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Author
Dumas, Christopher F.

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Cross-Media Pollution and Common Agency

by

Christopher Frank Dumas

B.S. (North Carolina State University) 1990
M.S. (University of California, Berkeley) 1991

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Committee in charge:

Professor Peter Berck, Chair
Professor David Zilberman
Professor Gregory Biging

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Ann Arbor, MI 48103

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Christopher Frank Dumas

The dissertation of Christopher Frank Dumas is approved:

Peter Berck 7/2/97

Chair Date

7/2/97

Date

Gregory S. Biging 8/20/97

Date

University of California, Berkeley

Fall 1997

This work is dedicated to my mother,
whose truth, compassion and optimism guide my way.

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Chapter 1

Introduction

1.1 Cross-Media Pollution and Common Agency

The United States expends significant economic resources in its efforts to control pollution. For example, in 1993 alone U.S. industries spent $26.4 billion to reduce pollution (U.S. Department of Commerce 1993); this figure does not include additional billions spent by federal, state and local governments on pollution control activities (Office of Management and Budget 1994).

Although political disagreements often arise over exactly how much should be spent on pollution control programs, sustained and widespread public support for such programs indicates society's willingness to incur significant costs in order to enjoy a cleaner environment. There is no doubt that pollution control programs have benefited society over the last few decades by reducing, or at least by holding fairly steady, the levels of several major types of pollution, even as national economic output has more than doubled (U.S. Environmental Protection Agency 1990).

However, as anticipated by Ayers and Kneese's (1969) seminal work on the "materials balance approach" to pollution regulation, the "success" of many pollution control programs may be somewhat illusory. Ayers and Kneese emphasized that pollution control often results in little true pollution *elimination*, but rather only *substitution* between different forms of pollution, each with associated benefits and costs to society. Often, pollution control amounts to simply transferring pollution from one environmental medium, such as water, to another environmental medium, such as air. In other cases, pollution control amounts to substituting one pollutant for another, as when controlling one type of air pollution emitted by motor vehicles results in an increase in another type of air pollution emitted by motor vehicles. Put directly, actions taken to control existing pollution problems often cause new pollution problems.

Cross-media (or "multimedia") *pollution* refers both to a pollutant that is directed from one environmental medium to another and to the substitution of one type of pollutant for another. Cross-media pollution exists because pollution sources often have several waste disposal options (i.e., firms have substitution possibilities in pollution abatement/disposal technology), and sources switch between disposal options in response to changing economic conditions. Sources choose a particular waste disposal option based on relative market incentives and regulatory pressures. For example, a factory may have two pollution control options: (1) emitting pollution into the air and paying a fine per unit of air pollution emitted and (2) installing "scrubber" pollution control machinery on its smokestacks (which would eliminate the air pollution and the associated fines) and paying for landfill disposal of the sludge produced by the scrubbers. The factory would choose between the two pollution control options depending on the relative costs of air pollution fines, on the one hand, and the costs of scrubber machinery and landfill dumping fees, on the other. If sludge dumped into the landfill has the potential to cause groundwater pollution, then the potential for cross-media pollution exists; i.e., reducing air pollution increases potential groundwater pollution, and avoiding potential groundwater pollution implies continued air pollution.

The significance of cross-media pollution varies from industry to industry and from pollutant to pollutant, but there is ample evidence to support the claim that cross-media pollution transfers can be significant. For example, ". . . an ARCO [a large petroleum company] spokesman has stated that fully 60 percent of all the hazardous wastes generated by his firm's refinery in Carson, CA, come from the required air and water pollution control devices" (Morell 1989, p. 43).

In addition to the *direct* cross-media pollution described above, *indirect* cross-media pollution can occur when industries that produce the goods and services used in pollution control activities themselves emit pollution. For example, when scrubber machinery is installed on smokestacks in order to control air pollution, the steel components of the scrubber machinery must be produced by the steel industry, and the steel industry emits some pollution in the course of producing the steel components. Empircial evidence of the significance of indirect cross-media pollution is presented in Chapter 4 of this dissertation. Results presented in Chapter 4 indicate that removing an estimated 1825 pounds per year of hazardous organic wastes from the groundwater beneath industrial sites located in the San Francisco Bay region of California results in the (net) indirect release of an estimated 5512 pounds per year of similar chemicals into the atmosphere of California. This clean up activity also results in the (net) indirect release of 9 tons per year of carbon monoxide, 8.5 tons per year of nitrogen oxides, 1711 pounds per year of sulfur oxides, 1029 pounds per year of heavy metals, and 1772 pounds per year of soot into the atmosphere of California and 5028 million gallons of industrial wastewater (classified as "potentially threatening" by the California Water Resources Control Board) per year into the navigable waters of the state.

Cross-media pollution is of increasing concern to environmental regulators for two related reasons. First, the "success" of traditional pollution control programs is exacerbating cross-media pollution problems. As traditional air and water pollution control programs have become more stringent, regulators are finding that "reductions" in pollution emissions often do not reflect the elimination of pollution, but rather merely the transfer of pollution between media (e.g., from air to water or vice versa) or to "new" media (groundwater, landfills, etc.), or the substitution of one pollutant for another. Former U.S. Environmental Protection Agency (EPA) Science Advisory Board chairman Raymond Loehr has emphasized the importance of addressing cross-media ("multi-media") pollution:

> Knowledge about ecosystem assimilative capacity and multi-media transfer of contaminants is critical to rational waste management policy and to the development of appropriate control technologies. It must be remembered that everything has to go someplace: there is no "away" into which residues can be placed or disposed . To have the benefits of a quality environment requires that a multi-media concept emerge as a component of a coherent national waste management policy. (R. Loehr 1989, p.11)

Second, the potential for cross-media pollution is exacerbated by the organizational structure of environmental regulatory agencies. Within the United States, pollution regulation is generally organized by environmental medium (e.g., water pollution control, air pollution control, landfill pollution control) and by class of pollutant (e.g., hazardous waste, solid waste, pesticides). At both the federal and state levels, different regulatory agencies or agency divisions regulate different environmental media and pollutants. In many cases, a regulated firm or industry must comply with the directives of multiple environmental regulators. These multiple regulators often operate quite independently of one another due to distinct enabling and program legislation, distinct funding sources, and specialization of staff.

The fragmented regulatory situation described above is an example of a general economic situation known as *common agency*.[1] Under common agency, multiple *principals* (e.g., regulatory agencies) attempt to modify the behavior of one or more *agents* (e.g., polluting firms or industries). Although many factors affect the efficiency of environmental regulation, including the choice of policy instruments, the choice of policy targets, uncertainty, monitoring and enforcement methods, common agency is particularly important in determining the efficiency of cross-media pollution regulation.

When separate regulatory agencies are responsible for alternative pollution control activities, the existence of several waste disposal options (i.e., the existence of the potential for cross-media pollution) can create a situation in which regulatory authorities implicitly compete with one another to reduce pollution in each of their separate jurisdictions. This competition among regulators can lead to inefficiencies in cross-media pollution regulation. If "air pollution control" amounts to forcing additional pollution into the water, and if environmental damages result from the increased water pollution, then a proper accounting of the costs of air pollution control should include increased water pollution damages. Single-media pollution regulation by multiple environmental regulators often fails to address the damages associated with substitute pollution emissions.

Common agency inhibits the policy coordination necessary to address cross-media pollution. For example, even if a water pollution regulator wished to take a

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[1] In the public policy literature, common agency is known as the problem of "policy fragmentation," or "regulatory fragmentation," or the "lack of policy integration"

comprehensive view of pollution control by, for example, considering the cross-media effects of water pollution control on air pollution, the water regulator would have no policy instruments with which to directly affect air pollution, and the water regulator would not be rewarded for achievements in air pollution control. Hence, early pollution control legislation which mandated the achievement of narrowly-defined, media-specific pollution targets "regardless of cost" not only failed to balance the environmental benefits of pollution control with the financial costs, but also failed to consider the costs of cross-media pollution.

Despite the institutional impediments to policy coordination, the growing significance of cross-media pollution may be driving environmental regulators to finally address the regulatory inefficiencies caused by common agency. Environmental regulators across the nation are currently experimenting with new organizational structures to facilitate cross-media regulation and permitting. For example, many EPA regional offices have begun to reorganize in order to better address cross-media pollution issues (McGuigan and Wisniewski 1995, Schwinn 1996, Contillo 1996).

This thesis investigates the significance of cross-media pollution and the implications of common agency for the efficiency of cross-media pollution regulation. The outline of the dissertation is as follows. Chapter 2 presents a literature review of common agency and cross-media pollution regulation from the perspectives of both public policy and economic theory. The literature review shows that cross-media pollution is a persistent and growing national problem. The review also indicates that cross-media pollution has received surprisingly little attention in the economics literature.

Chapter 3 develops an economic model of cross-media pollution regulation under common agency. Several results on the inefficiency of cross-media pollution regulation under common agency are derived, and the implications of several types of regulatory reform are examined. Chapter 4 is a case study of the significance of cross-media pollution in hazardous waste remediation in the San Francisco Bay region of California.

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Chapter 2

Literature Review

2.1 Environmental Policy Literature Review

The problems of cross-media pollution and common agency (or "policy fragmentation") in environmental regulation have been recognized by policy analysts for quite some time. The history of these problems before 1985 is perhaps best described in a series of publications by the Conservation Foundation (CF).[1] The Conservation Foundation convened a conference in November 1984, to "draw attention to the cross-media problem and attempts to address it" (Conservation Foundation 1985). The findings of this conference are summarized below and updated with results from more recent policy analyses.

The U.S. EPA was created in 1970, in part, to address common agency and cross-media problems by pulling together regulatory bodies from diverse federal departments and agencies (Conservation Foundation 1985, pp. 1, 7-8). Despite an initial motivation to address common agency and cross-media problems, in the end the EPA was structured along single-media lines; this allowed common agency and cross-media problems to continue (Conservation Foundation 1985, pp. 8-9), (Landy et al. 1994, pp. 31-33), (Rabe 1986, pp. 9-10).

The common agency problem latent in EPA's organizational structure was promoted by the single-media emphasis of early environmental statutes. The "first wave" of environmental legislation was promulgated in the early 1970's to address air and surface water pollution. The organizational separation of air pollution control programs from water pollution control programs created a situation of common agency that

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[1] Many prominent environmental policy makers were affiliated with the Conservation Foundation, including Russell Train, William Reilly, Bruce Babbitt, and J. Clarence Davies.

facilitated cross-media pollution between air and surface water (Morell 1989, pp. 32-33), (Loehr 1989, pp. 13-15), (Fontaine 1993, pp. 46-50). Even during a period of time when the air and water programs were located in the same physical office, their actions were not coordinated (Rabe 1986, pp. 13-14). Uncoordinated regulation led not only to cross-media pollution between air and surface water, but also to cross-media pollution into "new" media (e.g.'s: landfills and groundwater).

The "second wave" of environmental legislation arrived in the late 1970's and early 1980's. It addressed "new" environmental problems such as toxic and hazardous wastes, landfills, groundwater contamination and acid rain (Rabe 1986, p. 122). New statutes such as the Toxic Substances Control Act (TOSCA), the Resource Conservation and Recovery Act (RCRA), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or "Superfund") were created on an ad hoc basis to address these new problem areas (Conservation Foundation 1985, pp. 1-2). This second wave of environmental legislation also fostered common agency and cross-media problems (Rabe 1986, pp. xv, 14), (Morell 1989, pp. 30-39,), (Loehr 1989, p. 20), (Fontaine 1993, pp. 38-46).

In some cases, "solutions" to first wave problems created or exacerbated second wave problems (Morell 1989, pp. 29-30). For example, the construction of tall smokestacks to address local air pollution promoted acid rain (Fontaine 1993, p. 34). Some types of air and water pollution controls produced toxic sludges that presented hazards to groundwater when disposed of in landfills or on the ground (Conservation Foundation 1985, p. 9), (Morell 1989, p. 28-29). Problems associated with the disposal of toxic chlorinated solvents were due, to a large extent, to the success of "first wave" programs in cleaning the solvents from the air and water (Conservation Foundation 1985, p. 11). Calls to reduce the amount of sewage dumped into the ocean resulted in the creation of the "new" problem of how to dispose of the waste on land (Conservation Foundation 1985, p. 12).

Early EPA Administrators recognized cross-media and common agency problems, but successive Administrators failed to adequately address the institutional roots of the problems. This was likely due to a perceived need to move quickly on key regulatory programs in order to build the young agency's credibility and resources (Landy et al. 1994, p. 38). Any significant reorganization of the Agency's structure would have caused politically costly delays in the implementation of high-profile environmental programs.

During Ruckelshaus' second term as EPA Administrator in the early 1980's, and continuing into Lee Thomas' term as head of EPA (Landy et al. 1994, pp. 258-259), the Agency began two promising programs that highlighted the problems of common agency and cross-media pollution and began to formulate means to address tnem.

The first effort focused on fostering the use of comparative risk analysis to set regulatory priorities within the EPA. Comparative risk analysis encouraged a broader view of the agency's responsibilities and brought common agency and cross-media issues to the fore. The results of an agency-wide comparative risk analysis were published in *Unfinished Business--A Comparative Assessment of Environmental Priorities* (USEPA 1987b). *Unfinished Business* is widely regarded as the most important planning document produced at EPA in the 1980's. Although it laid the methodological groundwork for policy reform efforts to follow, no immediate policy reforms resulted from *Unfinished Business*.

