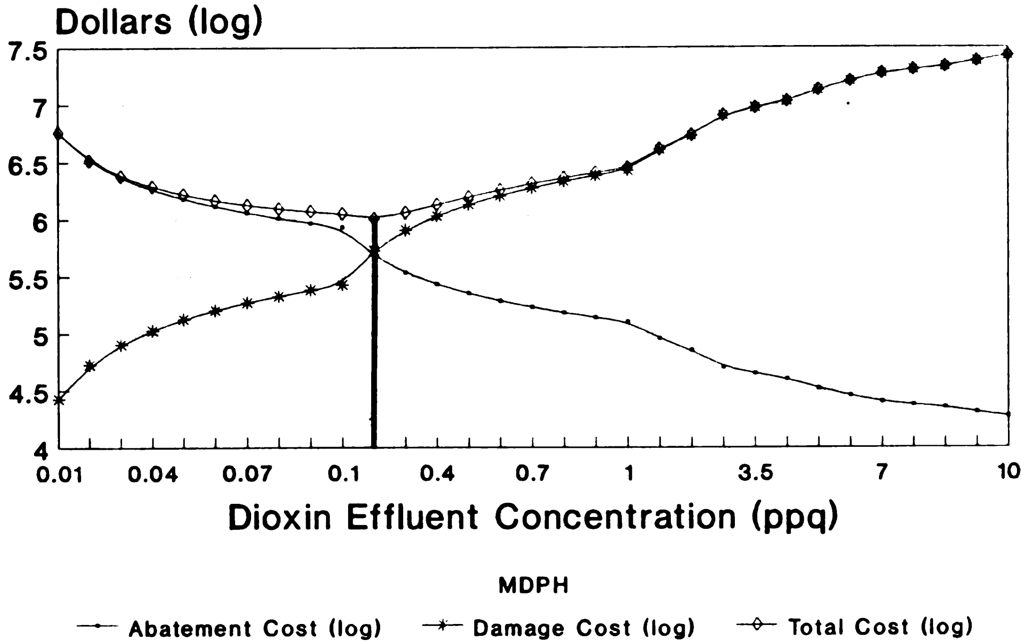

Figure 6.1 Mead total abatement cost, damage cost, and total cost of pollution for MDPH risk assessments, based on a willingness to pay value of $6.8 million dollars and a bioconcentration factor of 51,600, as a function of dioxin discharge.

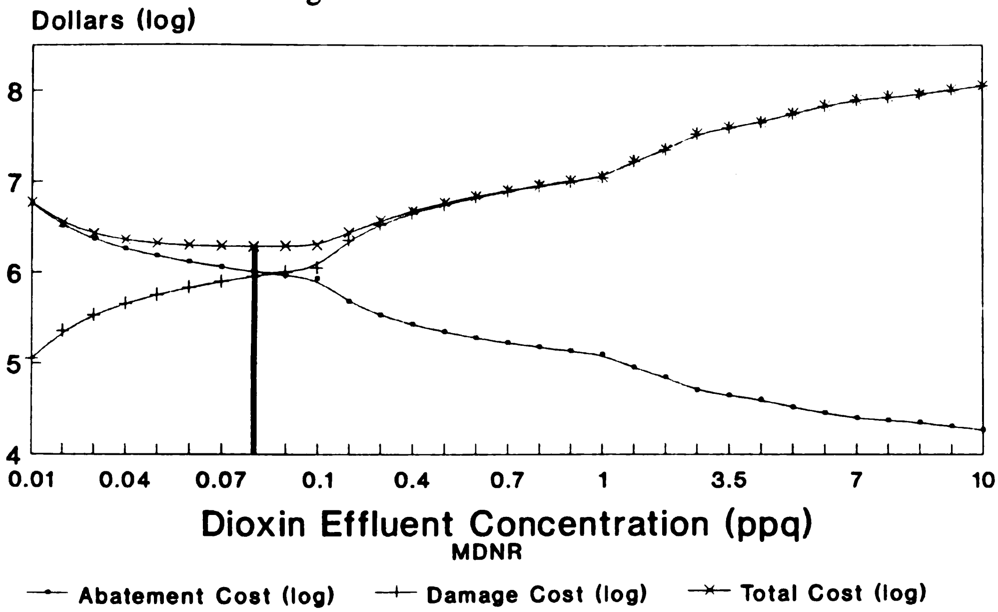

Figure 6.2 Mead total abatement cost, damage cost, and total cost of pollution for MDNR risk assessments based on a willingness to pay value of $6.8 million dollars and a BCF of 51,600, as a function of dioxin discharge.

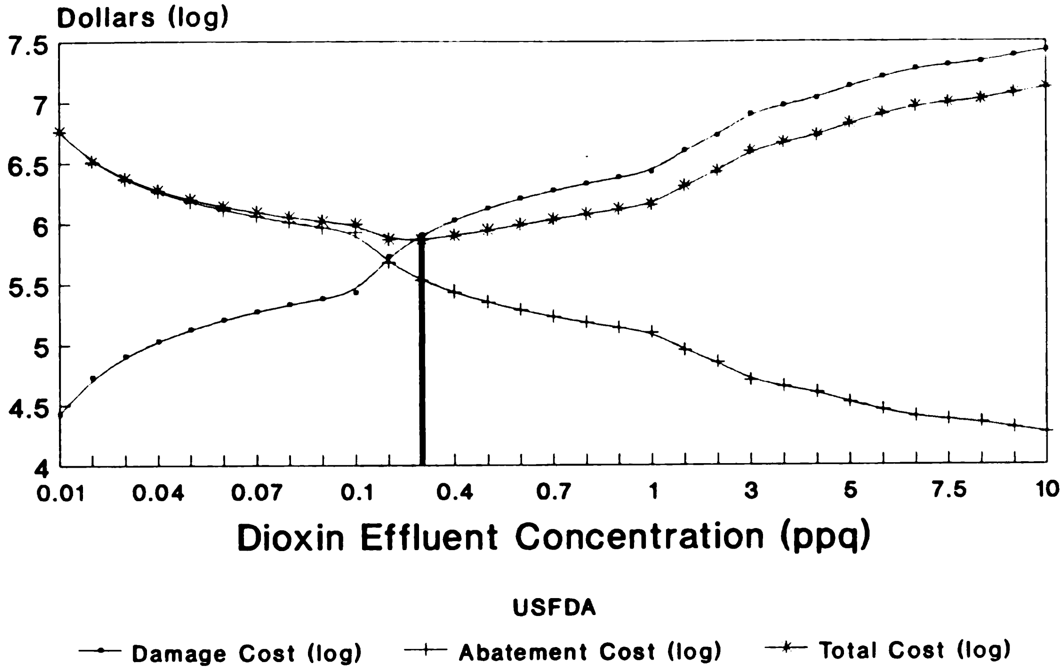

Figure 6.3 Mead total abatement cost, damage cost, and total cost of pollution for FDA risk assessments based on a willingness to pay value of $6.8 million dollars and a BCF of 51,600, as a function of dioxin discharge.

An alternative to measure the Pareto optimal level of dioxin discharge is the total abatement cost to willingness to pay ratio (TAC/WTP). A ratio of one indicates the break even point. This point is the level of protection (ppq) that people are willing to pay for. Beyond this point society is unwilling to pay for additional protection. Figure 6.4 graphically represents the concept of total abatement cost to willingness to pay for the policy scenario that includes a bioconcentration factor of 51,600 and the willingness to pay value of $6.8 million, and the risk assessment assumptions for each agency. The line drawn from the ratio curves to the x-axis indicates the optimal levels of dioxin discharges based on what people would be willing to pay for: 0.2 ppq for MDPH, 0.09 ppq for MDNR, and 0.3 ppq for FDA.

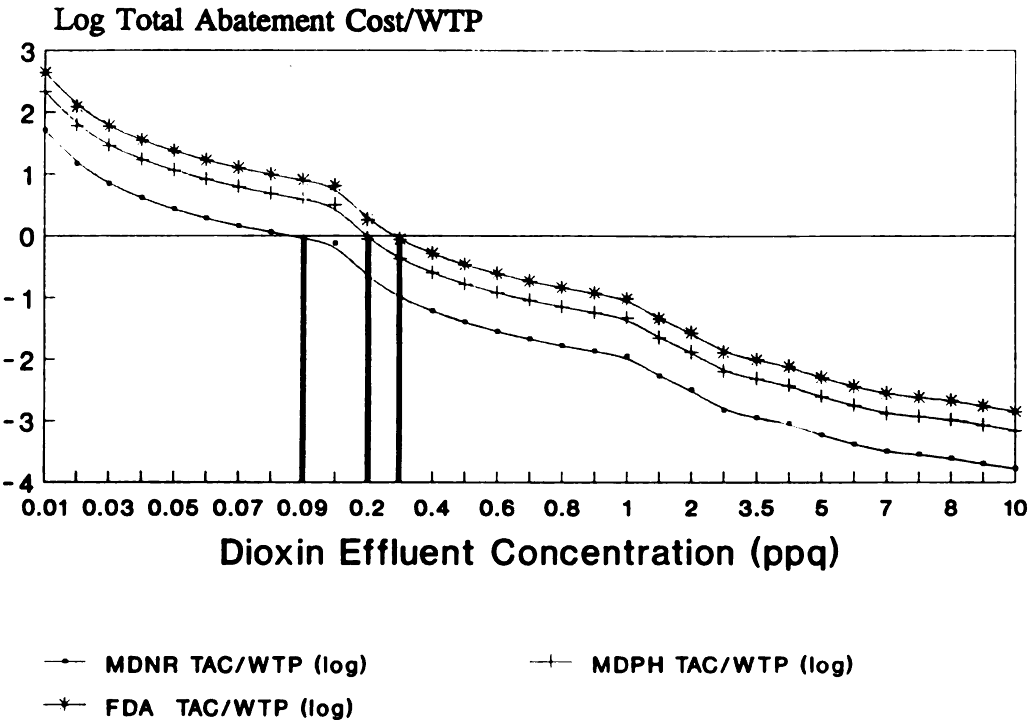

Figure 6.4 The log of the ratio total abatement cost/willingness to pay for MDNR, MDPH, and the FDA, and corresponding levels of dioxin discharge.

If compared, the total abatement costs to willingness to pay ratio closely resembles the values obtained from the minimum of the total cost of pollution curve (Figures 6.1 - 6.3). The slight difference exhibited among the MDNR values, 0.08 ppq (minimum of the total cost of pollution curve) compared to 0.09 ppq (total abatement cost to willingness to pay ratio), is most likely a result of an error in rounding the value.

Both types of graphic representations of the Pareto optimal level of dioxin discharge could be depicted for each of the 27 different policy scenarios, however to conserve space, Tables 6.1-6.6 have been constructed to present the results from all twenty-seven policy scenarios. The values presented in Tables 6.1-6.6 are based on the following assumptions: a 6.5 g/day consumption of sport fish from the Escanaba River by a 70 kg individual, 100% bioavailability of dioxin in water to fish, and 100% bioavailability of dioxin in fish to human. Tables 6.1 - 6.3 present the following information for both the MDPH and the MDNR risk assessment assumptions:[41]

1. total damage cost,
2. total abatement cost,
3. total cost of pollution,
4. the optimal level of dioxin discharge that corresponds with the minimum total damage costs,
5. the fish body burden of dioxin that corresponds with the optimal level of dioxin discharge given a specific bioaccumulation factor (BAF) or bioconcentration factor (BCF),
6. the total abatement cost to willingness to pay ratio,
7. the Delta County sport fish consumer risk of contracting cancer, and

[41] These assumptions include for both agencies, an acceptable risk level of one excess case of cancer per 100,000 exposed individuals (1×10^{-5}), the Kociba et al. (1978) rat study, and the use of a linearized multistage model. For the MDNR, a cancer potency factor for dioxin of 1.51×10^{5} mg/kg/day based on a body surface area extrapolation of the rat data, and for the MDPH, a cancer potency factor for dioxin of 3.57×10^{4} based on a body weight scaling factor is assumed.

8. an extrapolated risk per 100,000 individuals.

Tables 6.4-6.6 present the same information for the FDA risk assessment assumptions which include a cancer potency factor of 1.75×10^4 based on a body weight scaling factor used to extrapolate rat data to humans.

Table 6.1 Pareto optimal levels of dioxin discharge based on MDNR and MDPH risk assessment assumptions and a BAF of 7,238, for the Escanaba Mead pulp mill and the sport fish eating Delta County, MI population (costs per day - 1990).

	MDPH			MDNR		
Willingness to pay	$6,801,622	$1,360,323	$518,624	$6,801,622	$1,360,323	$518,624
Total Damage Cost ($)	187,360	29,681	33,335	316,990	62,770	60,426
Total Abatement Cost ($)	224,211	39,911	44,589	479,674	70,949	90,084
Total Cost of Pollution ($)	411,571	69,592	77,923	796,664	133,719	150,510
Optimal Pollution Level (ppq)	0.5	4.0	3.5	0.2	2.0	1.5
Fish Body Burden (ppt)	0.8	7.0	6.0	0.3	3.0	2.0
TAC/WTP (ppq)	0.6	5.0	4.0	0.3	3.0	2.0
Delta County sport fish consumer risk	0.023/8242	0.182/8242	0.159/8242	0.038/8242	0.384/8242	0.288/8242
risk per 100,000	0.28	2.20	1.93	0.46	4.66	3.49

Table 6.2 Pareto optimal levels of dioxin discharge based on MDNR and MDPH risk assessment assumptions and a BCF of 51,600, for the Escanaba Mead pulp mill and the sport fish eating Delta County, MI population (costs per day - 1990).

	MDPH			MDNR		
Willingness to pay	$6,801,622	$1,360,323	$518,624	$6,801,622	$1,360,323	$518,624
Total Damage Cost ($)	534,279	79,348	101,847	897,949	155,585	171,172
Total Abatement Cost ($)	479,674	90,084	90,084	1,026,210	169,578	192,724
Total Cost of Pollution ($)	1,013,954	169,432	191,931	1,930,145	326,200	365,038
Optimal Pollution Level (ppq)	0.2	1.5	1.5	0.08	0.7	0.6
Fish Body Burden (ppt)	2.0	18	18	1.0	8.0	7.0
TAC/WTP (ppq)	0.2	2.0	1.5	0.09	0.7	0.7
Delta County sport fish consumer risk	0.067/8242	0.486/8242	0.486/8242	0.110/8242	0.958/8242	0.823/8242
risk per 100,000	0.81	5.6	5.6	1.3	11.6	9.97

Table 6.3 Pareto optimal levels of dioxin discharge based on MDNR and MDPH risk assessment assumptions and a BAF of 140,000, for the Escanaba Mead pulp mill and the sport fish eating Delta County, MI population (costs per day - 1990).

	MDPH			MDNR		
Willingness to pay	$6,801,622	$1,360,323	$518,624	$6,801,323	$1,360,323	$518,624
Total Damage Cost ($)	724,798	114,819	128,954	1,532,835	242,825	233,758
Total Abatement Cost ($)	852,710	151,788	169,578	1,515,849	269,831	432,603
Total Cost of Pollution ($)	1,577,507	266,607	298,532	3,048,684	512,656	576,361
Optimal Pollution Level (ppq)	0.1	0.8	0.7	0.05	0.4	0.3
Fish Body Burden (ppt)	3	26	23	1.6	13	10
TAC/WTP (ppq)	0.2	1.0	0.9	0.05	0.5	0.4
Delta County sport fish consumer risk	0.088/8242	0.703/8242	0.615/8242	0.186/8242	1.486/8242	1.11/8242
risk per 100,000	1.07	8.50	7.46	2.30	18.0	13.5

Table 6.4 Pareto optimal levels of dioxin discharge based on FDA risk assessment assumptions ànd a BAF of 7,238, for the Escanaba Mead pulp mill and the sport fish eating Delta County, MI population (costs per day - 1990).

Willingness to pay	$6,801,622	$1,360,323	$518,624
Total Damage Cost ($)	128,581	21,824	23,334
Total Abatement Cost ($)	169,578	28,506	33,163
Total Cost of Pollution ($)	298,157	50,330	56,507
Optimal Pollution Level (ppq)	0.7	6	5
Fish Body Burden (ppt)	1.2	9.97	8.3
TAC/WTP (ppq)	0.9	7	7
Delta County sport fish consumer risk	0.016/8242	0.134/8242	0.111/8242
risk per 100,000	0.19	1.63	1.35

Table 6.5 Pareto optimal levels of dioxin discharge based on FDA risk assessment assumptions and a BCF of 51,600, for the Escanaba Mead pulp mill and the sport fish eating Delta County, MI population (costs per day - 1990).

Willingness to pay	$6,801,622	$1,360,323	$518,624
Total Damage Cost ($)	392,853	51,862	66,567
Total Abatement Cost ($)	342,603	70,949	70,949
Total Cost of Pollution ($)	735,455	122,811	137,516
Optimal Pollution Level (ppq)	0.3	2	2
Fish Body Burden (ppt)	3.5	24	24
TAC/WTP (ppq)	0.3	3	3
Delta County sport fish consumer risk	0.048/8242	0.317/8242	0.317/8242
risk per 100,000	0.58	3.85	3.85

Table 6.6 Pareto optimal levels of dioxin discharge based on FDA risk assessment assumptions and a bioaccumulation factor of 140,000, for the Escanaba Mead pulp mill and the sport fish eating Delta County, MI population (costs per day - 1990).

Willingness to pay	$6,801,622	$1,360,323	$518,624
Total Damage Cost ($)	479,674	90,084	126,125
Total Abatement Cost ($)	710,586	105,532	90,304
Total Cost of Pollution ($)	1,190,260	195,616	216,429
Optimal Pollution Level (ppq)	0.2	1.5	1
Fish Body Burden (ppt)	6.4	48.2	32.1
TAC/WTP (ppq)	0.2	1.5	1.5
Delta County sport fish consumer risk	0.086/8242	0.646/8242	0.432/8242
risk per 100,000	1.04	7.84	5.24

6.2 Discussion

In Search of a Pareto Optimum The Pareto optimal levels of dioxin discharge concentrations in Tables 6.1 - 6.6 indicate a range of optimal pollution levels, corresponding fish body burdens, and cancer risks per 100,000 exposed individuals for the MDNR, MDPH, and FDA risk assessment assumptions. The information presented in the tables places value on the damage costs of human exposure to dioxin, in an attempt to address the issues of whether or not Michigan state agency standards, which make up the state's dioxin policy, provide a consistent margin of safety.

The policy analysis model is designed to provide a "Pareto optimal pollution" for every set of variables under consideration. However, in determining whether a particular effluent dioxin concentration provides an adequate margin of safety the model results for the dioxin concentration (in fish) must meet two objectives: (1) be below the 10 ppt MDPH health advisory, and (2) not exceed a cancer risk of one excess case of cancer per 100,000 exposed individuals.

The following is an explanation of Tables 6.1-6.6. Each table is based on a different bioconcentration/bioaccumulation factor. Tables 6.1 and 6.4 are based on a bioaccumulation factor of 7,328. Tables 6.2 and 6.5 are based on a bioconcentration factor of 51,600, and Tables 6.3 and 6.6 on a bioaccumulation factor of 140,000. Each table presents different Pareto optimal levels of dioxin discharge, dioxin fish body burdens, cancer risk for the Delta County sport fish consuming population, and cancer risk per 100,000 exposed individuals for each of the three willingness to pay values. Each of the following bullets are organized to present the bioconcentration/bioaccumulation factor for which the information is based on, the three willingness to pay values, and for each willingness to pay value the (1) pareto optimal level of dioxin discharge, (2) fish dioxin body burden, and (3) cancer risk per 100,000 exposed individuals respectively. A Pareto optimal dioxin discharge concentration which meets both of the objectives (below 10 ppt and a 1×10^{-5} cancer risk) will be bolded.