The second effort, called the Integrated Environmental Management Program (IEMP), consisted of a series of field case studies that focused on addressing environmental problems in all environmental media simultaneously at specific geographic locations (USEPA 1987a, p. 1). The IEMP produced some of the first comprehensive, cross-media regulatory assessments (Conservation Foundation 1985, p. 13), (USEPA 1986). Unfortunately, the IEMP was only a temporary program (USEPA 1987a, Appendix p. 58).

In addition to these formal Agency programs, less formal initiatives such as "coordination working groups" (Conservation Foundation 1985, p. 10-12) and the Clusters Program (Landy et al. 1994, p. 295) formed within EPA from time to time in attempts to address cross-media pollution issues.

Concurrently, outside EPA, other public policy, scientific, and industry organizations recognized cross-media pollution and common agency problems, and various committees, councils and working groups formed in attempts to resolve them (Conservation Foundation 1985, p. 4), (Fontaine 1993, p. 34). These groups included Carter's Interagency Regulatory Liaison Group (Landy et al. 1994, pp. 172, 269-270), Reagan's Interagency Risk Management Council (Conservation Foundation 1985, pp. 10-11), the National Research Council (1987), and EPA's Science Advisory Board (USEPA 1990a-d).

Despite the many attempts to address cross-media pollution and common agency problems, policy assessments have repeatedly found that these problems persist (Conservation Foundation 1985, pp. Forward, 7), (Thomas 1985), (Morell 1989, pp. 28-29, 30), (Rabe 1986), (USEPA 1987a), (National Research Council 1987), (Loehr 1989, p. 9), (Guruswamy 1991), (Fontaine 1993, p. 35), (Landy et al. 1994, pp. 36, 300, 316-319, 330), (McGuigan and Wisniewski 1995), (USOTA. 1995), (Vig and Kraft 1997). The recent comments of current EPA Administrator Carol Browner attest to the continuing need to devote more attention to these problems:

> Perhaps most disturbing, some of the investments driven by our single-media decision-making process have simply shifted waste from one part of the environment to another.
>
> For example, wastewater treatment plants built to satisfy federal water quality requirements are now among the biggest source of toxic air emissions at industrial facilities and in some urban areas. (Browner 1993)

Hence, although common agency and cross media pollution have been on the policy agenda for over twenty years, and although many attempts have been made to address these problems, they continue to persist for a variety of reasons. These reasons will be explored in more detail below.

2.1.1 Fragmented Legislation and Incremental Policy Change

Two aspects of environmental legislation lead to common agency problems. First, environmental legislation is fragmented; i.e., each statute addresses a relatively narrow aspect of the general problem of environmental regulation. Second, in general, each piece of legislation is implemented by a separate administrative unit within the EPA. While this situation may be defended on the grounds that some simplification and division of bureaucratic duties is necessary to implement the complex task of environmental regulation (Conservation Foundation 1985, pp. 8-9), (Rabe 1986, pp. xiii-xiv, 12), in practice fragmented legislation and associated fragmented policy implementation place constraints on agency discretion and limit EPA's ability to engage in policy coordination and "objectives balancing" (Conservation Foundation 1985, pp. 8-9), (Loehr 1989, p. 24), (Fontaine 1993, p. 37). In short, fragmented legislation causes common agency problems within the EPA, and common agency exacerbates cross media pollution problems (Loehr 1989, pp. 15-17), (Morell 1989, p. 41). Fragmented legislation also creates common agency problems between the EPA and other federal agencies (Landy et al. 1994, pp. 298-300), between federal and state agencies, and between state agencies (Morell 1989, p. 42-43), (Fontaine 1993, pp. 53-54).

A succession of perceived "environmental crises" led to the incremental passage of environmental legislation, which in turn led to fragmented environmental law characterized by conflicting, inflexible mandates (Rabe 1986, pp. 4, 12, 14), (Loehr 1989, p. 11). As discussed in greater detail below, some incentives may lead Congress to create and maintain fragmented environmental legislation. Environmental advocates may also pursue fragmented legislation in order to limit the discretionary power of an unsympathetic White House (Landy et al. 1994, p. 33).

Efforts have been made to circumvent the problems associated with incremental policy change and common agency. For example, Nixon's "Quality of Life Review" process attempted to coordinate policy review and implementation (Landy et al. 1994, p. 37). However, such policy review procedures often focus narrowly on reducing the regulatory burden on industry and generally fail to address the common agency problems associated with fragmented legislation. In addition, such executive coordinating procedures have political drawbacks as a tool for integrating environmental regulatory decisions. Environmentalists and the press, who may see them as attempts to subvert the intent of environmental legislation, often view these procedures with suspicion. Increased scrutiny of White House actions can lead to the exposure of dicey political choices that delegation to executive agencies is supposed to obfuscate (Landy et al. 1994, pp. 33, 280). Finally, executive coordinating procedures rarely survive changes in administration and therefore do not result in lasting reform.

2.1.2 Overambitious Policy Reform

While incremental policy change may not be sufficiently broad in scope to accomplish meaningful reform of fragmented policy, a contrasting reason for the persistence of common agency and cross-media problems in environmental regulation is the overambitious nature of some policy reform attempts. Some genuine reform efforts have been hampered by lack of focus, resources or political support. The first example of such a sweeping but unrealistic attempt to reform environmental policy was the National Environmental Policy Act (NEPA) itself (Rabe 1986, p. 8). Other examples of failed, overambitious programs include EPA's Consolidated Grant and Consolidated Permit programs (Rabe 1986, p. 11).

2.1.3 Congressional Fragmentation and Legislative Competition

The problem of fragmented legislation and the difficulties associated with correcting it are due in large measure to conflicting objectives and incentives within Congress and among congressional committees. Congress has the responsibility to draft environmental statutes and to oversee the implementation of environmental regulations. Congressional committee and subcommittee members and their staffs write environmental laws. There are many committees, both in the House and in the Senate, with overlapping responsibilities. Committees compete for control over both the content of, and credit for, environmental legislation (Rabe 1986, pp. xiii-xiv, 16-17), (Barthold 1994, p. 144). Key committee and subcommittee chairpersons, members and staff have a profound influence on the character of environmental legislation. Once legislation is passed, congressional sponsors are identified with it and have a political interest in ensuring that it is "successful." Efforts directed toward ensuring success can take several forms, including "micromanaging" regulatory implementation through writing detailed statutes that restrict EPA discretion (including "hammer" clauses) (Landy et al. 1994, pp. 262-263, 286-291), holding frequent oversight hearings to review EPA implementation operations, and opposing attempts to reform "pet" statutes.[2]

The power of Congressional committees during the first wave of federal environmental legislation in the early 1970's was enhanced by an activist Supreme Court (Landy et al. 1994, p. 26). The control exerted by Congress over the EPA persisted

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[2] The roots of strong Congressional oversight of EPA--oversight that prevents a more integrated approach to pollution control--is exemplified by the political career of Senator Edmond Muskie (Landy et al 1994, 7;

throughout the 1970's during the tenures of EPA Administrators Train (Landy et al. 1994, pp. 38-39) and Costle (Landy et al. 1994, pp. 30, 42).

Beginning in 1980, the Reagan administration sought to reduce the burden of environmental regulation on business. Part of the administration's strategy was to reduce the influence of congressional committees on the EPA. This presented an opportunity for integrative policy reform (Landy et al. 1994, pp. 245-246). However, the Reagan administration chose to focus its efforts on impairing the ability of the agency to function rather than on improving regulatory efficiency through integrative reform of fragmented legislation (Landy et al. 1994, pp. 249-250). For example, Reagan's "Cabinet Councils" presented an opportunity for integrative reform of environmental regulation, but the administration used the Cabinet Councils to exclude, rather than to reform, the EPA (Landy et al. 1994, pp. 245-248). Reagan's Executive Order 12291 (Landy et al. 1994, p. 248) represented another missed opportunity for integrative reform. The review process inaugurated by 12291 was used to impede the functioning of EPA rather than to improve its operating efficiency. Perhaps the greatest missed opportunity was the failure of the Reagan administration to consider a proposal (with broad support within the EPA) for integrative policy reform proposed by EPA's Integrated Environmental Management Program (USEPA 1987a, Appendix, p. 46).

Reagan's first appointment to the post of EPA Administrator, Anne Gorsuch, resigned in March 1983 over controversy surrounding the Times Beach incident. William Ruckelshaus was her replacement. Although Ruckelshaus was instrumental in promoting comparative risk analysis at EPA--a policy perspective that would lead to several key reports (i.e., "Unfinished Business" and "Reducing Risk") highlighting the problems associated with common agency and cross-media pollution--he also reinitiated contacts with Congress. This allowed Congress to reassert its control over EPA (Landy et al. 1994, pp. 251-252). The effects of Congressional interference continued under the Bush administration under EPA Administrator William Reilly (Landy et al. 1994, p. 280, 284-285, 316-319).

2.1.4 Resistance to Policy Change

Although Congress bears the primary responsibility for fragmented environmental legislation, it is not alone when it comes to shirking responsibility for policy reform. Many presidential administrations have resisted organizational reform of EPA, despite acknowledging its necessity, in order to achieve "quick results" in resolving the environmental crisis of the day (Rabe 1986, pp. 10-11), (Landy et al. 1994, pp. 35, 35-36, 281).

In addition, various interest groups have been resistant to policy change. First, environmental advocacy groups may resist change, either because they fear that policy change is a euphemism for policy retrenchment, or because environmental analysts and lobbyists have invested significant human capital in understanding and manipulating current policies, and such capital would lose value with policy change (Rabe 1986, p. 127). Second, industry may resist policy change, especially if existing policies deter entry by new competitors (Rabe 1986, p. 128). Finally, environmental regulators themselves may have personal incentives to resist change (Rabe 1986, pp. xiii-xiv, 119-120, 126-

127), (Landy et al. 1994, p. 34), (Conservation Foundation 1985, pp. 8-9), (USEPA 1987a, Appendix, p. 45). The quest for additional agency resources may lead to the initiation of additional programs with possibly conflicting objectives. For example, the shift of emphasis at EPA in the late 1970's toward protecting public health--in addition to protecting the environment--exacerbated organizational fragmentation (Landy et al. 1994, 41-42).

In some cases, policy reform may be thwarted by the actions of a combination of groups with a common interest in the status quo. Legislators, regulators, industry groups and environmental groups may at times have incentives to resist policy integration. Hence, theories of regulatory capture and "Iron Triangles" may explain, in part, the persistence of fragmented legislation (Landy et al. 1994, p. 12), (Rabe 1986, p. 128).

In summary, although cross-media pollution has long been recognized as a serious environmental problem, and although fragmented legislation and fragmented regulatory implementation are known to foster common agency problems that exacerbate cross-media pollution, and although various attempts have been made to address these issues, common agency and cross-media pollution remain serious policy concerns.

2.2 Economics Literature Review

Common agency is a situation in which multiple principals (e.g., regulatory agencies) attempt to modify the behavior of one or more agents (e.g., polluting firms). There are two types of multiple-principal models in the economics literature. The first type examines a situation in which two principals compete for the exclusive services of an agent or client. This type of model arises in the analysis of insurance markets. The second type of model considers the case in which two principals "share" the services of a single agent; this type of multiple-principal model is termed a "common agency" model. Since this dissertation considers a situation in which multiple environmental regulatory agencies (principals) simultaneously regulate the activities of a polluting firm (agent), the common agency model is more appropriate and is explored in additional detail below.

Common agency itself may be classified as either "delegated" or "intrinsic" (Bernheim and Whinston 1986). In the case of delegated common agency with two principals, the agent can choose to contract with one, both or neither of the principals. Under intrinsic common agency, the agent must choose between contracting with both principals or neither principal. Intrinsic common agency appears to be the appropriate category for models of cross-media pollution regulation, because regulated firms must choose between either staying in business, in which case they are regulated by both regulatory agencies, or shutting down, in which case they are regulated by neither agency.

The literature on the economics of regulation does not fully address the problem of common agency. Viscusi, Vernon and Harrington (1995) do not address common agency in 870 pages on the economics of regulation and antitrust. Laffont and Tirole

(1993) cover the literature on common agency in one page out of 670 pages on the theory of incentives and regulation. Train (1991) does not mention common agency at all in 328 pages on optimal regulation. Noll's (1989) discussion of "Economic Perspectives on the Politics of Regulation" in the *Handbook of Industrial Organization* is mostly a review of the interest-group theory of regulatory policy and regulatory capture with no coverage of common agency. Baron's (1989) chapter in the *Handbook of Industrial Organization* entitled "Design of Regulatory Mechanisms and Institutions" limits discussion of multiple regulators to a one-page review of a specific case (Baron (1985b), discussed below). In addition, Baron and Besanko (1984), Baron (1988), Banerjee and Beggs (1989) and Sappington (1991) do not address common agency. Stole (1991) summarizes: ". . . to date, we know very little about the problem of mechanism design with multiple principals and a single agent--what has been termed the problem of common agency."

Many authors have compared the impacts of alternative pollution control instruments and targets on the efficiency of pollution regulation, both in the short run and the long run, for both outputs and inputs, and under conditions of uncertainty and asymmetric information. However, the literature on pollution regulation does not fully address the problem of common agency. For example, Bohm and Russell (1985) do not consider common agency in their widely cited chapter in the *Handbook of Natural Resource and Energy Economics* entitled "Comparative Analysis of Alternative Policy Instruments." Nichol's (1984) book *Targeting Economic Incentives for Environmental Protection* does not consider common agency. Barthold's (1994) survey article in the *Journal of Economic Perspectives* on "Issues in the Design of Environmental Excise

Taxes" does not address common agency.

Tinbergen's (1956) discussion of the "targets and instruments problem" is related to, but distinct from, the common agency issue. In contrast to the situation considered by Tinbergen, in the model of common agency regulation developed in Chapter 3 a sufficient number of policy instruments (two Pigouvian taxes) exist to address all policy targets (two pollution externalities). Nevertheless, inefficient regulation may result. The common agency problem arises when control over what may be a sufficient number of policy instruments is divided among multiple principals, and the desired level of one principal's policy instrument depends on that of another principal. In other words, while a mismatch in the number of policy instruments and the number of policy targets may be sufficient for inefficient regulation under common agency, it is not necessary.

MacDonald (1973) considers the "targets and instruments" problem in a dynamic setting. MacDonald develops a "systematic and rigorous approach to the dynamics of selecting instruments to achieve a set of fixed targets at the end of a certain number of time periods." MacDonald shows that the statement "A well-known proposition in the theory of economic policy is that to achieve n targets (except by coincidence) there must be at least n instruments" can be modified to: "For a discrete dynamic system, in order to achieve n targets in k time periods (except by coincidence) there must be at least n divided by k instruments." He also addresses the question "What is the set of targets that can be reached given constraints on the instrument variables?" In MacDonald's work, one principal controls potentially many instruments in an attempt to achieve potentially many policy targets over several time periods. MacDonald does not address common agency problems. The common agency problem is not the "number of targets / number of instruments" problem; rather, the common agency problem is: given a sufficient number of policy instruments to achieve desired policy targets, how does *allocation of control* of the instruments among multiple principals affect the ability of the principals to achieve the targets?

Hochman and Zilberman (1978) consider multiple policy instruments (taxes and standards) and multiple targets (output, employment and pollution), but they do not consider multiple principals. Hochman and Zilberman use a microparameter distribution approach to obtain aggregate measures of output, employment and pollution across many firms that exhibit heterogeneous output/labor and pollution/labor ratios. The paper derives the effects of pollution taxes and standards on the solvency boundary of these firms in (output/labor, pollution/labor) space. Because Hochman and Zilberman's paper does not consider multiple principals, it does not address common agency.

Baron (1985a) considers the "regulation of prices and pollution for a monopolist with private information . . . with a focus on the relative efficiency of standard-setting and emissions taxation . . ." (Baron 1985a, p. 211). However, Baron's model only considers the trivial, cooperative case of common agency: "The regulation of prices and pollution is accomplished by a single regulator or equivalently by a public utility regulator and an environmental regulator who cooperate" (Baron 1985a, p. 230).

Although Helfand (1995) considers cross-media pollution in terms of multiple polluting inputs, she does not consider multiple regulators. Although Jin (1994) considers multi-media waste disposal under uncertainty in an investigation of socially-optimal waste disposal options for sewage sludge in coastal New York and New Jersey, Jin does not consider the case of multiple principals. In addition, Kwerel (1977), Yohe (1976), Young (1977), Oates and Strassman (1984), and Newbery (1980) do not address multiple principals.

Although the literature on the principal-agent problem is quite extensive, relatively few papers address common agency. Bernheim and Whinston (1986) and Stole (1991) appear to be the seminal works on the pure theory of common agency.

Bernheim and Whinston (1986) consider a situation in which multiple, identical, risk-neutral principals simultaneously and independently attempt to influence a common (risk neutral or risk averse) agent. Principals offer incentive schemes to the agent in compensation for the agent's unobservable action. The situation is one of "moral hazard with hidden action" (Rasmusen 1990, p. 133): after outcome-contingent contracts specifying payments from each principal to the agent are signed, the agent takes an unobservable action which affects the probability distribution over the outcome support.[3]

The agent's reaction function is derived by maximizing her Von Neumann-Morgenstern utility function (specified as a separable function of the net aggregate payment from the principals and the action itself (i.e., the action itself might affect the variance of payment)), taking the principals' schedules of outcome-contingent payments as given. Each principal maximizes expected profit (an outcome-determined value minus payment to the agent) subject to three constraints: agent individual rationality, agent incentive compatibility and principal individual rationality (each principal has a

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[3] Fraysse's (1993) note presents a proof of the existence of an equilibrium in Bernheim and Whinston's model for the case in which there are only two possible *outcomes*, but many possible types of *actions*.

reservation payoff).

Bernheim and Whinston first describe the cooperative (2nd best) equilibrium. They next give sufficient conditions for the existence of a noncooperative equilibrium in a preliminary lemma. Bernheim and Whinston then prove four theorems. First, they show that the principals' aggregate cost of ensuring a given agent action are at a minimum in equilibrium. Second, they give sufficient conditions for the noncooperative equilibrium to achieve the cooperative (2nd best) equilibrium. Third, Bernheim and Whinston give necessary conditions for a noncooperative equilibrium to achieve the cooperative equilibrium. Finally, the authors show that for a special case (a particular type of "effort" model) the noncooperative equilibrium does not achieve the cooperative equilibrium.

In contrast with the model developed in Chapter 3 of this dissertation, the principals in Bernheim and Whinston's model are identical (except for possibly differing reservation payoffs). Not only are the principals' objective functions identically linear in form, but, most importantly, the set of instruments available to each principal is effectively identical. Bernheim and Whinston assume that each principal can offer a contract to the agent that "undoes" the offer of every other principal; in this sense, each principal can manipulate the instrument of every other principal. The authors point out that this assumption is a key to the proof of their first theorem. However, this assumption is unlikely to be met in the case of multiple *regulators*, because law often prohibits regulators from directly affecting other regulators' policy instruments. For example, a water pollution control agency may not give an air pollution subsidy to a firm in order to induce the firm to shift pollution emissions from water to air.

Stole (1991) considers common agency under adverse selection, in contrast to Bernheim and Whinston (1986), who consider common agency under moral hazard. Stole limits attention to the case of intrinsic common agency. In contrast to Baron (1985b) (discussed below), who considers common agency under adverse selection using a Stackelberg solution concept, Stole (1991) considers common agency under adverse selection using a Nash solution concept.

Stole develops a model of contracting between two principals and a single agent in which the agent has private information about her type. Stole characterizes the Nash equilibrium in the cooperative case, the case of contractual independence (in which the marginal utility of the agent's contract with one principal is not affected by the agent's contract with the other principal), the case in which contracting activities are complements, and the case in which contracting activities are substitutes. Stole finds that in the case of contractual interdependence (i.e., when contracting activities are either complements or substitutes), incentive compatibility and individual rationality constraints are more complicated than in the simple principal-agent model because the constraints must rule out cases in which (1) the agent might lie to both principals in equilibrium and (2) one principal induces the agent to lie to the other principal. Stole explicitly characterizes the set of pure-strategy differentiable Nash equilibrium contracts under contractual interdependence and shows that "if the agent has private information regarding his gains from the contracting activity and the contracting activities in the principal-agent relationship are substitutes (complements), the principals will typically extract less (more) information rents in total and induce less (more) productive inefficiency in the contracting equilibrium than if there were a single principal contracting over the same activities." Stole considers two applications: the choice of internal vs. external agency in marketing, and the regulation of a single firm by multiple regulators. The second case addresses the scenario first considered by Baron (1985b) (discussed below), but Stole uses a Nash solution concept rather than the Stackelberg solution concept. Two regulators with divergent objectives and policy instruments that are strategic substitutes regulate a single firm. In equilibrium, each regulator over-regulates and total welfare is lower compared with the cooperative outcome. However, this common agency equilibrium is actually closer to the full information outcome than is the cooperative (2nd best) outcome because noncooperative regulatory incentives run counter to information-revealing incentives.

Bernheim and Whinston (1986) and Stole (1991) examined relatively general, abstract models of common agency. The papers reviewed below address the problem of common agency in more applied policy settings.

Spiller (1990) develops a political economy model in which two differentiated principals, Congress and an industry group, compete to influence the actions of a common agent, a governmental regulatory agency. An interesting result proved by Spiller is that although one principal (Congress) may have the power to limit the influence of the second principal (industry) on the agent, the powerful principal may allow the weak principal to influence the agent if side payments are not allowed between principals but the stronger principal can extract the rents earned by the agent from interactions between the agent and the weaker principal.

Gal-Or (1991) considers the decision by two identical, competing principals to employ separate agents or to employ a common agent. Whereas Bernheim and Whinston found that employing a common agent allows the two competing principals to achieve the collusive (second-best) outcome, Gal-Or shows that the principals may improve on the second-best outcome by employing separate agents if the unit costs of separate agents are correlated. By employing separate agents, each principal reduces the information asymmetry between herself and her agent by observing market information generated by transactions between all principals and agents.

Laffont and Tirole (1991) examine the gains in efficiency associated with privatizing public firms from a common agency perspective. Tirole (1994) assesses the current state of incentive theory as applied to the "internal organization of government" and suggests directions for future research. Most recently, Rizzo and Sindelar (1996) address the problem of common agency in the regulation of the provision of physician's services.

Only two authors examine the problem of common agency in the context of applied pollution regulation. Baron (1985b) extends the work of Baron and Meyerson (1982) to consider the implications of using incentive compatible mechanisms to regulate pollution under asymmetric information and common agency. Although Baron does not phrase his results in terms of common agency, Baron shows that common agency can lead to the inefficient regulation of a polluting public utility when one agency regulates the price of utility output and a different agency regulates pollution. However, Baron focuses attention on the role of asymmetric information in determining inefficiency rather than on the role of common agency *per se*. Furthermore, Baron does not explicitly consider the case of cross-media pollution, in which reducing pollution in one medium increases pollution in another.

Oates (1984) considers the cross-media pollution problem explicitly through a model consisting of one firm capable of emitting pollution into either or both of two media and two regulators, each of whom regulates pollution emitted into one of the two media. Oates shows that the cross-media problem (substitution in pollution emissions) can lead to inefficiency in two special cases of command-and-control regulation. However, one regulator in Oates' model has a fixed policy instrument; hence, Oates' model effectively contains but one active regulator and is therefore not a common agency model.

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Chapter 3

A Model of Cross-Media Pollution Regulation under Common Agency

3.1 Introduction

In Chapter 3, a model of cross-media pollution regulation under common agency and full information is developed. There are three actors in the model, a polluting firm and two environmental regulatory agencies. A single price taking firm emits pollution in two environmental media. The firm can dispose of its waste products in either medium, though disposal in one medium is not a perfect substitute for disposal in the other medium. Without regulation, the firm suffers no consequences from emitting pollution. Each of the two environmental regulatory agencies uses a policy instrument[1] to reduce the firm's emissions of pollution into the medium it regulates. A situation of common agency exists, i.e., two distinct principals (the two environmental regulatory agencies) regulate the activities of a single agent (the polluting firm). The two regulatory agencies may or may not cooperate in their regulatory efforts.

3.2 The Modeling Framework

3.2.1 Production and Pollution Structure

The firm uses inputs, $\mathbf{x}' = \{x_1, x_2, \ldots, x_n\}$, to produce output Y and two types of pollution emissions, y_1 and y_2, as joint products. The output production function is $Y(\mathbf{x},\theta)$, where θ is a vector of parameters. Pollution emissions y_1 depends on the firm's use of input x_1. Similarly, pollution emissions y_2 depends on the firm's use of input x_2. The vector of pollution emissions functions is $\mathbf{y}' = \{y_1(x_1), y_2(x_2)\}$. Environmental quality (measured in monetary units) in environmental medium 1 is $Q_1(y_1)$, which is a function of pollution emissions y_1. Similarly, the monetary measure of environmental quality in environmental medium 2 is $Q_2(y_2)$, which is a function of pollution emissions y_2.

3.2.2 Firm Behavior

The price-taking, tax-taking firm chooses inputs to maximize profit $\pi(\mathbf{x}|\theta,P,\mathbf{w},\mathbf{t}) = P\cdot Y(\mathbf{x},\theta) - \mathbf{t'y} - \mathbf{w'x}$, where P is output price, $\mathbf{w}' = \{w_1, w_2, \ldots, w_n\}$ are input prices, $\mathbf{t}' = \{t_1, t_2\}$are per-unit-of-emissions pollution taxes, and θ are parameters of the production function. The firm's input choice is given by $\hat{\mathbf{x}}(\theta,P,\mathbf{w},\mathbf{t}) \equiv \underset{\mathbf{x}}{\arg\max}\ \pi(\mathbf{x}|\theta,P,\mathbf{w},\mathbf{t})$. The firm's profit function is then $\hat{\pi}(\theta,P,\mathbf{w},\mathbf{t}) = \pi(\hat{\mathbf{x}}|\theta,P,\mathbf{w},\mathbf{t})$. For later use, note that $\frac{\partial\hat{\pi}}{\partial t_1} = -y_1$ and $\frac{\partial\hat{\pi}}{\partial t_2} = -y_2$ by way of Hotelling's Lemma.