The Pareto optimal level of dioxin discharge, the dioxin body burden in fish, and the cancer risk per 100,000 exposed individuals based on a bioaccumulation factor of <u>7,238</u> and corresponding to the following societal willingness to pay factors for reducing a member's risk of death from avoidable behavior (the value of a statistical life) are:

- For <u>$6.8 million</u>: **0.5** ppq, 0.8 ppt, 0.28 x 10^{-5} for MDPH; **0.2** ppq, 0.3 ppt, 0.46 x 10^{-5} for MDNR; and **0.7** ppq, 1.2 ppt, 0.19 x 10^{-5} for FDA.
- Based on a $1,360,323 (<u>$1.4 million</u>) willingness to pay value the range includes: 4.0 ppq, 7.0 ppt, 2.20 x 10^{-5} for MDPH; 2.0 ppq, 3.0 ppt, 4.66 x 10^{-5} for MDNR; and 6.0 ppq, 9.97 ppt, 1.63 x 10^{-5} for FDA.
- And, based on a $518,624 (<u>$0.5 million</u>) willingness to pay value the range includes: 3.5 ppq, 6.0 ppt, 1.93 x 10^{-5} for MDPH; 1.5 ppq, 2.0 ppt, 3.49 x 10^{-5} for MDNR, and 5.0 ppq, 8.3 ppt, 1.35 x 10^{-5} for FDA.

Based on a bioconcentration factor of <u>51,600</u> and corresponding societal willingness to pay factors for reducing a member's risk of death from avoidable behavior the Pareto optimal level of dioxin discharge, the dioxin body burden in fish, and the cancer risk per 100,000 exposed individuals are:

- Based on <u>$6.8 million</u>, the Pareto optimal level of dioxin discharge, the dioxin body burden in fish, and the cancer risk per 100,000 individuals are as follows: **0.2** ppq, 2.0 ppt, 0.81 x 10^{-5} for MDPH; 0.08 ppq, 0.3 ppt, 1.3 x 10^{-5} for MDNR; and **0.3** ppq, 3.5 ppt, 0.58 x 10^{-5} for FDA.
- Based on a <u>$1.4 million</u> willingness to pay value the range includes: 1.5 ppq, 18 ppt, 5.6 x 10^{-5} for MDPH; 0.7 ppq, 8.0 ppt, 11.6 x 10^{-5} for MDNR; and 2.0 ppq, 24 ppt, 3.85 x 10^{-5} for FDA.
- And, based on a <u>$0.5 million</u> willingness to pay value the range includes: 1.5

ppq, 18 ppt, 5.6 x 10^{-5} for MDPH; 0.6 ppq, 7.0 ppt, 9.97 x 10^{-5} for MDNR, and 2.0 ppq, 24 ppt, 3.85 x 10^{-5} for FDA.

Based on a bioaccumulation factor of 140,000 and corresponding societal willingness to pay factors for reducing a member's risk of death from avoidable behavior the Pareto optimal level of dioxin discharge, the dioxin body burden in fish, and the cancer risk per 100,000 exposed individuals are:

- Based on $6.8 million, the Pareto optimal level of dioxin discharge, the dioxin body burden in fish, and the cancer risk per 100,000 individuals are as follows: 0.1 ppq, 3.0 ppt, 1.07 x 10^{-5} for MDPH; 0.05 ppq, 1.6 ppt, 2.3 x 10^{-5} for MDNR; and 0.2 ppq, 6.4 ppt, 1.04 x 10^{-5} for FDA.
- Based on a $1.4 million willingness to pay value the range includes: 0.8 ppq, 26 ppt, 8.50 x 10^{-5} for MDPH; 0.4 ppq, 13.0 ppt, 18.0 x 10^{-5} for MDNR; and 1.5 ppq, 48.2 ppt, 7.84 x 10^{-5} for FDA.
- And, based on a $0.5 million willingness to pay value the range includes: 0.7 ppq, 23 ppt, 7.46 x 10^{-5} for MDPH; 0.3 ppq, 10.0 ppt, 13.5 x 10^{-5} for MDNR, and 1.0 ppq, 32.1 ppt, 5.24 x 10^{-5} for FDA.

If considering only the first objective, providing a dioxin concentration which when bioaccumulated in fish provides a contamination value below the 10 ppt MDPH health advisory trigger, 15 of the 27 policy combinations would provide a sufficient margin of safety. Figure 6.5 is a series of three graphs, one for each of the three bioconcentration/bioaccumulation factors, which illustrates the variability among the fish dioxin body burdens for the MDNR (DNR), MDPH, and FDA for each willingness to pay value.

The fish body burdens of dioxin associated with the willingness to pay value of \$6.8 million dollars all fall significantly below the MDPH health advisory trigger. While a number of the fish body burdens of dioxin fall below the MDPH 10 ppt health advisory for both the \$1.4 million and the \$0.5 million willingness to pay values, it appears that these values closely parallel each other. For example, the fish body burdens of dioxin for a BCF of 51,600 and willingness to pay values of \$1.4 million and \$0.5 million respectively are: 18 ppt and 18 ppt for MDPH, 8.0 ppt and 7.0 ppt for MDNR, and 24 and 24 ppt for FDA.

One explanation for the similar values is that although the \$1.4 million willingness to pay value is more than twice the amount of the \$0.5 million willingness to pay value, the \$0.5 million value has a mean risk level threefold smaller than that of the \$1.4 million value, 3×10^{-4} and 10.1×10^{-4} respectively. In developing the damage cost function, the Delta County sport fish eating population's risk of contracting cancer is first multiplied by the willingness to pay value and is secondly divided by the mean risk level of the sample used to determine the willingness to pay value. Dividing by the mean risk of the study sample equalizes the willingness to pay values. As a result, once equalized, the \$1.4 million and \$0.5 million willingness to pay values are relatively similar.

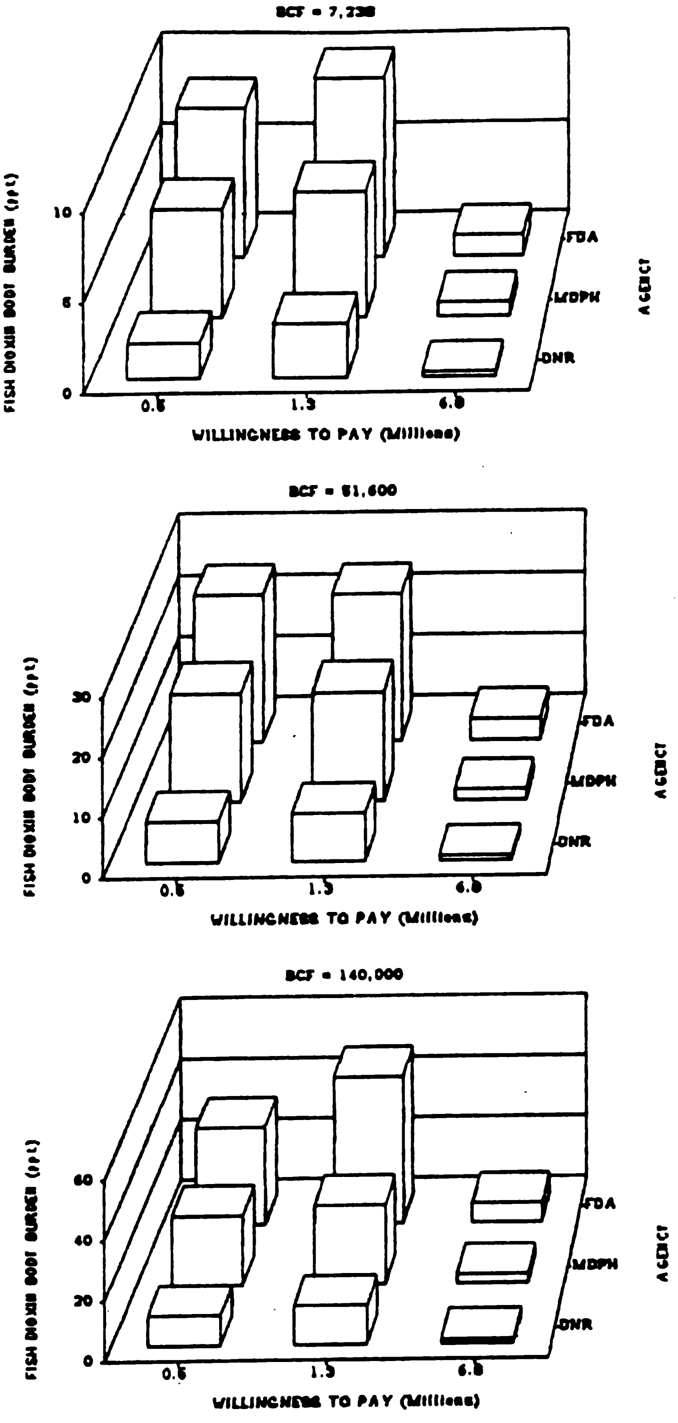

Figure 6.5 Comparison of MDPH, MDNR, FDA, fish dioxin body burdens based on willingness to pay values and bioconcentration factors.

The 15 body burdens of dioxin values (as listed in Tables 6.1-6.6) that are below 10 ppt, from low to high are: 0.3 ppt, 0.8 ppt, 1.0 ppt, 1.2 ppt, 2.0 ppt (listed twice), 3.0 ppt (listed twice), 3.5 ppt, 6.0 ppt, 6.4 ppt, 7.0 ppt (listed twice), 8.3 ppt, and 9.97 ppt. The lowest fish body burden (0.3 ppt) of dioxin results from the policy combination which includes an MDNR cancer potency factor, bioaccumulation factor of 7,238, and a willingness to pay value of $6.8 million (Table 6.1). The highest concentration, which is still below the 10 ppt MDPH health advisory, (9.97 ppt) results from the policy combination which includes an FDA cancer potency factor, a BCF of 7,238, and a willingness to pay value of $1.4 million. The significance of these two values is that although there is a difference of 9.67 ppt of dioxin, yet they are both under the MDPH health advisory and are therefore both deemed to be safe to eat.

The differences in the fish body burdens of dioxin are associated with each of the different bioconcentration/bioaccumulation factors. The lower the value of the bioconcentration/bioaccumulation factor the lower the value will be for dioxin in fish. Based on the BCF used by the MDNR in making dioxin regulatory decisions (51,600) in Figure 6.5 and Tables 6.2 and 6.5, fish body burdens of dioxin span the range of a low of 1.0 ppt for a MDNR cancer potency factor and $6.8 million willingness to pay value to a high of 24 ppt for a FDA cancer potency factor and willingness to pay values of $1.4 million and $0.5 million. Clearly, the different agency risk assessment assumptions, when the BCF is held constant at a current regulatory level, provide an inconsistent margin of safety. The fish body burdens of dioxin estimates indicate that the different potency values used for estimating excess lifetime cancer risk result in different levels of protection. However, meeting the MDPH health advisory for dioxin of 10 ppt is only one of the policy objectives, the cancer risk level must also be evaluated.

The second objective in determining whether a particular effluent dioxin concentration provides an adequate margin of safety is to evaluate whether it provides the same cancer risk used by the MDPH, MDNR, and FDA in their risk assessment processes: a risk of one excess case of cancer per 100,000 exposed individuals. Figures 6.6 - 6.8 illustrate the cancer risks per 100,000 exposed individuals associated with fish dioxin body burdens. The cancer risks were extrapolated from the potential excess cases of cancer for the Delta County sport fish consuming population of 8,242 individuals (Tables 6.1 -6.6).

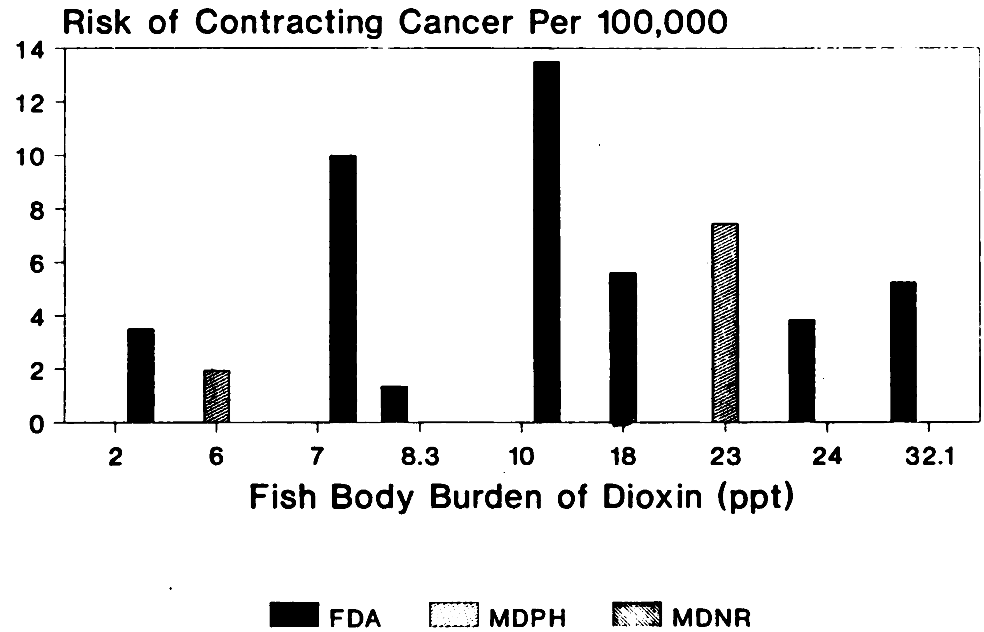

Figure 6.6 The risk of contracting cancer for a population dioxin contaminated fish based for FDA, MDPH and MDNR cancer potency factors and a willingness to pay value of $0.5 million.

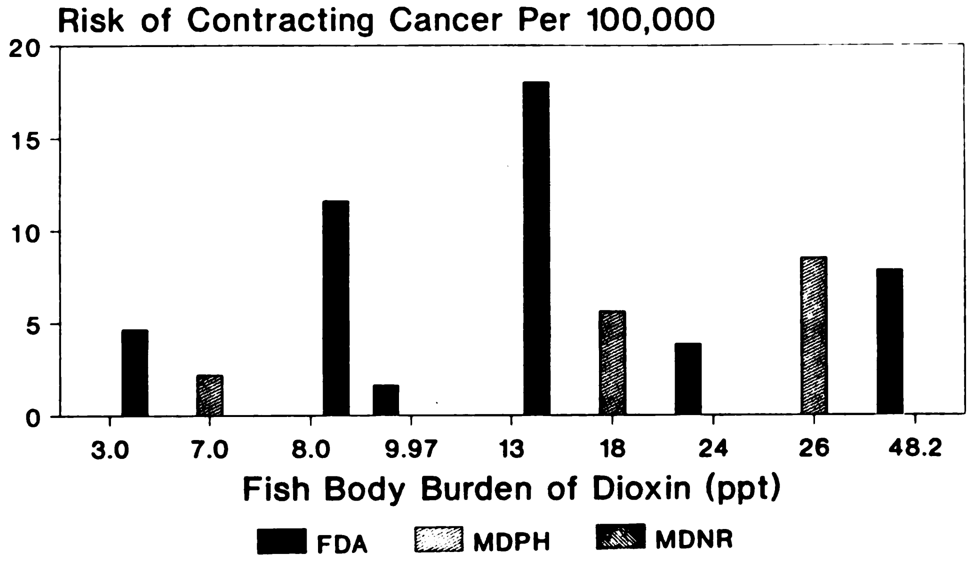

Figure 6.7 The risk of contracting cancer for a population dioxin contaminated fish based for FDA, MDPH and MDNR cancer potency factors and a willingness to pay value of $1.4 million.

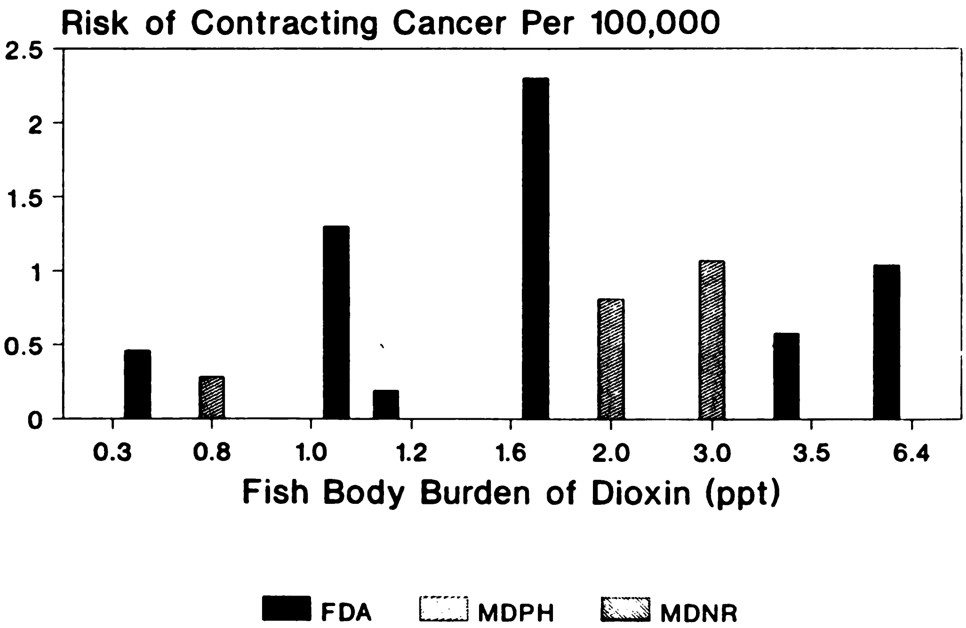

Figure 6.8 The risk of contracting cancer for a population dioxin contaminated fish based for FDA, MDPH and MDNR cancer potency factors and a willingness to pay value of $6.8 million.

One trend that is particularly evident from Figures 6.6-6.8 is that the MDNR risk of contracting cancer values far exceeds the same values for MDPH and FDA. This is directly related to the cancer potency factor, which for the MDNR (1.51 x 10^5) is an order of magnitude less than either MDPH (3.57 x 10^4) or FDA (1.75 x 10^4).

Only five of the policy combinations provide the 1 x 10^{-5} margin of safety used by the MDPH, MDNR and FDA in their dioxin regulatory programs. An evaluation of the fish dioxin body burdens and the cancer risks levels enables the range of potential dioxin discharge concentrations to be narrowed to only those that meet the objectives of Michigan's dioxin policy: (1) be below the 10 ppt MDPH health advisory, and (2) not exceed a cancer risk of one excess case of cancer per 100,000 exposed individuals.

The following five Pareto optimal dioxin discharge concentrations meet both criteria: (1) 0.5 ppq for MDPH, (2) 0.2 ppq for MDNR, and (3) 0.7 ppq for FDA all with a bioaccumulation factor of 7,238 and a willingness to pay value of $6.8 million; and (4) 0.2 ppq, for MDPH, and (5) 0.3 ppq for FDA with a 51,600 bioconcentration factor and a willingness to pay value of $6.8 million. In effect, based on the assumptions provided in Chapter 5, these dioxin effluent concentrations would provide the range of Pareto optimal solutions. Each of the dioxin effluent concentrations are tenfold above the current 0.022 ppq MDNR effluent limit for the Mead pulp mill.

If the second criteria is relaxed to accommodate cancer risks below 2 excess cases of cancer per 100,000 exposed individuals, the number of Pareto optimal dioxin discharge concentrations increases by five to include: 6.0 ppq for FDA with a 7,238 bioaccumulation and a willingness to pay of \$1.4 million; 3.5 ppq for MDPH with a 7,238 bioaccumulation and a willingness to pay of \$0.5 million; 0.08 ppq for MDNR with a 51,600 bioconcentration factor and willingness to pay of \$6.8 million; 0.1 ppq for MDPH and 0.2 ppq for FDA with a 140,000 bioaccumulation factor and willingness to pay of \$6.8 million. In examining these additional values only one, 0.08 ppq for MDNR with a 51,600 bioconcentration factor and a willingness to pay of \$6.8 million, comes close to the current 0.022 ppq MDNR effluent limit for dioxin in the Mead mill discharge.