3.2.3 Accounting for Emissions Tax Revenues

The issue arises as to how to account for any emissions tax revenues collected by the regulators. It seems most natural to consider two polar modeling options, discussed below, each of which has both merits and drawbacks from a modeling perspective.

The first modeling option is to include emissions tax revenues explicitly in the model and to assume that any emissions tax revenues collected are returned to consumers through lump sum payments.[2] This modeling option has the merit that regulatory outcomes are more closely comparable to full social welfare. However, in actuality,

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[1] Here, a per unit tax on pollution emissions is considered. Alternatively , other policy instruments, such as emissions quotas/standards or marketable emissions permits, could be considered.

[2] Or, where lump-sum payments are not feasible, through a mechanism which results in Ramsey reductions in all prices in the economy (see Baumol and Oates, 1988, p.23).

emissions taxes are not refunded in lump sum payments, and regulators (in contrast to society as a whole) probably do not value emissions taxes for their revenue-raising potential for reasons to be outlined below. Furthermore, this modeling option reduces the transparency of the model and distracts attention from the main points of the analysis.

The second polar option is to assume that any emissions tax revenues collected by the regulators are exactly dissipated by the government bureaucracy. This option will be termed "The Chicago Assumption." Under the Chicago Assumption, regulators do not value emissions tax revenues for their revenue-raising potential, either because the regulators must pass the revenues on to the government's general fund, or because administrative or transactions costs associated with emissions tax revenue processing by the regulators completely dissipates the value of the revenue. A drawback of the Chicago Assumption is that it is a simplification of actual accounting circumstances. It is possible that the general equilibrium welfare effects of emissions tax revenues could be significant, especially if these revenues were substituted for other sources of government revenue and thereby reduce distortions elsewhere in the economy (Goulder and Bovenberg, 1996). However, environmental regulators might attach a zero weight to these effects within their own regulatory objective functions, such effects being so far removed from their direct influence. Moreover, it is not impossible that regulators attach a *negative* weight to emissions tax revenues, desiring to avoid political accusations of using pollution taxes to increase agency budgets. Finally, invoking the Chicago Assumption greatly enhances the transparency of the model.

On balance, it appears that the Chicago Assumption option would be more appropriate for the present case, given that the focus of the model is not on the effects of taxes and revenue constraints on regulatory efficiency, a topic which is covered elsewhere in the literature, but rather on the effects of common agency and cross-media substitution on regulatory outcomes.

3.2.4 Regulator Behavior

There are two environmental regulatory agencies, Regulator 1 and Regulator 2. Regulator 1 maximizes regulatory objective R_1 by choosing the level of her regulatory instrument, emissions tax t_1, levied on pollution emissions y_1. Regulator 2 maximizes regulatory objective R_2 by choosing the level of her regulatory instrument, emissions tax t_2, levied on pollution emissions y_2. R_1 is the sum of the monetary measure of environmental quality in medium 1, profits, and possibly the monetary measure of environmental quality in medium 2. Similarly, R_2 is the sum of the monetary measure of environmental quality in medium 2, profits, and possibly the monetary measure of environmental quality in medium 1. Invoking the Chicago Assumption, the regulators place no value on any emissions tax revenues collected. The particular specifications of R_1 and R_2 depend on the model case under consideration and will be described further below.

3.2.5 Social Welfare

Society would like to maximize net social welfare, $W \equiv \pi + Q_1 + Q_2$, which is the sum of profits and the monetary measures of environmental quality in media 1 and 2 (under the Chicago Assumption, emissions tax revenues are exactly dissipated). As discussed below, the regulators' objectives may differ from net social welfare.

3.3 Model Cases

In this section, three model cases are examined. The cases differ among themselves in two dimensions. First, the cases differ with respect to the specification of regulatory objectives--each regulator's objective may be either "congruent" with social welfare or "divergent" from social welfare. A congruent regulatory objective is identically equal to social welfare W. A divergent regulatory objective differs from W. Here, a divergent objective is taken to be one in which a regulator does not consider environmental quality in the other regulator's medium. Second, the cases differ with respect to the type of behavior exhibited by the regulators: "Unified," Stackelberg, or Nash. The definitions of the three types of regulator behavior are given below as they arise in the case-by-case model descriptions.

3.3.1 Case 1: Unified Regulation

The first case is the benchmark case of "Unified" cooperative regulation, in which the two regulators behave as if they were a single "unified" regulator. In the unified case there is no common agency problem, by definition. There are no separate regulatory objectives R_1 and R_2 in the unified case; rather, the single regulatory objective is simply to maximize W (hence, the regulatory objective is trivially of the congruent type). In Case 1, the single, unified regulator has control over *both* policy instruments, t_1 and t_2.

In this case of unified regulation, *the regulators act jointly as a single decision maker* to maximize social welfare through the cooperative use of the two available policy instruments, t_1 and t_2. The unified regulator's problem is:

(1.1) $$\max_{t_1,t_2} W = \hat{\pi}(\theta, P, w, t) + Q_1\left(y_1\left(\hat{x}_1(\theta, P, w, t)\right)\right) + Q_2\left(y_2\left(\hat{x}_2(\theta, P, w, t)\right)\right)$$

The first order necessary conditions (FONCs) for this problem are:

(1.2) $$\frac{\partial W}{\partial t_1} = \frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_1} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_1} \equiv 0$$

(1.3) $$\frac{\partial W}{\partial t_2} = \frac{\partial \hat{\pi}}{\partial t_2} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_2} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2} \equiv 0$$

or, rearranging

(1.4) $$\frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_1} = -\frac{\partial \hat{\pi}}{\partial t_1} - \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_1}$$

(1.5) $$\frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2} = -\frac{\partial \hat{\pi}}{\partial t_2} - \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_2}$$

Equations 1.4 and 1.5 give the necessary conditions for maximizing social welfare under unified regulation of cross-media pollution involving two environmental media. Equation 1.4 states that the marginal benefit of increasing t_1, namely, the increase in welfare from an increase in Q_1, must equal the marginal cost of increasing t_1, namely, the sum of the change in profit and the change in Q_2. Note that the change in Q_2 may be positive or negative, depending on whether x_1 and x_2 are substitutes or complements in production. A symmetric interpretation holds for Equation 1.5.

Assuming that a solution to the FONC system exists, and assuming that all partial derivatives in the FONC system exist, then by the implicit function theorem the solution may be written as a function of the parameters of the system ($t_1^U(\theta, P, w)$, $t_2^U(\theta, P, w)$), where the "U" superscript stands for "Unified Regulation."

The solution may be written in terms of relative pollution levels, marginal damages and input elasticities of the firm at the optimum. Define the following elasticities:

Elasticity of $\hat{x}_1$ with respect to t_1 ≡ $\varepsilon_{\hat{x}_1,t_1} \equiv \frac{\partial \hat{x}_1}{\partial t_1}\frac{t_1}{\hat{x}_1}$

Similarly, $\varepsilon_{\hat{x}_1,t_2} \equiv \frac{\partial \hat{x}_1}{\partial t_2}\frac{t_2}{\hat{x}_1}$, $\varepsilon_{\hat{x}_2,t_1} \equiv \frac{\partial \hat{x}_2}{\partial t_1}\frac{t_1}{\hat{x}_2}$, $\varepsilon_{\hat{x}_2,t_2} \equiv \frac{\partial \hat{x}_2}{\partial t_2}\frac{t_2}{\hat{x}_2}$.

Substituting into Equations 1.4 and 1.5 and rearranging:

$$(1.6)\ t_1^U = \frac{\frac{\partial Q_1}{\partial \hat{x}_1}\varepsilon_{\hat{x}_1,t_1}\hat{x}_1 + \frac{\partial Q_2}{\partial \hat{x}_2}\varepsilon_{\hat{x}_2,t_1}\hat{x}_2}{\hat{x}_1}$$

$$(1.7)\ t_2^U = \frac{\frac{\partial Q_1}{\partial \hat{x}_1}\varepsilon_{\hat{x}_1,t_2}\hat{x}_1 + \frac{\partial Q_2}{\partial \hat{x}_2}\varepsilon_{\hat{x}_2,t_2}\hat{x}_2}{\hat{x}_2}$$

Equation 1.6 says that the per unit tax on emissions into medium 1 in equilibrium is the sum of two terms, each of which is equal to marginal damage in one of the two environmental media, multiplied by the elasticity of emissions into that medium with respect to the tax rate in medium 1, multiplied by level of emissions into that medium relative to the level of emissions into medium 1. A symmetric interpretation holds for Equation 1.7.

The next model case shows that, under common agency regulation of cross-media pollution where regulators have divergent objectives, Stackelberg regulatory behavior may cause the necessary conditions for a regulatory equilibrium to differ from the necessary conditions for the unified regulatory equilibrium.

3.3.2 Case 2: Stackelberg Regulation with Divergent Objectives

Case 2 differs from the case of unified regulation in two fundamental respects. First, the two regulators behave noncooperatively. In contrast to the case of unified regulation, in Case 2 there are two separate, noncooperative regulators, and control over the two policy instruments, t_1 and t_2, is split between them. Second, the objectives of the regulators are divergent; i.e., they are not congruent with social welfare W. Although each regulator considers the impact of regulation both on environmental quality in her medium and on firm profits, i.e., $R_1 = \pi + Q_1$ and $R_2 = \pi + Q_2$, neither regulator considers the effect of her regulatory actions on environmental quality in the other regulator's environmental medium., i.e., each regulator neglects cross-media pollution.

In Case 2, not only are the two regulator's noncooperative, but they are also *asymmetric in regulatory behavior* in that one regulator can be considered a Stackelberg leader in regulatory action with respect to the regulatory actions of the other regulator. Thus, this case seeks to model situations in which regulators are of unequal size or standing, or in which one regulator has a "first-mover advantage" in regulatory action. In this case, Regulator 1 may be viewed as a Stackelberg "leader" in regulatory action, and Regulator 2 may be viewed as a Stackelberg "follower."[3]

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[3] Of Cases 2 through 6, Case 2 differs most from the case of unified regulation in that Case 2 features both noncooperative, asymmetric regulatory behavior and divergent regulatory objectives. Because Case 2 differs most, one might *most* expect the necessary conditions for a regulatory outcome under Case 2 to differ from those obtained under unified regulation. The analysis shows that this expectation is fulfilled Cases 3-6 represent situations closer to that of unified regulation in that regulatory behavior is somewhat cooperative (or symmetric if noncooperative) and/or regulatory objectives are congruent. What will prove most interesting in the analysis of the remaining cases is to see how close one might approach the case of unified regulation and still obtain conditions for a regulatory outcome that differ from those associated with unified regulation.

The problem is solved by first finding Regulator 2's reaction function, then substituting the reaction function into Regulator 1's objective function, and finally solving Regulator 1's choice problem.

Regulator 2 chooses the level of her policy instrument, t_2, to maximize her regulatory objective, R_2, taking the level of Regulator 1's policy instrument, t_1, as given. Regulator 2's objective function, R_2, is simply the sum of profits and environmental quality in medium 2. Regulator 2's problem is:

$$(2.1)\quad \max_{t_2|t_1} R_2 = \hat{\pi}(\theta, P, w, t) + Q_2\left(y_2\left(\hat{x}_2(\theta, P, w, t)\right)\right)$$

The first order condition for Regulator 2's problem is:

$$(2.2)\quad \frac{\partial R_2}{\partial t_2} = \frac{\partial \hat{\pi}}{\partial t_2} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2} \equiv 0$$

Equation 2.2 states that Regulator 2 will set the marginal monetary benefit of improvement in environmental quality in medium 2 equal to the marginal decrease in firm profits caused by the change in the policy instrument level. In contrast to the corresponding optimizing condition under unified regulation (Equation 1.3), here Regulator 2 does not take into consideration the impact of her actions on environmental quality in Regulator 1's medium.

Assuming sufficient regularity, Equation 2.2 may be solved for $t_2^{SD}(t_1, \theta, P, w)$, Regulator 2's reaction function, where "SD" in the superscript stands for "Stackelberg Behavior / Divergent Objectives."