Returning to Table 6.2, this 0.08 ppq Pareto optimal level of dioxin discharge can be further investigated. The total damage costs, which are based on a societal willingness to pay to reduce a members risk of contracting cancer, associated with this 0.08 ppq value is \$897,949/day. The abatement cost to the Mead pulp mill is \$1,026,210 a day. The mill currently spends \$23,585 to reach a 7.5 ppq value for dioxin in its effluent. Using the same assumptions which provided the 0.08 ppq effluent limit, a value of 7.5 ppq has the potential for resulting in a fish dioxin body burden of 88.9 ppt. The following cancer risks are associated with a 7.5 ppq value are: 125×10^{-5} (MDNR assumptions), 14×10^{-5} (FDA assumptions), and 30×10^{-5} (MDPH assumptions). Each of these risks, in particular the 125×10^{-5}, which is based on the MDNR risk assessment assumptions, exceeds the 1.3×10^{-5} risk associated with a 0.08 ppq value.

Clearly under the study assumptions the current dioxin discharge level of 7.5

ppq comes no where near the margin of safety which the Michigan dioxin policy demands. However, the margin of safety provided by a 0.08 ppq effluent value may be excessive. The resulting potential dioxin fish body burden is 1.0 ppt which is far below the 10 ppt MDPH health advisory. This 0.08 ppq level would force the Mead mill to spend $1,026,210/day to meet a margin of safety for dioxin in fish which is ten times less than MDPH requires. It is difficult to imagine the mill operating under such a scenario. These two effluent extremes of 7.5 ppq and 0.08 ppq suggest that perhaps a true Pareto optimal solution lies somewhere in this range.

Figure 6.9 is a series of three graphs, one for each of the three bioconcentration/bioaccumulation factors, which illustrate the Pareto optimal dioxin effluent concentrations. In comparing the fish dioxin body burdens from Figure 6.5 and the Pareto optimal level of dioxin in Figure 6.9 two observations stand out.

First, because fish dioxin body burdens are directly related to effluent concentration of dioxin the shapes of the bars are similar. Second, there is a significant difference between the $6.8 million willingness to pay values and the $1.4 million and $0.5 million values. This difference is directly related to the value placed on a statistical life. The value of a statistical life which is higher ($6.8 million) indicates that people are willing to pay more for more protection. This greater protection is manifested in a lower Pareto optimal level of dioxin discharge.

After evaluating Tables 6.1 - 6.6 and determining the Pareto optimal levels of dioxin concentration which meet the Michigan dioxin policy criteria, it is evident that the MDNR water quality based effluent limit of 0.022 ppq for the Mead pulp mill

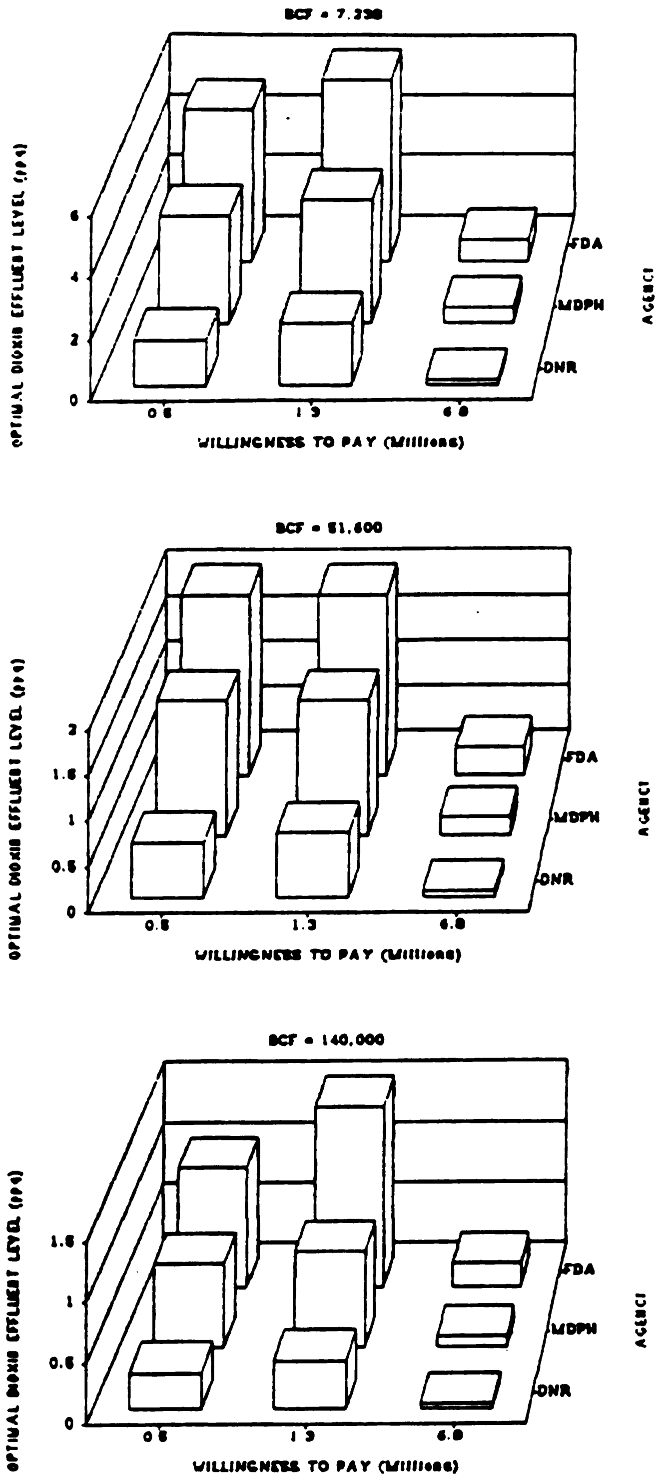

Figure 6.9 Comparison of MDPH, MDNR, FDA, Pareto optimal dioxin effluent levels based on willingness to pay values and bioconcentration factors.

does not fall into the range of possible Pareto optimal solutions.

Evaluation of Michigan's Dioxin Policy The current MDNR National Pollutant Discharge Elimination System permit authorizes the Mead pulp mill to meet a water quality based effluent limit of 0.022 ppq of dioxin from June, 1992 until the permit expires in 1994. Until June, 1992, any discharge of dioxin at or above the level of detection, which currently ranges 3-4 ppq, is considered in violation of the permit (Zugger, 1990). In the absence of a match between a Pareto optimal level of dioxin discharge and the MDNR effluent limit of 0.022 ppq, the policy analysis model can be used to evaluate the specific MDNR dioxin effluent limit.

The potential costs associated with meeting an effluent of 0.02 ppq for the Mead pulp mill is $3,242,995/day. The damage costs for a 0.02 ppq dioxin effluent concentration, based on the MDNR bioconcentration factor of 51,600, are presented in Table 6.7

Table 6.7 Damage Costs per day and associated cancer risks,based on MDPH, MDNR and FDA cancer potencies and a BCF of 51,600, for a dioxin effluent limit of 0.02 ppq.

Damage Cost	MDPH	MDNR	FDA
Based on a: $6.8 million WTP	$ 53,428	$225,984	$ 26,190
$1.4 million WTP	$ 1,058	$ 4,475	$ 519
$0.5 million WTP	$ 1,358	$ 5,744	$ 666
Delta County fish consumer risk level	0.0065/8,242	0.027/8,242	0.00317/8,242
General risks			
per 100,000	.08	0.3	.04
per 1,000,000	0.8	3.0	0.4
per 10,000,000	8.0	30	4.0

At first glance it appears that the abatement cost incurred by the Mead mill to meet a 0.02 ppq dioxin level far exceeds any of the potential damage costs identified in Table 6.7. In fact, it is 14 times greater than the highest potential damage cost ($225,984), which is based on an MDNR risk assessment assumptions and a $6.8 million willingness to pay, and 6,249 times higher than the lowest potential damage cots ($519), based on FDA risk assessment assumptions and a $1.4 million willingness to pay value. However, if the corresponding cancer risk is significantly high then these costs may well be warranted. In the case of the 0.02 ppq dioxin discharge level, however, the cancer risks are far below the 1×10^{-5} risk level, ranging from a low of 0.4×10^{-6} to 3.0×10^{-6}, which indicates that perhaps that the 0.022 ppq value is excessive.

Fish body burdens of dioxin that correspond with a dioxin effluent limit of 0.02 ppq are: 0.033 ppt for the 7,238 bioaccumulation factor, 0.237 for the 51,600 bioconcentration factor, and 0.643 for the 140,000 bioaccumulation factor. These are two to three orders of magnitude below the health advisory trigger. This standard exceeds the 10 ppt MDPH health advisory trigger by a significant margin placing the potential burden of a $3,242,995/day total abatement cost on the mill. Table 6.3 (which is based on the 140,000 bioaccumulation factor, MDNR cancer potency factor, and a willingness to pay of $6.8 million) indicates that the greatest amount people would be willing to pay to reduce associated risks for dioxin is 0.05 ppq, based on the ratio of total abatement cost to willingness to pay. This level indicates that individuals are willing to accept a risk of contracting cancer greater than 1×10^{-5}

(Table 6.3). The corresponding abatement cost for a 0.05 ppq dioxin effluent discharge ($1,515,849, Table 6.3) is over 50 percent less that the 0.02 ppq level.

This evaluation addresses the issues of meeting the MDPH health advisory trigger and the agency cancer risk level, and provides a bases for addressing the researchable question posed in Chapter 1: do the private costs to the Mead Corporation's Escanaba kraft pulp mill, incurred as a result of the MDNR's dioxin effluent limit, exceed the benefits of the reduced risk of contracting cancer, which are based on the MDPH and MDNR risk management approaches, received by the Delta County sport fish eating population?

Based on the above analysis it can be stated that **the permitted MDNR water quality based effluent limit is not Pareto optimal; the private costs to the Mead pulp mill, incurred as a result of the MDNR regulations, exceeds the benefits to the Delta County sport fish consuming population of the reduced risk of contracting cancer from dioxin contaminated fish.** The MDNR effluent limit places an undue burden upon the mill at a cost that society is unwilling to pay.