Regulator 1 now chooses the level of her policy instrument, t_1, to maximize her regulatory objective, R_1, taking Regulator 2's reaction function into account. Regulator 1's problem is:

$$(2.3)\qquad \max_{t_1|t_2(t_1,\theta,P,\mathbf{w})} R_1 = \hat{\pi}(\theta,P,w,t) + Q_1\left(y_1\left(\hat{x}_1(\theta,P,w,t)\right)\right)$$

The first order condition for Regulator 1's problem is:

$$(2.4)\qquad \frac{\partial R_1}{\partial t_1} = \frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial \hat{\pi}}{\partial t_2}\frac{\partial t_2}{\partial t_1} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\left[\frac{\partial \hat{x}_1}{\partial t_1} + \frac{\partial \hat{x}_1}{\partial t_2}\frac{\partial t_2}{\partial t_1}\right] \equiv 0$$

or, rearranging,

$$(2.5)\qquad \frac{\partial R_1}{\partial t_1} = \frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_1} + \left[\frac{\partial \hat{\pi}}{\partial t_2} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_2}\right]\frac{\partial t_2}{\partial t_1} \equiv 0$$

Equation 2.5 states that Regulator 1 will set the marginal decrease in firm profits caused by the change in Regulator 1's policy instrument level (term 1) equal to the (negative of) the marginal monetary benefit of improvement in environmental quality in medium 1 (term 2) plus an adjustment term that captures the indirect effect of Regulator 2's responses to Regulator 1's actions on the elements of Regulator 1's objective function. Regulator 1 does not take into consideration the impact of her actions on environmental quality in Regulator 2's medium. The adjustment term in Equation 2.5 is composed of two effects, the effect of Regulator 2's actions on profits (an element of Regulator 1's objective function) and the effect of Regulator 2's actions on environmental quality in Regulator 1's medium, both of which are multiplied by the slope of Regulator 2's reaction function, dt_2/dt_1. The slope of Regulator 2's reaction function is defined implicitly by Equation 2.2:

$$(2.6)\quad \frac{dt_2}{dt_1} \equiv \frac{-\frac{\partial}{\partial t_1}\left(\frac{\partial R_2}{\partial t_2}\right)}{\frac{\partial}{\partial t_2}\left(\frac{\partial R_2}{\partial t_2}\right)} = \frac{-\left[\frac{\partial \hat{x}_2}{\partial t_1} + \left(\frac{\partial Q_2}{\partial \hat{x}_2}\frac{\partial^2 \hat{x}_2}{\partial t_1 \partial t_2} + \frac{\partial^2 Q_2}{\partial \hat{x}_2^2}\frac{\partial \hat{x}_2}{\partial t_1}\frac{\partial \hat{x}_2}{\partial t_2}\right)\right]}{-\frac{\partial \hat{x}_2}{\partial t_2} + \left(\frac{\partial Q_2}{\partial \hat{x}_2}\frac{\partial^2 \hat{x}_2}{\partial t_2^2} + \frac{\partial^2 Q_2}{\partial \hat{x}_2^2}\frac{\partial \hat{x}_2}{\partial t_2}\frac{\partial \hat{x}_2}{\partial t_2}\right)}$$

The sign of the denominator in Equation 2.6 is negative by the second order conditions for a maximum for problem 2.1; hence, the slope of Regulator 2's reaction function depends on the sign of the numerator in Equation 2.6, which depends on the signs and magnitudes of (a) the own-price derivative (which, or course, is negative in sign) and cross-price derivative of $\hat{x}_2$ (which depends on whether the production technology exhibits substitutability or complementarity), (b) the second cross-price derivative of $\hat{x}_2$, and (c) the curvature of the environmental quality function for medium 2. The signs and magnitudes of these factors and terms depend on the model specification (an illustrative example is considered below), and, in general, the slope of Regulator 2's reaction function may be either positive or negative.

Assuming sufficient regularity, Equation 2.5 may be solved for Regulator 1's policy instrument level, $t_1^{SD}(\theta, P, w)$. Substituting $t_1^{SD}(\theta, P, w)$ into Regulator 2's reaction function yields Regulator 2's policy instrument level, $t_2^{SD}(\theta, P, w)$. Because the first order conditions for Case 2 (Equations 2.2 and 2.4) do not match the corresponding necessary conditions for an equilibrium under unified regulation (Equations 1.2 and 1.3), the regulatory outcome in Case 2 (t_1^{SD}, t_2^{SD}) will differ from the outcome under unified regulation (t_1^U, t_2^U),[4,5] except by coincidence, even though a full set of policy instruments

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[4] A similar result was first shown by Baron (1985b) for a particular case. However, Baron's case involved a tradeoff between a pollution externality and a market distortion due to market power, rather than a tradeoff between two pollution externalities due to cross-media pollution. Furthermore, Baron's main objective was

exists to address all externalities and each externality is targeted correctly (i.e., the Pigouvian taxes, t_i, are levied directly on pollution emissions, y_i).

Using a simulation model, it is verified below that, for the case of a Constant Elasticity of Substitution production technology, either overregulation or underregulation may occur under Stackelberg common agency regulation of cross-media pollution. The direction of regulatory distortion depends upon whether production technology exhibits substitution (e.g.'s: Jin (1994), Sigman (1996), publically-owned water treatment works (POTW's), scrubber sludge, etc.) or complementarity (e.g.: agriculture--Grimm, Paris and Williams (1987)): there is overregulation in the case of substitution and underregulation in the case of complementarity.

In summary, Case 2 shows that the regulatory equilibrium under common agency regulation of cross-media pollution may diverge from the unified regulatory equilibrium, even though (1) *all* externalities are addressed by some regulatory agency, (2) a sufficient number of policy instruments exists to address *all* policy targets, (3) regulators consider the general equilibrium effects of regulation on firm profits, and (4) *full* information

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to examine how *asymmetric information* can lead to inefficient regulation. From the point of view of examining the implications of asymmetric information for economic efficiency, Baron's model is more general than the model used here, because Baron allows for the possibility of asymmetric information between the regulators and the regulated firm (Specifically, a situation of adverse selection exists in which the regulators do not know the firm's type.). From this point of view, the model in Case 2 is the special case of Baron's model, where the probability distribution over firm types is reduced to a point mass However. If the objective of the analyst is to describe the *weakest conditions* under which common agency might lead to inefficient regulation of cross-media pollution (which is the objective of the present analysis), then Baron's model can be considered a special case of the model above. The reason is that Baron's inefficiency result depends on an additional condition, the existence of asymmetric information, whereas the inefficiency result derived above does not.

[5] In an unpublished manuscript, Oates (1984) derived similar results for two special cases--two types of "command and control" pollution emissions policy instruments: emissions standards and technology standards. In Oates' model, Regulator 2 does not have an explicit objective function; the level of Regulator 2's policy instrument is set arbitrarily. Oates focuses on the first regulator's problem, given the fixed level of Regulator 2's policy instrument. Regulator 2 does not have a reaction function, per se.

exists regarding (4a) firm production and pollution abatement technology, (4b) the quantity of pollution emissions, and (4c) the monetary value of damages caused by pollution emissions.

Might the result in Case 2 derive from the fact that regulator behavior is asymmetric (in the Stackelberg sense)? The next case shows that, under common agency regulation of cross-media pollution where regulators have divergent objectives, *symmetric* (Nash) regulatory behavior will not produce the necessary conditions for the unified regulatory equilibrium. Notice that this result, too, obtains under full information: i.e., asymmetric information is not required for this result.

3.3.3 Case 3: Nash Regulation with Divergent Objectives

The third case maintains divergent regulatory objectives but considers Nash noncooperative behavior between the two regulators. Case 3 seeks to address situations in which the regulators still do not consider the effects of their regulatory actions on environmental quality in the other regulator's medium, but now the regulators are symmetric in that they are of comparable size and standing, neither has a "first-mover advantage," and hence neither regulator may be considered a Stackelberg leader in regulatory action.

In Case 3, as in the preceding case, each regulator considers the impact of regulation both on environmental quality in her medium and on firm profits, i.e., $R_1 = \pi + Q_1$ and $R_2 = \pi + Q_1$. Similarly, each regulator's objective continues to diverge from

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hence, the regulatory outcome is not strictly a Stackelberg equilibrium. Yet, of the cases considered here, Oates' model seems closest in spirit to the Case 2 model.

social welfare in that each does not consider the social benefits of environmental quality in the other regulator's medium, i.e., each regulator neglects cross-media pollution.

The interaction between the regulators is modeled as a simple Nash equilibrium in the choice of policy instruments, t_1 and t_2, where Regulator 1 chooses t_1 and Regulator 2 chooses t_2. Notice that although a sufficient number of policy instruments exists to address the two relevant policy targets (i.e., the two externalities associated with y_1 and y_2), *control* over the policy instruments is *divided* between multiple principals (i.e., the two regulatory agencies); this divided control is an example of common agency in regulation.

Regulator 1 chooses the level of its policy instrument, t_1, to maximize its regulatory objective, R_1, taking as given the level of Regulator 2's policy instrument, t_2. Regulator 1's decision problem is:

$$(3.1) \qquad \max_{t_1|t_2} R_1 = \tilde{\pi}(\theta, P, w, t) + Q_1\left(y_1\left(\hat{x}_1(\theta, P, w, t)\right)\right)$$

The first order condition for this problem is:

$$(3.2) \qquad \frac{\partial R_1}{\partial t_1} = \frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_1} \equiv 0$$

Equation 3.2 states that Regulator 1 will set the marginal monetary benefit of improvement in environmental quality in medium 1 equal to the marginal decrease in firm profits caused by the change in the policy instrument level. In contrast to the corresponding optimizing condition under unified regulation (Equation 1.2), here Regulator 1 does not take into consideration the impact of her actions on environmental quality in Regulator 2's medium.

Assuming sufficient regularity, Equation 3.2 may be solved for $t_1^{ND}(t_2, \theta, P, w)$, Regulator 1's reaction function, where "ND" in the superscript stands for "Nash Behavior / Divergent Objectives."

Regulator 2 chooses the level of its policy instrument, t_2, to maximize its regulatory objective, R_2, taking as given the level of Regulator 1's policy instrument, t_1. Regulator 2's decision problem is:

$$(3.3) \quad \max_{t_2|t_1} R_2 = \tilde{\pi}(\theta, P, w, \mathbf{t}) + Q_2\left(y_2\left(\hat{x}_2(\theta, P, w, \mathbf{t})\right)\right)$$

The first order condition for this problem is:

$$(3.4) \quad \frac{\partial R_2}{\partial t_2} = \frac{\partial \tilde{\pi}}{\partial t_2} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2} \equiv 0$$

Equation 3.4 states that Regulator 2 will set the marginal monetary benefit of improvement in environmental quality in medium 2 equal to the marginal decrease in firm profits caused by the change in the policy instrument level. In contrast to the corresponding optimizing condition under unified regulation (Equation 1.3), here Regulator 2 does not take into consideration the impact of her actions on environmental quality in Regulator 1's medium.

Assuming sufficient regularity, Equation 3.4 may be solved for $t_2^{ND}(t_1, \theta, P, w)$, Regulator 2's reaction function.

Assuming that a solution to the system (Equations 3.2 and 3.4) of reaction functions exists, and assuming that all partial derivatives in the reaction function system exist, then by the implicit function theorem the solution may be written as a function of the parameters of the system ($t_1^{ND}(\theta, P, w)$, $t_2^{ND}(\theta, P, w)$). The first order conditions of both regulators (Equations 3.2 and 3.4) do not match the corresponding necessary conditions under unified regulation (Equations 1.2 and 1.3), except by coincidence. Hence, except by coincidence, the regulatory outcome in Case 3 (t_1^{ND}, t_2^{ND}) will differ from the outcome under unified regulation (t_1^U, t_2^U),[6] even though a full set of policy instruments exists to address all externalities and each externality is targeted correctly (i.e., the Pigouvian taxes, y_i, are levied directly on pollution emissions).

The solution may be written in terms of relative pollution levels, marginal damages and input elasticities of the firm at the optimum. Using the elasticities defined in the description of Case 1, Equations 3.2 and 3.4 may be rewritten:

$$(3.5)\quad t_1^N = \frac{\frac{\partial Q_1}{\partial \hat{x}_1} \varepsilon_{\hat{x}_1, t_1} \hat{x}_1}{\hat{x}_1} = t_1^U - \frac{\frac{\partial Q_2}{\partial \hat{x}_2} \varepsilon_{\hat{x}_2, t_1} \hat{x}_2}{\hat{x}_1}$$

$$(3.6)\quad t_2^N = \frac{\frac{\partial Q_2}{\partial \hat{x}_2} \varepsilon_{\hat{x}_2, t_2} \hat{x}_2}{\hat{x}_2} = t_2^U - \frac{\frac{\partial Q_1}{\partial \hat{x}_1} \varepsilon_{\hat{x}_1, t_2} \hat{x}_1}{\hat{x}_2}$$

Equation 3.5 says that the per unit tax on emissions into medium 1 in equilibrium is equal to marginal damage of emissions in medium 1 in equilibrium, multiplied by the elasticity of emissions into medium 1 with respect to the tax rate in medium 1. Comparing Equations 1.6 and 3.5, it is apparent that the tax under Nash regulation differs from the tax under Unified regulation by the second term in Equation 1.6. This term is positive in

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[6] Similar results were recently shown by Stole (1990) in an unpublished manuscript for a particular example. However, Stole's main objective was to show how *asymmetric information* can lead to inefficient regulation. However, as with Baron's (1985b) model for the case of a Stackelberg solution concept, if the objective of the analyst is to describe the weakest conditions under which regulatory inefficiency may arise under common agency, then Stole's model could be considered a special case of the above model in that Stole's inefficiency result depends on an additional condition, the existence of asymmetric information, whereas the above model result does not. Most recently, Rizzo and Sindelar (1996) reached similar conclusions for another particular case: the market for physicians' services.

the case of substitution in the firm's production technology and negative in the case of complementarity in the firm's production technology; hence, the tax is set too high under Nash regulation for the case of a production technology exhibiting substitution, and the tax is set too low under Nash regulation for technology exhibiting complementarity. A symmetric interpretation holds for Equation 3.6.

It is verified below that, for the case of a Constant Elasticity of Substitution production technology, either overregulation or underregulation may occur under Nash common agency regulation of cross-media pollution. The direction of regulatory distortion depends upon whether production technology exhibits substitution or complementarity: there is overregulation in the case of substitution and underregulation in the case of complementarity.

Comparing the first order conditions under Nash regulation (Equations 3.2 and 3.4) with the corresponding first order conditions under Stackelberg regulation (Equations 2.2 and 2.4), it is evident that the difference between the two cases is the presence of the "adjustment term" in Regulator 1's FOC in the Stackelberg case. How will the presence of this term cause the regulatory outcomes to differ between the two cases? Recall that the adjustment term is composed of two effects, the effect of Regulator 2's (the Stackelberg follower) actions on profits and the effect of Regulator 2's actions on environmental quality in Regulator 1's (the Stackelberg leader) medium. Each of these effects represents an additional "cost or benefit of regulation" from Regulator 1's perspective. The two effects are of the same sign when the production technology exhibits substitution but are of different signs when the production technology exhibits complementarity.

With substitution in production, the net effect of the adjustment term is to unambiguously raise the "cost of regulation" to Regulator 1, causing Regulator 1 to set a lower tax rate under Stackelberg regulation than under Nash regulation. Because the slope of Regulator 2's reaction function is positive under substitution, the lower tax rate set by Regulator 1 will induce Regulator 2 to also set a lower tax rate, as compared to the tax rate Regulator 2 would have set under Nash regulation. Hence, tax rates under Stackelberg regulation will be closer to the tax rates under unified regulation than tax rates under Nash regulation.

With complementarity in production, the net effect of the adjustment term is ambiguous. From Regulator 1's perspective, the effect of Regulator 2's (the Stackelberg follower) reactions on profits would be positive, representing a "benefit of regulation," but the effect of Regulator 2's reactions on environmental quality in Regulator 1's medium would be negative, representing a "cost of regulation." Hence, under complementarity in production, the tax rate set by Regulator 1 in the Stackelberg case may be higher or lower than the tax rate set by Regulator 1 in the Nash case. However, it is possible to say that, because the slope of Regulator 2's reaction function is negative in the case of complementarity, if Regulator 1's tax rate is higher under Stackelberg behavior than under Nash behavior, then Regulator 2's tax rate will be lower under Stackelberg behavior than under Nash behavior, and vice versa. Therefore, if Regulator 1's tax rate would be *closer* to the unified tax rate under Stackelberg regulation than it would be under Nash regulation, then Regulator 2's tax rate would be *farther* from the unified tax rate under Stackelberg regulation then it would be under Nash regulation.

3.4 Reforming Common Agency Regulation

In model Cases 2 and 3 above, three key model features interact to produce regulatory inefficiency—separation of control of policy instruments (i.e., common agency), substitution in pollution possibilities (i.e., cross-media pollution), and divergent regulatory objectives. Full regulatory reform would, of course, entail the coordinated use of all policy instruments to achieve a regulatory objective congruent with social welfare, i.e., full regulatory reform would be represented by Case 1. This section of Chapter 3 will attempt to distinguish between the effects of common agency, *per se*, and the effects of divergent regulatory objectives, *per se*, on regulatory efficiency through an examination of a series of model cases representing various "partial reforms" of model Cases 2 and 3.[*]

Several cases of partial regulatory reform are considered. These cases may be classified along three dimensions: congruency of regulatory objectives with social welfare, coordination of regulatory policy instruments (i.e., removing common agency), and, where policy instruments remain uncoordinated, type of regulator behavior (Nash or Stackelberg). In general, the different types of partial reform have different implications for the various actors in the model. As the next two cases show, some types of only partial reform may produce the unified regulatory outcome.

3.4.1 Case 4: Nash Regulation with Convergent Objectives

Although there are many reasons why regulatory objectives might diverge from full social welfare (Noll 1989, pp. 1277-1278), and divergent objectives certainly appears

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[*] Section 6.0 considers the effects of different assumptions regarding substitution in pollution possibilities on regulatory efficiency.

to be the norm within the current regulatory environment, suppose instead that regulators were to have objectives congruent with social welfare[8]; i.e., suppose each regulator considered the effects of her actions on environmental quality in the other regulator's medium. Regulators might come to have such congruent objectives in any of several ways (Noll 1989, pp. 1278-1279). For example, the regulators might be endowed with congruent objectives at the time of agency creation, or the agencies might undergo a "reform" process that leaves them both with congruent objectives.[9] The analysis in Case 4 answers the question: What would be the regulatory outcome if regulatory objectives were congruent with social welfare but regulators exhibited noncooperative Nash behavior and policy instruments remained uncoordinated?

Case 4 differs from that of unified regulation (Case 1) in that control over regulatory policy instruments remains divided among the two regulators, i.e., common agency exists in Case 4. Case 4 differs from Cases 2 and 3 in that each regulator now considers the impact of regulation on environmental quality in the other regulator's medium; the objectives of the two regulators are now $R_1 = \pi + Q_1 + Q_2$ and $R_2 = \pi + Q_1 + Q_2$, and thus each regulator's objective is now congruent with social welfare, i.e., $R_1 = R_2 = W$. Case 4 shows that, with symmetric Nash behavior and regulatory objectives that are congruent with social welfare, the necessary conditions for the regulatory equilibrium are congruent with the necessary conditions for equilibrium under unified regulation. Hence, common agency does not *necessarily* thwart attainment of the unified regulatory

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[8] There is evidence that some regulators do attempt to meet regulatory objectives, and some may even try, perhaps, to promote general social welfare (Noll 1989, pp 1278-1279).

[9] If agencies are endowed with congruent objectives through a reform process, it is assumed in Case 4 that *both* agencies obtain congruent objectives *simultaneously* (Case 6 considers the situation in which only one regulator's objective is reformed).

outcome; for example, it does not in the present case, where each regulator considers full social welfare and where the regulators exhibit Nash behavior between themselves.

In Case 4, Regulator 1 chooses the level of its policy instrument, t_1, to maximize its regulatory objective, R_1, taking as given the level of Regulator 2's policy instrument, t_2. Regulator 1's decision problem is:

$$(4.1)\quad \max_{t_1|t_2} R_1 = \hat{\pi}(\theta, P, \mathbf{w}, \mathbf{t}) + Q_1\left(y_1\left(\hat{x}_1(\theta, P, \mathbf{w}, \mathbf{t})\right)\right) + Q_2\left(y_2\left(\hat{x}_2(\theta, P, \mathbf{w}, \mathbf{t})\right)\right)$$

The first order condition for this problem is:

$$(4.2)\quad \frac{\partial R_1}{\partial t_1} = \frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_1} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_1} \equiv 0$$

Assuming sufficient regularity, Equation 4.2 may be solved for $t_1(t_2, \theta, P, \mathbf{w})$, Regulator 1's reaction function.

Regulator 2 chooses the level of its policy instrument, t_2, to maximize its regulatory objective, R_2, taking as given the level of Regulator 1's policy instrument, t_1. Regulator 2's decision problem is:

$$(4.3)\quad \max_{t_2|t_1} R_2 = \hat{\pi}(\theta, P, \mathbf{w}, \mathbf{t}) + Q_1\left(y_1\left(\hat{x}_1(\theta, P, \mathbf{w}, \mathbf{t})\right)\right) + Q_2\left(y_2\left(\hat{x}_2(\theta, P, \mathbf{w}, \mathbf{t})\right)\right)$$

The first order condition for this problem is:

$$(4.4)\quad \frac{\partial R_2}{\partial t_2} = \frac{\partial \hat{\pi}}{\partial t_2} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_2} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2} \equiv 0$$

Assuming sufficient regularity, Equation 4.4 may be solved for $t_2(t_1, \theta, P, \mathbf{w})$, Regulator 2's reaction function.

Assuming that a solution to the system of reaction functions exists, and assuming that all partial derivatives in the reaction function system exist, then by the implicit function theorem the solution may be written as a function of the parameters of the system ($t_1^{NC}(\theta, P, w)$, $t_2^{NC}(\theta, P, w)$), where the "NC" superscript stands for "Nash Behavior / Congruent Objectives." The necessary conditions for a regulatory equilibrium in Case 4 (Equations 4.2 and 4.4) are identical to the necessary conditions for equilibrium under unified regulation (Equations 1.2 and 1.3). It follows that the regulatory outcome in Case 4 will be identical to the unified regulatory outcome.

An important policy implication of Case 4 is that "decentralized" common agency regulation of cross-media pollution under full information *can* achieve the unified regulatory outcome, even if regulator behavior is noncooperative (in the Nash sense), *if* the regulators' objective functions can be made congruent with social welfare.

The next case examines the question of whether this result is an artifact of the symmetric, Nash behavior of the regulators.

3.4.2 Case 5: Stackelberg Regulation with Convergent Objectives

Case 5 is similar to the preceding case in that each regulator is simultaneously endowed with objectives congruent with social welfare, i.e., $R_1 = \pi + Q_1 + Q_2$ and $R_2 = \pi + Q_1 + Q_2$. However, Case 5 returns to the assumption of asymmetric Stackelberg "leader-follower" behavior between the regulators. Despite the asymmetry between the regulators implied by Stackelberg behavior, the necessary conditions for regulatory equilibrium under Stackelberg behavior will be identical to those under unified regulation. Hence, if each regulator considers full social welfare under full information, "decentralized" regulation by two separate *asymmetric* (in the Stackelberg sense) regulatory agencies will not thwart cross-media pollution regulation. This result hinges on a type of "envelope theorem in regulation," illustrated below.

As in Case 2, the problem in Case 5 is solved by first finding Regulator 2's reaction function, $t_2(t_1, \theta, P, \mathbf{w})$, and then substituting the reaction function into Regulator 1's objective function and solving Regulator 1's choice problem. Regulator 2's problem is:

$$(5.1) \quad \max_{t_2|t_1} R_2 = \hat{\pi}(\theta, P, \mathbf{w}, \mathbf{t}) + Q_1\left(y_1\left(\hat{x}_1(\theta, P, \mathbf{w}, \mathbf{t})\right)\right) + Q_2\left(y_2\left(\hat{x}_2(\theta, P, \mathbf{w}, \mathbf{t})\right)\right)$$

The first order condition for Regulator 2's problem is:

$$(5.2) \quad \frac{\partial R_2}{\partial t_2} = \frac{\partial \hat{\pi}}{\partial t_2} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_2} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2} \equiv 0$$

Assuming sufficient regularity, Equation 4.2 may be solved for $t_2(t_1, \theta, P, \mathbf{w})$, Regulator 2's reaction function.

Regulator 1 now chooses the level of her policy instrument, t_1, to maximize her regulatory objective, R_1, taking Regulator 2's reaction function, $t_2(t_1, \theta, P, \mathbf{w})$, into account. Regulator 1's problem is:

$$(5.3) \quad \max_{t_1|t_2(t_1, \theta, P, \mathbf{w})} R_1 = \hat{\pi}(\theta, P, \mathbf{w}, \mathbf{t}) - Q_1\left(y_1\left(\hat{x}_1(\theta, P, \mathbf{w}, \mathbf{t})\right)\right) + Q_2\left(y_2\left(\hat{x}_2(\theta, P, \mathbf{w}, \mathbf{t})\right)\right)$$

The first order condition for Regulator 1's problem is:

$$(5.4) \quad \begin{aligned} \frac{\partial R_1}{\partial t_1} = & \left[\frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial \hat{\pi}}{\partial t_2}\frac{dt_2}{dt_1}\right] + \left[\frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\left(\frac{\partial \hat{x}_1}{\partial t_1} + \frac{\partial \hat{x}_1}{\partial t_2}\frac{dt_2}{dt_1}\right)\right] \\ & + \left[\frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\left(\frac{\partial \hat{x}_2}{\partial t_1} + \frac{\partial \hat{x}_2}{\partial t_2}\frac{dt_2}{dt_1}\right)\right] \equiv 0 \end{aligned}$$

Rearranging Equation 5.4:

$$\begin{aligned} \frac{\partial R_1}{\partial t_1} &= \left[\frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_1} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_1}\right] \\ &+ \left[\frac{\partial \hat{\pi}}{\partial t_2} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_2} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2}\right]\frac{dt_2}{dt_1} \equiv 0 \end{aligned} \tag{5.5}$$

it can be seen that the first factor of the second term in Equation 5.5 is identically equal to zero by Regulator 2's first order condition, Equation 5.2. Hence, Regulator 1's first order condition is identical to her FOC under unified regulation (Equation 1.2); this is the aforementioned "envelope" result.[10]

Assuming sufficient regularity, Equations 5.2 and 5.5 may be solved simultaneously for the regulatory outcome $\{t_1^{SC}(\theta, P, w), t_2^{SC}(\theta, P, w)\}$, where "SC" in the superscript stands for "Stackelberg Behavior / Congruent Objectives." Because the necessary conditions for a regulatory equilibrium in Case 5 (Equations 5.2 and 5.5) are identical to the necessary conditions for equilibrium under unified regulation (Equations 1.2 and 1.3), the regulatory outcome in Case 5 will be identical to the unified regulatory outcome.

An important policy implication of Case 5 is that "decentralized" common agency regulation of cross-media pollution under full information *can* achieve the unified regulatory outcome, even if regulator behavior is noncooperative *and asymmetric* (in the Stackelberg sense), *if* the regulators' objective functions can be made congruent with social welfare.