Table 6.7 also illustrates the range of cancer risks using the MDNR bioconcentration factor for the MDNR, MDPH, and FDA cancer potency factors. All three potency factors indicate that the level of protection is a magnitude below that which the MDNR and MDPH base their policies. As indicated by the results, a dual formulation of policy is not efficient and affords more protection than society is willing to pay based on the 10 ppt health advisory trigger.

As indicated in Chapter 3, there is a difference between the purpose of the values derived by MDPH and MDNR dioxin policies. The MDPH health advisory trigger is based on communicating the risk of consuming dioxin contaminated fish to potential consumers. The MDNR water quality based effluent limit is designed to prevent future harm (Sills, 1990). Until the risks of dioxin exposure are fully understood it is difficult to determine the level of control for dioxin sources. Although the MDPH and the MDNR are working under different regulatory philosophies, societal willingness to pay indicates that the current MDNR effluent limit for dioxin of 0.022 ppq is excessive.

CHAPTER SEVEN: SUMMARY AND CONCLUSIONS

The final chapter of this thesis presents a summary of the important issues and findings, offers conclusions for the development of persistent toxic substance policy and suggests additional research.

7.1 Summary

As pointed out in Chapter 1, a model is merely an abstraction of reality. The information that it provides is only as good as the information used in its development. In this research a simple model linking the fate of a persistent toxic chemical (dioxin) with potential economic impacts was developed in an effort to provide risk managers with information concerning the economic impacts of the persistent toxic chemical policies that they develop. The general objective of this study has been to shed some light on the risk assessment/management policy development process and, in particular, to illustrate that environmental standards, regardless of how they are developed, have real economic impacts on society.

To address this general thesis a specific objective was to develop a policy analysis model that could be used to evaluate toxic substance regulation in Michigan by identifying the private costs to industry, and the benefits to society of decreased risk to adverse effects of toxic contaminated surface water, through the determination of a range of Pareto optimal solutions.

In Michigan, the goal for persistent toxic chemical policy is to protect the public health, safety, and welfare from exposure to toxic compounds. Depending on particular state agency mandates this goal can be expanded to include the protection of plant and animal life as well as the designated uses of a water body from the presence of toxic substances. This research focused specifically on the persistent toxic chemical 2,3,7,8-TCDD (referred to as dioxin) and the policies designed by the Departments of Natural Resources and Public Health to protect the citizens of Michigan from exposure.

To evaluate this dual agency approach the following researchable question was posed: **do the private costs to the Mead Corporation's Escanaba kraft pulp mill, incurred as a result of the Michigan Department of Natural Resource's dioxin effluent limit, exceed the benefits of the reduced risk of contracting cancer, which are based on MDPH and MDNR risk management approaches, received by the Delta County sport fish eating population?**

Before this question could be addressed a general presentation of the sources of dioxin and its chemical characteristics was provided. Since the initiation of the National Dioxin Strategy the generation of dioxin has been associated with a number of sources, including: chemical production, municipal incinerators, smelting processes, automobile exhaust and the bleaching sequence in kraft pulp mill operations. Persistence and bioaccumulation are the two primary properties of dioxin that increase the hazard potential to humans and the environment. Combined, these factors pose a significant threat to Great Lakes sport fisherpersons who consume their catch.

The health effects of dioxin were briefly examined with the general conclusion that due to a number of deficiencies in current epidemiological studies, no specific cause and effect relationships can be determined for dioxin exposure and damage to human health. However, a number of animal studies have linked dioxin exposure with the development of cancer. As most regulatory agencies assume that all animal carcinogens are human carcinogens, for regulatory purposes, human exposure to dioxin is assumed to pose the potential for cancer development in humans.

The regulatory policies for dioxin were examined for four agencies: the Environmental Protection Agency, the Food and Drug Administration, the Michigan Department of Natural Resources, and the Michigan Department of Public Health. Each agency was identified as using a risk assessment /management process for developing persistent toxic substance policy. The following three specific similarities are shared by the agencies in their risk assessment policies: (1) the use of the Kociba (1978) cancer rat study, (2) a 1×10^{-5} cancer risk, and (3) a linearized multistage model for extrapolation. However, a number of inconsistencies also exist between the agencies in their policy development approaches. The following list summarizes the differences in agency risk assessment/management processes:

1. type of tumors counted in the Kociba study;
2. potency factors;
3. species conversion factor; and
4. regulatory mandate.

The environmental protection agencies, the EPA and MDNR, use risk assessment\management to develop effluent limits and technology based standards to control the amount of dioxin which is discharged by a polluting firm. The health protection agencies use risk assessment/management to provide consumption advice concerning either the interstate commerce of fish (FDA) or the in state consumption of sport caught fish (MDPH).

In Michigan, the MDNR has developed a water quality based effluent limit for dioxin of 0.01 ppq for new mills sited tributary to the Great Lakes and 0.022 ppq for the Mead pulp mill in Escanaba, as part of an EPA authorized state National Pollutant Discharge Elimination System. The effluent limit communicates to the pulp mill that discharges above the limit will not be tolerated. The MDPH has set a health advisory trigger for dioxin of 10 ppt in fish. The health advisory trigger communicates to fisherpersons that there is potentially a substantial risk involved in eating fish above the health advisory trigger.

To address the researchable question of determining optimal mill costs and societal benefits two issues had to be addressed. The first issue was whether the level of dioxin permitted into the environment, by water quality-based effluent limits, when bioaccumulated by fish, provides the same margin of safety as the MDPH health advisory trigger. A second issue necessary in determining whether the costs to the Mead mill exceed the benefits to society (referred to as searching for a Pareto optimal solution), was to determine the value of damage caused when organisms are exposed to dioxin in the environment.

The policy model designed in Chapter five was used to address both of these issues. The foundation for the policy model is the traditional pollution control model, as explained in Chapter 4, which seeks to maximize social welfare and minimize costs. The model depends on the development of a damage function, abatement function, and a total cost of pollution, which is the sum of the damage and abatement functions.

A series of six equations were used to link effluent concentration of dioxin to a specific point on a damage cost curve. The dioxin effluent concentration was translated to a concentration of dioxin in the river. Through the use of bioaccumulation factors the river concentration of dioxin was transformed to a concentration of dioxin in fish. The value of dioxin in fish was then used as a human dose of dioxin and through the use of the risk equation: risk = potency x dose, was translated to a risk of contracting cancer as a result of dioxin exposure. The general cancer risk was multiplied by a value of the sport fish consuming population in Michigan to derive a specific cancer risk for Delta County sport fish eaters. And, finally, this specific cancer risk was multiplied by a willingness to pay value to reduce a member of society's risk of death from avoidable behavior.

The total costs per day of three abatement technologies scheduled for addition to the Mead pulping and bleaching process were plotted against the associated decrease in dioxin discharge, and a power function was fitted to these values in an attempt to derive an extended pollution abatement cost curve. The abatement cost curve was added to twenty-seven different damage costs curves and the resulting minimum values were compared to the current dual agency dioxin policy to determine whether the Michigan policy was Pareto optimal.

Five dioxin discharges which met the policy objectives of having associated dioxin fish burdens below 10 ppt and cancer risk levels below 1 x 10^{-5} were identified as Pareto optimal: (1) 0.5 ppq for MDPH, (2) 0.2 ppq for MDNR, and (3) 0.7 ppq for FDA all with bioaccumulation factor of 7,238 l/kg and a willingness to pay value of \$6.8 million; and (4) 0.2 ppq, for MDPH, and (5) 0.3 ppq for FDA with a 51,600 bioconcentration factor and willingness to pay value of \$6.8 million. Each of these dioxin effluent concentrations are tenfold above the current 0.022 ppq MDNR effluent limit for the Mead pulp mill.

A subsequent analysis of the 0.022 ppq effluent limit indicated a cancer risk range from 0.4 x 10^{-6} to 3.0 x 10^{-6}, associated fish body burdens of dioxin of 0.033 ppt (7,238 bioaccumulation factor), 0.237 ppt (51,600 bioconcentration factor), and 0.643 ppt (140,000 bioconcentration factor), potential abatement costs of \$3,242,995/day and damage costs range from a low of \$519 to \$225,984/day. Based on the lack of a match with a Pareto optimal solution, as well as the fish body burden of dioxin and the cancer risk values corresponding with a 0.022 ppq dioxin effluent limit, it was concluded that **the permitted MDNR water quality based effluent limit is not Pareto optimal; the private costs to the Mead pulp mill, incurred as a result of the MDNR regulations, exceeds the benefits to the Delta County sport fish consuming population of the reduced risk of contracting cancer from dioxin contaminated fish.**

7.2 Conclusions

The conclusions are addressed in the following five categories: (1) potential damage caused by persistent toxic substances, (2) using risk assessment/management to develop persistent toxic substance policy, (3) damage costs associated with persistent toxic substance policy, (4) policy implications

Potential Damage Caused by Persistent Toxic Substances This research addressed one specific potential damage related to the discharge of dioxin in the environment: the potential of a specific population contracting cancer. There are, however, a number of other potential damages associated with the discharge of a persistent toxic substance such as dioxin into the environment. The same laboratory data that is used to extrapolate risks to humans can be used to extrapolate risks to animals which live in environments contaminated by dioxin or other persistent toxic substances. Further, as was earlier indicated, studies have been conducted which indicate potential links between health hazards to various animal species and dioxin exposure.

Since dioxin is persistent there is potential for damage to animals in the immediate vicinity of a discharge as well as downstream or perhaps elsewhere within the Great Lakes ecosystem. The bioaccumulation characteristic of dioxin provides a pathway for dioxin to contaminate species in the aquatic community as well as the terrestrial community. Fish can bioaccumulate dioxin, and predators both in aquatic and terrestrial environments can be exposed to dioxin by consuming contaminated fish. This research did not account for potential dioxin damage beyond that of contracting caner by humans due to dioxin exposure.

Using Risk Assessment/Management for Policy Development The risk assessment/management process is based on a number of variables including: the determination of whether or not a particular chemical is causally linked to a particular health effect, the determination of the relation between the magnitude of exposure and the probability of occurrence of the proposed effects, and the estimation of the number of people who will be exposed and the characteristics of the exposure before and after application of regulatory controls.

For each of these variables risk managers must assess the appropriateness of data provided from industry, public interest groups, the scientific community and the regulatory community. The submission of new data from any reputable source requires thorough analysis and justification of the assumptions used by risk managers before regulatory controls can be adjusted. In a process wrought by uncertainty this can be a herculean task. However, the regulatory standards that are based on these data do provide real environmental and economic impacts and deserve intensive scrutiny.

A Michigan newspaper editorial exemplifies the task before the Michigan risk managers. In response to the release of re-analysis of dioxin dose response data, the *Detroit News* (10 June 1990) wrote:

> The "good news" about dioxin comes from many sources, but most notable is Robert Squire, the John Hopkins University scientist who analyzed rodent studies on the poison for the Environmental Protection Agency (EPA) in the 1970s. He wrote the report on which today's excessively stringent standards

> are based. Newer technology, he says, has shown that the safe daily dosage he originally calculated for humans could be increased as much as 30 times. "I do not believe that dioxin poses a cancer risk to humans at any anticipated levels of exposure," Mr Squire said in a devastating letter to EPA.

Based on the information provided by the Squire letter the *Detroit News* editorial board concluded:

> The evidence is piling up. The scientists were wrong and the dioxin scare was another environmental ripoff. Michigan's standards should be cut drastically to reflect the real risks of this "weak carcinogen".

If additional evidence provides support for Squire's conclusion then the *Detroit News* editorial board's request may prove necessary. However, if risk managers change current regulatory standards based on the assertion of one scientist they would not be adequately protecting the health, welfare, and safety of society. Current standards are based on one particular dioxin rat study because the study is "generally regarded as the most biologically defensible of the low dose extrapolation models" (MDPH, 1986 p.6. It has withstood the test of time. In time, perhaps the Squire re-evaluation will prove to be the most "biologically defensible".

Another matter that complicates the risk manager's policy making is defining "how safe is safe". Persistent toxic substance policy is based on an acceptable level of risk. This acceptable level of risk is the value the risk manager takes to reflect the society's acceptable level of protection. In the case of MDNR's Rule 57 an expert panel defined acceptable risk to be one excess case of cancer per 100,000 exposed individuals. Once the risk level is established the risk manager's concerns are shifted to other facets of the risk assessment/management process. However, individuals are left to contend with the impacts of the resulting regulatory polices.

People have different risk tolerances. One person may only be willing to accept a one excess case of cancer per one billion exposed individuals. No matter how unreasonable this risk seems to the risk manager an individual's perception of risk defines an individual's reality. For an individual only willing to accept a 1×10^{-7} risk, accepting any greater could make life unbearable. Conversely, another individual may be willing to accept a 1×10^{-4} risk and be bothered by a health advisory trigger which recommends limiting fish consumption.

The risks that people accept are also related to whether the risk is voluntary or involuntary. In the case of dioxin tainted fish, a fisherperson may be greatly affected by the closure of a fishery due to high levels of dioxin while a non fisherperson may not be affected at all. A general societal solution is to reduce the risk of exposure to persistent toxic substances by reducing the release of the compound in the environment, thereby reducing the potential for exposure. In this manner the voluntary risk of eating sportfish would be reduced. This is precisely the aim of the effluent limit.

While science must drive the risk assessment/management process, public perception and political/economic climate will continue to influence policy outcomes. The policy model developed in this research allows risk managers to identify potential economic impacts of risk management options and as a result be better equipped to predict reactions to risk assessment/management based environmental standards.

Costs Associated with Persistent Toxic Substances Policy Economist suggest that zero discharge requires zero economic activity. However, consumer behavior can be altered to demand a product whose production process does not damage the environment to the same severity of current production processes. For example, if consumers preferred near-white paper to bleached white paper there would be no cause for dioxin concern from pulp mills. The near white paper could be produced by a process that does not require chlorine bleaching, the main cause of dioxin in pulp production.

In addition to the cost to society of contracting cancer, and the potential cost associated with the loss of species, there is the economic costs related to a closed fishery. If a fishery is closed, demand for related goods and services such as gas, fishing gear, and food may decline. While these costs are related to not meeting environmental standards there are also potential costs associated with meeting standards. For example, if consumer preference remains steadfast to bleached white paper, abatement costs, incurred as a result of meeting environmental standards, may increase to a level that is prohibitive of producing paper. This would result in damage costs of a different sort, that of the community economic costs associated with a mill shutdown such as the loss of a percentage of the tax base or lost employment opportunities.

Policy Implications Each Michigan agency is bestowed with a specific protection mandate. The MDNR has the responsibility to protect the natural resources of the state from pollution, impairment or destruction. The MDPH has the responsibility of protecting public health. Although these are fairly these broad mandates, basing dioxin policy solely on effluent limits and health triggers restricts state policy options. The MDNR and MDPH programs provide a dioxin policy which is based specifically on limiting exposure through end of the discharge pipe limitations (effluent limits) and as secondary protection, through fish consumption advise. Given the results of the policy analysis model indicate the MDNR standards may be excessive, especially when compared to MDPH health advisory triggers, there are alternative policy recourses other than simply raising the effluent limit.

Instituting educational program on toxic substance is one policy option. The jury is still out on the human health effects of dioxin, yet public perception that it presents a significant danger to humans remains widespread. To address this perception Michigan's regulatory agencies could embark on an education campaign. Two major issues could be stressed.

First, the risks associated with dioxin exposure should be adequately communicated. Public perception is driven by the news media which provides conflicting information. For example, one month journalists report, "Fishing downstream of a paper mill can be dangerous to your health (Port Huron *Times Herald*, 1 May 1990)," and the next, "Michigan's standards should be cut drastically to reflect the real risks of this 'weak carcinogen' (*Detroit News*, 10 June 1990)."

Second, if dioxin continues to be a major concern the then society must be provided with information concerning viable alternatives to bleached white paper. Of course, as a State sponsored activity the Department of Commerce may have a difficult time excepting such an educational objective as decreasing economic opportunity in the state.

At a minimum, consistency in risk assumption/management processes would provide consistent information to society. Attempts at intrastate coordination of risk assessment/management approaches, such as the Michigan Council of Environmental Quality risk assessment guidelines, are needed to ensure that scarce state financial resources are more efficiently allocated. Similarly, the continuation of interstate attempts at coordinating risk assessment/management approaches to developing persistent toxic substance policy is also needed. The EPA Great Lakes Water Quality Initiative and the Great Lakes Fish Consumption Advisory Task Force are two examples of this type of coordination (USEPA, 1989; Hesse, 1990). Inconsistencies among state approaches can fuel interstate competition for pulp mill development. The result of this competition could ultimately be environmental degradation rather than the coveted and desired economic development. The EPA recently approved Maryland's 1.2 ppq effluent standard for dioxin (Inside EPA, 1990). Echoing the uncertainty addressed in this research, an EPA official commented that "a standard one hundred times weaker than EPA's 'isn't surprising given the degree of dispute within the scientific community' about the potency of dioxin (Inside EPA, 1990). This decision could have a significant impact on where pulp mills locate. Although a readily available source of wood fiber is critical to pulp mill siting, a sufficiently lower standard in one state, given the same wood fiber supply, could entice a pulp mill to relocate.

The policy analysis model presented in this research provides a framework by which a number of variables can be linked and analyzed to determine the economic impacts of regulatory approaches. These variables include: the flow of receiving water, the amount of fish consumed, the weight of a fish consumer, cancer potency factors, bioaccumulation factors/bioconcentration factors, site specific willingness to pay values, and variable abatement costs.

7.3 Recommendation for Future Research

Although there are a tremendous amount of research possibilities which could improve the general understanding of dioxin, of critical importance to policy makers is that of determining what the health consequences are of human exposure to dioxin. If dioxin is determined to no longer be as toxic as it once was thought to be, perhaps current effluent standards could be relaxed. However, as long as there is a significant degree of uncertainty, prudent policy dictates a conservative standard. If a standard is relaxed under uncertainty only time will prove whether the decision to relax the standard was appropriate.

Other research possibilities include:

(1) The transport and fate of dioxin in aquatic and terrestrial ecosystems could be further explored. A better understanding of dioxin pathways in the environment

could provide information that would allow economists to utilize valuation techniques to attempt to quantify damage costs.

(2) The use of non-market valuation techniques such as willingness to pay is still considered quite controversial among economists. Continued research into the validation of non-market valuation techniques could ensure the appropriateness of using these techniques to evaluate policy.

(3) Studies have been conducted in Michigan to assess the attitudes of fisherpersons to the presence of toxic substances in Michigan rivers (Udd, 1985 and Smith and Enger, 1988). However, specific studies to assess what risk level the fish consuming public would be willing to pay for have yet to be conducted. To get a better understanding of the Delta County fish consuming public's attitudes studies could be performed to determine the County population's willingness to accept risk and to pay for risk.

(4) Research into cost effective non dioxin generating technologies would provide pulp mills alternatives in selecting abatement strategies.

(5) Behavioral research may provide insight into individual preferences and result in educational programs that empower individuals to make choices based on health considerations rather than only aesthetic considerations.

The variables evaluated in this research, cancer potencies, bioconcentration factors, and willingness to pay, are plagued with uncertainty and at times are controversial. Instead of providing a specific defensible policy endpoint, this research provides a framework in which policy makers can evaluated a number of combinations of potential policy variables. Through careful evaluation of scientifically defensible variables the risk manager can predict potential outcomes and develop programs that ensure the proper communication to society of policy objectives.