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[10] Intuitively, because Regulator 2's objective is congruent with social welfare, Regulator 1 may safely assume that Regulator 2 will adjust the level of her policy instrument to the level that would obtain under unified regulation, given the level of Regulator 1's policy instrument. Hence, given that Regulator 1's objective is congruent with social welfare in this model case, Regulator 1 may simply neglect Regulator 2 when setting the level of her policy instrument.

Cases 4 and 5 are similar to the common agency problem considered by Bernheim and Whinston (1986), "BW," but they differ in a fundamental aspect. At a general level, the difference is that BW's principals are *private* entities (firms), whereas the principals in Cases 4 and 5 are *public* entities (regulatory agencies). In order to further illuminate this difference, it may be helpful to review the relevant aspects of BW's model and results in more detail. In BW's model, the costs of inducing agent action in BW's model differ across principals, i.e., the costs of inducing agent action are "private costs" to principals. In contrast, the benefits accruing to the principals as a result of the agent's action are shared equally among the principals (this is the result of the incentive mechanism imposed upon the principals in an attempt to force them to achieve the cooperative equilibrium), i.e., the benefits of agent action are "public benefits" to principals. Because the costs of inducing agent action are "private," but the benefits accruing to the principals as a result of agent action are "public," the principals may have incentives to "free-ride" on each other's efforts to induce agent action. Such free-riding would cause the principals to "under-induce" action in the agent, relative to the cooperative amount of agent induction. BW show that this free-riding behavior definitely does occur (and that therefore the noncooperative outcome diverges from the cooperative outcome) for a particular case.[11]

The difference between Cases 4 and 5 and BW's model is that in Cases 4 and 5 both the costs and benefits of principals' actions are "public" (affecting each principal equally) from the perspective of the principals. In Cases 4 and 5, the costs of regulatory

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[11] The case is Holmstrom's (1979) well-know "effort" model.

action consist of (1) reduced firm profits and (2) decreased[12] environmental quality in the other regulator's medium, and in Cases 4 and 5 both costs affect all principals equally (i.e., they are "public costs"). Because both costs and benefits are "public" across principals in Cases 4 and 5, there is no incentive for principals to free-ride on each other. It follows that the noncooperative regulatory outcome equals the unified regulatory outcome. BW's model does not exhibit completely congruent *objectives* across principals, but rather only congruent *benefits*, whereas Cases 4 and 5 exhibit congruent *costs* as well as benefits. If BW's mechanism were altered to make costs, as well as benefits, congruent across principals, then the noncooperative outcome would equal the cooperative outcome. Conversely, if the objective functions of the regulators in Cases 4 and 5 were altered to allow the costs or benefits of regulation to differ across regulators, the noncooperative outcome might not attain the unified regulatory outcome in some cases. For example, if the objective of each regulator in Cases 4 and 5 were altered to depend on the *decrease* in firm profits resulting from the level of that regulator's policy instrument alone[13], rather than on the total profits remaining after the emissions taxes of *both* regulators were collected, then the costs of regulatory action would differ across the regulators, and it would be expected that noncooperative behavior would not lead to the unified regulatory outcome.

3.4.3 Case 6: Nash Regulatory Behavior with Mixed Objectives

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[12] In the case of production technology exhibiting substitution (see Section 6.0).

[13] As might be the case when firms lodge regulator-specific complaints with Congress, based on the amount of emissions taxes paid by medium, rather than a general complaint against all regulators taken together, based on the decrease in firm profits after emissions taxes are paid for all media.

Case 6 differs from the preceding two cases in that only one of the two regulators has "reformed" objectives, i.e., only one of the two regulators has objectives congruent with social welfare; the other regulator retains her divergent objective. Let this situation, in which one regulator has congruent objectives and the other regulator has divergent objectives, be termed "mixed objectives."

Case 6 models a situation in which either regulators are initially endowed with mixed objectives or mixed objectives come about through a process of partial regulatory reform in which it is not possible (e.g., for legal or bureaucratic reasons) to reform the objectives of both regulators simultaneously. Let Regulator 2 have the reformed objective; the objectives of the two regulators are now $R_1 = \pi + Q_1$ and $R_2 = \pi + Q_1 + Q_2$. In Case 6, it is assumed that the regulators' exhibit symmetric (Nash) behavior (Cases 7 and 8 will consider the implications of asymmetric (Stackelberg) behavior with mixed regulatory objectives).

In Case 6, Regulator 1 chooses the level of her policy instrument, t_1, to maximize her regulatory objective, R_1, taking as given the level of Regulator 2's policy instrument, t_2. Regulator 1's decision problem is:

$$(6.1) \qquad \max_{t_1|t_2} R_1 = \hat{\pi}(\theta, P, \mathbf{w}, \mathbf{t}) + Q_1\left(y_1\left(\hat{x}_1(\theta, P, \mathbf{w}, \mathbf{t})\right)\right)$$

The first order condition for this problem is:

$$(6.2) \qquad \frac{\partial R_1}{\partial t_1} = \frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_1} \equiv 0$$

Assuming sufficient regularity, Equation 6.2 may be solved for $t_1^{NM}(t_2, \theta, P, w)$, Regulator 1's reaction function, where the "NM" superscript stands for "Nash Behavior / Mixed Objectives."

Regulator 2 chooses the level of her policy instrument, t_2, to maximize her regulatory objective, R_2, taking as given the level of Regulator 1's policy instrument, t_1. Regulator 2's decision problem is:

$$(6.3) \quad \max_{t_2|t_1} R_2 = \hat{\pi}(\theta, P, w, t) + Q_1\left(y_1\left(\hat{x}_1(\theta, P, w, t)\right)\right) + Q_2\left(y_2\left(\hat{x}_2(\theta, P, w, t)\right)\right)$$

The first order condition for Regulator 2's problem is:

$$(6.4) \quad \frac{\partial R_2}{\partial t_2} = \frac{\partial \hat{\pi}}{\partial t_2} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_2} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2} \equiv 0$$

Assuming sufficient regularity, Equation 6.4 may be solved for $t_2^{NM}(t_1, \theta, P, w)$, Regulator 2's reaction function.

Assuming that a solution to the system of reaction functions exists, and assuming that all partial derivatives in the reaction function system exist, then by the implicit function theorem the solution may be written as a function of the parameters of the system $(t_1^{NM}(\theta, P, w), t_2^{NM}(\theta, P, w))$.

Because the first order conditions for Case 6 (Equations 6.2 and 6.4) do not match the corresponding necessary conditions for an equilibrium under unified regulation (Equations 1.2 and 1.3), the regulatory outcome in Case 6 (t_1^{NM}, t_2^{NM}) will differ from the outcome under unified regulation (t_1^{U}, t_2^{U}), except by coincidence, even though a full set of policy instruments exists to address all externalities and each externality is targeted correctly (i.e., the Pigouvian taxes, t_i, are levied directly on pollution emissions, y_i).

3.4.4. Case 7: Stackelberg Regulatory Behavior with Mixed Objectives—Leader Has Congruent Objective

Case 7 is similar to Case 5 except that only Regulator 1, the Stackelberg leader, has objectives congruent with social welfare, i.e., $R_1 = \pi + Q_1 + Q_2$ and $R_2 = \pi + Q_2$.

The problem in Case 7 is solved by first finding Regulator 2's reaction function, then substituting the reaction function into Regulator 1's objective function, and finally solving Regulator 1's choice problem. Regulator 2's problem is:

$$(7.1) \quad \max_{t_2|t_1} R_2 = \hat{\pi}(\theta, P, w, t) + Q_2\left(y_2\left(\hat{x}_2(\theta, P, w, t)\right)\right)$$

The first order condition for Regulator 2's problem is:

$$(7.2) \quad \frac{\partial R_2}{\partial t_2} = \frac{\partial \hat{\pi}}{\partial t_2} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2} \equiv 0$$

Assuming sufficient regularity, Equation 7.2 may be solved for $t_2^{SML}(t_1, \theta, P, w)$, Regulator 2's reaction function, where "SML" in the superscript stands for "Stackelberg Behavior / Mixed Objectives / Leader has Congruent Objectives."

Regulator 1 now chooses the level of her policy instrument, t_1, to maximize her regulatory objective, R_1, taking Regulator 2's reaction function into account. Regulator 1's problem is:

$$(7.3) \quad \max_{t_1|t_2(t_1,\theta,P,w)} R_1 = \hat{\pi}(\theta, P, w, t) + Q_1\left(y_1\left(\hat{x}_1(\theta, P, w, t)\right)\right) + Q_2\left(y_2\left(\hat{x}_2(\theta, P, w, t)\right)\right)$$

The first order condition for Regulator 1's problem is:

$$(7.4)\quad \begin{aligned}\frac{\partial R_1}{\partial t_1} = &\left[\frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial \hat{\pi}}{\partial t_2}\frac{dt_2}{dt_1}\right] + \left[\frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\left(\frac{\partial \hat{x}_1}{\partial t_1} + \frac{\partial \hat{x}_1}{\partial t_2}\frac{dt_2}{dt_1}\right)\right] \\ &+ \left[\frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\left(\frac{\partial \hat{x}_2}{\partial t_1} + \frac{\partial \hat{x}_2}{\partial t_2}\frac{dt_2}{dt_1}\right)\right] \equiv 0\end{aligned}$$

Rearranging Equation 7.4 (and substituting Equation 7.2):

$$(7.5)\quad \frac{\partial R_1}{\partial t_1} = \left[\frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_1} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_1}\right] + \left[\frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_2}\right]\frac{dt_2}{dt_1} \equiv 0$$

Assuming sufficient regularity, Equations 7.2 and 7.5 may be solved simultaneously for the regulatory outcome $\{t_1^{SML}(\theta, P, w), t_2^{SML}(\theta, P, w)\}$. Because the necessary conditions for a regulatory equilibrium in Case 7 (Equations 7.2 and 7.5) differ from the necessary conditions for equilibrium under unified regulation (Equations 1.2 and 1.3), the regulatory outcome in Case 7 will differ from the unified regulatory outcome, except perhaps by coincidence.

3.4.5 Case 8: Stackelberg Regulatory Behavior with Mixed Objectives—Follower Has Congruent Objective

Case 8 is similar to Case 5 except that only Regulator 2, the Stackelberg follower, has objectives congruent with social welfare, i.e., $R_1 = \pi + Q2$ and $R2 = \pi + Q_1 + Q_2$.

The problem in Case 8 is solved by first finding Regulator 2's reaction function, then substituting the reaction function into Regulator 1's objective function, and finally solving Regulator 1's choice problem. Regulator 2's problem is:

$$(8.1)\quad \max_{t_2|t_1} R_2 = \hat{\pi}(\theta, P, w, t) + Q_2\big(y_2(\hat{x}_2(\theta, P, w, t))\big) + Q_1\big(y_1(\hat{x}_1(\theta, P, w, t))\big)$$

The first order condition for Regulator 2's problem is:

(8.2) $$\frac{\partial R_2}{\partial t_2}=\frac{\partial \tilde{\pi}}{\partial t_2}+\frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \tilde{x}_2}\frac{\partial \tilde{x}_2}{\partial t_2}+\frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \tilde{x}_1}\frac{\partial \tilde{x}_1}{\partial t_2}\equiv 0$$

Assuming sufficient regularity, Equation 8.2 may be solved for $t_2^{SMF}(t_1, \theta, P, w)$, Regulator 2's reaction function, where "SMF" in the superscript stands for "Stackelberg Behavior / Mixed Objectives / Follower has Congruent Objectives."

Regulator 1 now chooses the level of her policy instrument, t_1, to maximize her regulatory objective, R_1, taking Regulator 2's reaction function into account. Regulator 1's problem is:

(8.3) $$\max_{t_1 | t_2(t_1,\theta,P,w)} \quad R_1=\tilde{\pi}(\theta,P,w,t)+Q_1\left(y_1\left(\tilde{x}_1(\theta,P,w,t)\right)\right)$$

The first order condition for Regulator 1's problem is:

(8.4) $$\frac{\partial R_1}{\partial t_1}=\left[\frac{\partial \tilde{\pi}}{\partial t_1}+\frac{\partial \tilde{\pi}}{\partial t_2}\frac{dt_2}{dt_1}\right]+\left[\frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \tilde{x}_1}\left(\frac{\partial \tilde{x}_1}{\partial t_1}+\frac{\partial \tilde{x}_1}{\partial t_2}\frac{dt_2}{dt_1}\right)\right]\equiv 0$$

Rearranging Equation 8.4 (and substituting Equation 8.2):

(8.5) $$\frac{\partial R_1}{\partial t_1}=\left[\frac{\partial \tilde{\pi}}{\partial t_1}+\frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \tilde{x}_1}\frac{\partial \tilde{x}_1}{\partial t_1}\right]-\left[\frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \tilde{x}_2}\frac{\partial \tilde{x}_2}{\partial t_2}\right]\frac{dt_2}{dt_1}\equiv 0$$

Assuming sufficient regularity, Equations 8.2 and 8.5 may be solved simultaneously for the regulatory outcome $\{t_1^{SMF}(\theta, P, w), t_2^{SMF}(\theta, P, w)\}$. Because the necessary conditions for a regulatory equilibrium in Case 8 (Equations 8.2 and 8.5) differ from the necessary conditions for equilibrium under unified regulation (Equations 1.2 and 1.3), the regulatory outcome in Case 8 will differ from the unified regulatory outcome, except perhaps by coincidence.