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APPENDIX A

Calculation of a Regional Bioaccumulation Factor for the Escanaba River for Dioxin (Anderson et al., 1990)

Fish Species	WT (lbs)	TCDD (ppt)	Fish Species	WT (lbs)	TCDD (ppt)
Northern Pike	6.1	3.31	Smallmouth Bass	2.0	5.51
Northern Pike	6.3	23.40	White Sucker	3.7	8.44
Northern Pike	5.7	10.20	White Sucker	3.0	8.29
Northern Pike	5.7	12.00	White Sucker	4.4	17.60
Northern Pike	5.0	13.60	White Sucker	3.7	9.06
Northern Pike	5.2	24.40	White Sucker	3.0	13.40
Northern Pike	4.0	7.15	White Sucker	2.9	15.30
Northern Pike	3.7	4.90	White Sucker	3.1	12.40
Northern Pike	4.6	9.81	White Sucker	3.9	8.80
Northern Pike	3.3	2.86	White Sucker	3.5	8.55
Northern Pike	2.5	6.62	White Sucker	4.1	9.61

Mean TCDD concentration = 10.69 ppt

Date	Effluent Flow (MGD)	Effluent TCDD Conc. (ppq)
12/87	35	17.2
03/88	33	39.9
06/88	39	18.6
09/88	37	47.9
12/88	34	20.6
03/89	43	40.0
06/89	39	11.9
09/89	39	13.7

Weighted Average Effluent TCDD Concentration = 26.20 ppq

River TCDD Concentration

$$\frac{26.20 \text{ ppq} \times 36 \text{ mgd}}{602.63 \text{ mgd} + 36 \text{ mgd}} = 1.48 \text{ ppq}$$

BAF calculation

$$\frac{10.69 \text{ ppt}}{1.48 \text{ ppq}} = 7238$$

APPENDIX B

Rule 57 (*Mich. Admin. Code. r.323.1057*)

R 323.1057. Toxic substances.

Rule 57. (1) Toxic substances shall not be present in the waters of the state at levels which are or may become injurious to the public health, safety, or welfare; plant and animal life; or the designated uses of those waters. Allowable levels of toxic substances shall be determined by the commission using appropriate scientific data.

(2) All of the following provisions apply for purposes of developing allowable levels of toxic substances in the surface waters of the state applicable to point source discharge permits issued pursuant to Act No. 245 of the Public Acts of 1929, as amended, being §323.1 et seq. of the Michigan Compiled Laws:

(a) Water quality-based effluent limits developed pursuant to this subrule shall be used only when they are more restrictive than technology-based limitations required pursuant to R 323.2137 and R 323.2140.

(b) The toxic substances to which this subrule shall apply are those on the 1984 Michigan critical materials register established pursuant to Act No. 245 of the Public Acts of 1929, as amended, being §323.1 et seq. of the Michigan Compiled Laws; the priority pollutants and hazardous chemicals in 40 C.F.R. §122.21, appendix D (1983); and any other toxic substances as the commission may determine are of concern at a specific site.

(c) Allowable levels of toxic substances in the surface water after a discharge is mixed with the receiving stream volume specified in R 323.1082 shall be determined by applying an adequate margin of safety to the MATC, NOAEL, or other appropriate effect end points, based on knowledge of the behavior of the toxic substance, characteristics of the receiving water, and the organisms to be protected.

(d) In addition to restrictions pursuant to subdivision (c) of this subrule, a discharge of carcinogens, not determined to cause cancer by a threshold mechanism, shall not create a level of risk to the public health greater than 1 in 100,000 in the surface water after mixing with the allowable receiving stream volume specified in R 323.1082. The commission may require a greater degree of protection pursuant to R 323.1098 where achievable through utilization of control measures already in place or where otherwise determined necessary.

(e) Guidelines shall be adopted pursuant to Act No. 306 of the Public Acts of 1969, as amended, being §24.201 et seq. of the Michigan Compiled Laws, setting forth procedures to be used by staff in the development of recommendations to the commission on allowable levels of toxic substances and the minimum data necessary to derive such recommendations. The commission may require the applicant to provide the minimum data when otherwise not available for derivation of allowable levels of toxic substances.

(f) For existing discharges, the commission may issue a scheduled abatement permit pursuant to R 323.2145 upon a determination by the commission that the applicant has demonstrated that each of the following conditions is met:

(i) Immediate attainment of the allowable level of a toxic substance is not economically or technically feasible.

(ii) No prudent alternative exists.

(iii) During the period of scheduled abatement, the permitted discharge will be consistent with the protection of the public health, safety, and welfare.

(iv) Reasonable progress will be made toward compliance with this rule over the term of the permit, as provided for in a schedule in the permit.

APPENDIX C

Michigan Department of Natural Resources Rule 57 (2) and Water Quality Based Effluent Limit for Mead, Escanaba Calculations

Rule 57 (2)[1]

$$C = \frac{D \times W_h}{WC + (F \times BCF)}$$

where:

C	=	Concentration of carcinogen (mg/l)
D	=	Dose (6.62×10^{-5} ng/kg/day)
W_h	=	Weight (70 kg)
WC	=	0.01 l/day for surface water
F	=	Fish consumption (0.0065 kg/day)
BCF	=	Bioconcentration factor (51,600)

$$C = \frac{6.62 \times 10^{-5} \times 70 \text{ kg}}{0.01 \text{ l} + (0.0065 \text{ kg} \times 51{,}600)} = 1.4 \times 10^{-5} \text{ ng/l}$$

Water Quality Based Effluent Limit for Mead, Escanaba[2]

$$WQBEL = \frac{V((1/4\ QR) + QE) - CRQR}{QE}$$

where:

V	=	Rule 57 (2) value of 1.4×10^{-5} ng/l
QE	=	Mead outfall design maximum flow (50 mgd)
QR	=	95% exceedence flow for the Escanaba River (122.8 mgd)
CR	=	Ambient river dioxin concentration (zero assumed)

$$\frac{1.4 \times 10^{-5} \text{ ng/l}((.25 \times 122.8) + 50 \text{ mgd}) - (0 \times 122.8)}{50 \text{ mgd}}$$

$= WQBEL = 2.2596 \times 10^{-5}$ ng/l = 0.022 pg/l = 0.022 ppq

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1 MDNR, 1989

2 Anderson et al., 1990

APPENDIX D

Average Fishing Population in Delta County[42]

Type of License	1986	1987	1988	1989	Average
Resident	7,129	7,241	7,005	6,909	7,071
Senior	1,174	1,146	1,205	1,160	1,171
Average					8,242
Non Resident	1,645	2,070	1,952	2,175	1,961
Daily Permit	3,183	3,545	3,291	3,410	3,357

[42] **MDNR, 1989b**

APPENDIX E

Mead Escanaba Pulp Mill Draft Dioxin Minimization Plan for Wastewater Treatment and Kraft Pulp Mill Modifications (Abbott, 1990)

Key Action Plans	Timetable
▸ Continue the evaluation of alternative brownstock washing defoamers to minimize DBD and DBF precursor contamination while providing satisfactory washing performance.	Nov., 1989-Dec., 1990
▸ Survey the process for other sources of DBD and DBF contamination in the brownstock pulp before bleaching (e.g., evaporator condensates used on the brownstock washer showers).	Nov., 1989-Dec., 1990
▸ Initiate the use of a new brownstock washing defoamers and other appropriate process changes which can lower DBD and DBF contamination in the brownstock pulp to the levels present as a result of background levels of DBD and DBF contamination in the environment (e.g., mill fresh water).	Nov., 1989-Dec., 1990
▸ Study the operation of the wastewater treatment facility to identify operating conditions which improve the removal of TCDD and TCDF.	May, 1990-Jan., 1991
▸ Convert the existing SVP process ClO_2 generator to the R-8 process increasing the production capacity for ClO_2.	May, 1990
▸ Improve the efficiency of application of Cl_2 and ClO_2 in the first bleaching stage by replacing the existing static mixer with two new static mixers in series.	May, 1990
▸ Convert the first bleaching stage from a simultaneous C_D to a $D + C_D$ sequential bleaching chemical application.	May, 1990
▸ Increase the ClO_2 substitution for Cl_2 beyond the 10% level.	June, 1990
▸ Optimize the $D + C_D$ first bleaching stage using the following process variables: - ClO_2 split between the D and C_D application - Temperature - Water recycle practices - pH - Etc.	May, 1990-Jan., 1991

Key Action Plans	Timetable
▸ Study process control improvements to minimize the molecular chlorine usage in the first bleaching stage.	Feb., 1990-Jan., 1991
▸ Continue pilot plant process research studies to minimize TCDD and TCDF production during the bleaching of kraft pulps. Key process variables to be investigated are:	Nov., 1989-Jan., 1991

- Level of ClO_2 substitution
- ClO_2 split between the D and C_D application
- pH of D + C_D stage
- E_o versus E_{op} second bleaching stage with resulting molecular Cl_2 reductions
- E_o or E_{op} bleaching stage before D + C_D stage

E_o (D + C_D) E_o D

or

E_{op} (D + C_D) E_{op} D

versus

(D + C_D) E_o D E D

▸ Assuming promising results are obtained from a pilot plant evaluation of adding hydrogen peroxide to an oxidative extraction stage (i.e., E_o) to reduce molecular chlorine usage, conduct full scale mill trials evaluating the benefits of E_{op} versus E_o bleaching.	Nov., 1990
▸ If significant process modifications are required beyond the actions being taken in 1990 to meet the goals of the DMP, the following additional process improvements are projected based on today's knowledge:	
- Convert E_o stage to full time E_{op} operation by adding new H_2O_2 storage, handling, and process control equipment.	Oct., 1991
- Convert the (D + C_D) E_oDED bleaching line to a E_o (D + C_D) E_oD sequence through extensive modification and additions (e.g., long delivery time high shear mixers).	Oct., 1992

APPENDIX F

Base Year Value Calculations for Willingness to Pay Values

GNP deflator
U.S. Department of Labor
Consumer Price Index Monthly Press Release
CPI-U All Urban Consumers

	Annual Average 1967 Base	Percent Change
1986	328.4	
1987	340.4	.035
1988	354.3	.039
1989	371.3	.046
1990 (up to 7/90)	386.2	.039
Ave.		.040

$$Z = X(1/r)^n$$

Where
Z = Corrected \$
X = \$ amount
r = average inflation rate from 1986-90
n = equals number of years in period

Study	1986 Value (\$)	1990 Equivalent[1] (\$)
Olsen (1981)	8,000,000	6,801,622
Gegax et al (1985)	1,600,000	1,360,323
Blomquist (1979)	610,000	518,624

1. 1986 dollars have been adjusted to reflect 1990 purchasing power.