3.4.6 Case 9: Consolidated Instruments / Divergent Objective /

Regulatory Objective Constraint

In Cases 7 and 8, partial regulatory reform consisted of aligning one regulator's objective with social welfare while leaving control over policy instruments divided among the two regulators. In Cases 9 and 10, partial reform consists of consolidating control of policy instruments with one regulator while leaving the regulator's objective divergent. The regulator given control of both policy instruments must account for environmental quality in the other regulator's medium indirectly through a constraint placed on the controlling regulator's optimization problem. In Case 9, the constraint is that the level of the non-controlling regulator's divergent objective function must be maintained at the Nash equilibrium level (see Case 3). In Case 10, the constraint is that the level of environmental quality in the non-controlling regulator's environmental medium must be maintained at the Nash equilibrium level.

Suppose Regulator1 retains a divergent objective, is given control over both policy instruments, and is required to maintain the level of the non-controlling regulator's divergent objective function at the Nash equilibrium level. Regulator 1's problem is:

$$(9.1)\quad \begin{aligned} &\max_{t_1,t_2} R_1 = \tilde{\pi}(\theta, P, w, t) - Q_1\big(y_1(\hat{x}_1(\theta, P, w, t))\big) \\ &\text{subject to:}\quad \tilde{\pi}(\theta, P, w, t) + Q_2\big(y_2(\hat{x}_2(\theta, P, w, t))\big) \equiv \overline{R}_2^N \end{aligned}$$

where $\overline{R}_2^N$ is the level of the non-controlling regulator's divergent objective function at the Nash equilibrium described in Case 3. The Lagrangian expression for this problem is:

(9.2)

$$L = \tilde{\pi}(\theta, P, w, t) + Q_1\big(y_1(\hat{x}_1(\theta, P, w, t))\big) + \lambda\Big(\overline{R}_2^N - \tilde{\pi}(\theta, P, w, t) - Q_2\big(y_2(\hat{x}_2(\theta, P, w, t))\big)\Big)$$

and the first order conditions for a solution to the problem are:

$$(9.3)\quad \frac{\partial L}{\partial t_1} = \frac{\partial \tilde{\pi}}{\partial t_1} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_1} - \lambda\left(\frac{\partial \tilde{\pi}}{\partial t_1} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_1}\right) \equiv 0$$

$$(9.4)\quad \frac{\partial L}{\partial t_2} = \frac{\partial \tilde{\pi}}{\partial t_2} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_2} - \lambda\left(\frac{\partial \tilde{\pi}}{\partial t_2} + \frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2}\right) \equiv 0$$

$$(9.5)\quad \frac{\partial L}{\partial \lambda} = \overline{R}_2^N - \tilde{\pi}(\theta, P, w, t) - Q_2\left(y_2\left(\hat{x}_2(\theta, P, w, t)\right)\right) \equiv 0$$

3.4.7 Case 10: Consolidated Instruments / Divergent Objective / Environmental Quality Constraint

Instead of maintaining the level of the non-controlling regulator's objective function at the Nash equilibrium level, as in Case 9, suppose now that Regulator 1 is required to maintain the level of *environmental quality* in the non-controlling regulator's environmental medium at the Nash equilibrium level. As in Case 9, Regulator1 retains a divergent objective and is given control over both policy instruments. Regulator 1's problem is now:

$$(10.1)\quad \begin{aligned} &\max_{t_1, t_2} R_1 = \tilde{\pi}(\theta, P, w, t) + Q_1\left(y_1\left(\hat{x}_1(\theta, P, w, t)\right)\right) \\ &\text{subject to:} \quad Q_2\left(y_2\left(\hat{x}_2(\theta, P, w, t)\right)\right) \equiv \overline{Q}_2^N \end{aligned}$$

where $\overline{Q}_2^N$ is the level of environmental quality in the non-controlling regulator's environmental medium attained in the Nash equilibrium described in Case 3. The Lagrangian expression for this problem is:

$$(10.2)\quad L = \tilde{\pi}(\theta, P, w, t) + Q_1\left(y_1\left(\hat{x}_1(\theta, P, w, t)\right)\right) + \lambda\left(\overline{Q}_2^N - Q_2\left(y_2\left(\hat{x}_2(\theta, P, w, t)\right)\right)\right)$$

and the first order conditions for a solution to the problem are:

$$(10.3)\quad \frac{\partial L}{\partial t_1} = \frac{\partial \hat{\pi}}{\partial t_1} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_1} - \lambda\left(\frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_1}\right) \equiv 0$$

$$(10.4)\quad \frac{\partial L}{\partial t_2} = \frac{\partial \hat{\pi}}{\partial t_2} + \frac{\partial Q_1}{\partial y_1}\frac{\partial y_1}{\partial \hat{x}_1}\frac{\partial \hat{x}_1}{\partial t_2} - \lambda\left(\frac{\partial Q_2}{\partial y_2}\frac{\partial y_2}{\partial \hat{x}_2}\frac{\partial \hat{x}_2}{\partial t_2}\right) \equiv 0$$

$$(10.5)\quad \frac{\partial L}{\partial \lambda} = \overline{Q}_2^N - Q_2\left(y_2\left(\hat{x}_2(\theta, P, w, t)\right)\right) \equiv 0$$

3.5 Simulations

3.5.1 Simulation Model

In order to explore the policy implications of the various model cases presented in the preceding sections, a simulation model of cross-media pollution regulation under common agency is constructed using a three-factor Constant Elasticity of Substitution (CES) production technology.[14] It can be shown using the simulation model that, for example, different values of the model parameters may produce either overregulation and underregulation under the conditions of model Cases 2 and 3.[15] The outline of this section is as follows: First, the firm's factor demand equations are derived under the CES technology. Second, the first and second partial derivatives of the factor demand equations are derived (for use in evaluating the regulators' reaction functions in some model cases). Third, the simulation model is used to find equilibrium values for several key variables for all model cases described in the preceding sections.

Consider the model outlined in Case 2 where the firm produces output Y using a CES technology with three inputs x_i, i = 1..3. The firm's production function is then:

$$(6.1)\quad Y(x_1, x_2, x_3; \theta) = \left(\sum_{i=1}^{3} \alpha_i x_i^{\rho} \right)^{\mu/\rho}, \quad \mu < 1.$$

where $\theta \equiv \{\alpha_1, \alpha_2, \alpha_3, \rho, \mu\}$. The production function is homogeneous of degree μ.

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[14] It is necessary to have at least three inputs for the CES technology to potentially exhibit complementarity, a desired model property.

[15] Operationally, a simulation model of the unified regulator's choice problem (with embedded, profit-maximizing firm behavior) is constructed using spreadsheet software. The expressions for the firm's factor demands and partial derivatives of the factor demands are also programmed into the spreadsheet. Model parameters are chosen arbitrarily, and the unified regulator's objective function is maximized with respect to t_1 and t_2. The last step is iterated until a set of parameters is found that generates complementarity in the CES (i.e., $dx_1/dt_2 < 0$ and $dx_2/dt_1 < 0$) and a set of parameters is found that generates substitutability (i.e., $dx_1/dt_2 > 0$ and $dx_2/dt_1 < 0$).

The use of input x_1 causes pollution emissions $y_1(x_1)$ into environmental medium 1; in this case, let $y_1(x_1) \equiv x_1$. The use of input x_2 results in pollution emissions $y_2(x_2)$ into environmental medium 2; in this case, let $y_2(x_2) \equiv x_2$. Input x_3 does not contribute to pollution. Let environmental quality in medium 1, Q_1, be given by $Q_1(y_1) = 1 - 0.1*(y_1)^2$. Similarly, let environmental quality in medium 2, Q_2, be given by $Q_2(y_2) = 1 - 0.1*(y_2)^2$.

Let the price of output P (the numeraire) equal 1. The three inputs are available in competitive factor markets at constant normalized prices w_i, i = 1..3.

Firm profits are:

$$(6.2)\quad \pi(x_1, x_2, x_3; \theta) = 1 \cdot Y(\cdot) - \left(\sum_{i=1}^{3} w_i x_i \right) - t_1 y_1(x_1) - t_2 y_2(x_2)$$

The firm's problem is:

$$(6.3)\quad \begin{array}{l} \max\limits_{x_1, x_2, x_3} \ \pi = 1 \cdot Y(\cdot) - \left(\sum\limits_{i=1}^{3} w_i x_i \right) - t_1 y_1(x_1) - t_2 y_2(x_2) \\ \text{where:} \quad Y(\cdot) = \left(\sum\limits_{i=1}^{3} \alpha_i x_i^{\rho} \right)^{\mu/\rho}, \quad \mu < 1 \end{array}$$

The first order necessary conditions (FONC's) for a maximum of the firm's profit maximization problem are:

$$(6.4)\quad \frac{\partial \pi}{\partial x_1} = 1 \frac{\partial Y}{\partial x_1} - w_1 - t_1 \equiv 0$$

$$(6.5)\quad \frac{\partial \pi}{\partial x_2} = 1 \frac{\partial Y}{\partial x_2} - w_2 - t_2 \equiv 0$$

$$(6.6)\quad \frac{\partial \pi}{\partial x_3} = 1 \frac{\partial Y}{\partial x_3} - w_3 \equiv 0$$

where the substitution $\partial y_1/\partial x_1 \equiv \partial y_2/\partial x_2 \equiv 1$ has been made based on the definitions of y_1 and y_2. Assuming that the second order conditions for a maximum are satisfied, the firm's profit function $\hat{\pi}(\mathbf{w}, t_1, t_2)$, where $\mathbf{w} = \{w_1, w_2, w_3\}$, is (see Lau 1978, p. 192):

(6.7)

$$\hat{\pi}(w,t_1,t_2) = \mu^{\frac{\mu}{1-\mu}}(1-\mu)\left(\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}} + \alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}} + \alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right)^{\frac{-\mu(\rho-1)}{\rho(1-\mu)}}$$

By Hotelling's Lemma, the firm's supply function $Y(\mathbf{w}, t_1, t_2)$ is:

$$(6.8) \quad Y(w,t_1,t_2) = \frac{\hat{\pi}(w,t_1,t_2)}{(1-\mu)}$$

and the firm's unconditional factor demand functions $\hat{x}_i(\mathbf{w}, t_1, t_2)$, i = 1..3, are:

(6.9) . . . (6.11)

$$\hat{x}_i(w,t_1,t_2) = \mu^{\frac{1}{1-\mu}}\left(\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}} + \alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}} + \alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right)^{\frac{(\mu-\rho)}{\rho(1-\mu)}}\left(\frac{w_i+t_i}{\alpha_i}\right)^{\frac{1}{\rho-1}}$$

Next, the first and second partial derivatives of the factor demands are derived. These expressions are necessary to determine the signs of key factors in the first order conditions of some model cases.[16] Most importantly, the expressions for the first partials

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[16] Of course, the signs of some factors are known. Recall that factors $\frac{\partial Q_1}{\partial y_1}$ and $\frac{\partial Q_2}{\partial y_2}$ are negative by definition of Q_1 and Q_2. Factors $\frac{\partial y_1}{\partial \hat{x}_1}$ and $\frac{\partial y_2}{\partial \hat{x}_2}$ are positive by definition of y_1 and y_2. Because it has been assumed that $y_2 \equiv x_2$, and because input demands are decreasing in own-input prices by Hotelling's Lemma, $\frac{\partial \hat{x}_2}{\partial t_2} < 0$.

are necessary to determine whether input demands are increasing or decreasing in cross-input prices. Also of importance, the sign of factor $\frac{dt_2}{dt_1}$, the slope of Regulator 2's reaction function, is determined by the first and second partial derivatives. Finally, the *magnitudes* of these partial derivatives are also important, because several key terms in the first-order conditions may exhibit opposite signs.

The sign of factor $\frac{dt_2}{dt_1}$ is the *slope of Regulator 2's reaction function*, $t_2(t_1)$. If $\frac{dt_2}{dt_1} < 0$, then t_1 and t_2 may be called *strategic substitutes in regulation* from the perspective of the regulators. If $\frac{dt_2}{dt_1} > 0$, then t_1 and t_2 may be called *strategic complements in regulation*. Assuming sufficient regularity, Regulator 2's reaction function is defined implicitly by the identity:

$$(6.12)\quad \frac{\partial R_2(t_2,t_1)}{\partial t_2} \equiv 0.$$

By the implicit function theorem:

$$(6.13)\quad \frac{dt_2}{dt_1} \equiv -\frac{\dfrac{\partial^2 R_2}{\partial t_1 \partial t_2}}{\dfrac{\partial^2 R_2}{\partial t_2^2}}$$

Assuming that the sufficient conditions for Regulator 2's maximization problem are satisfied, the denominator on the right hand side in Equation 6.13 is negative. Hence, the slope of the reaction curve depends on the sign of the cross-partial derivative in the numerator. However, because it may be necessary to determine both the magnitude and the sign of $\frac{dt_2}{dt_1}$, expressions for both the numerator and the denominator of Equation 6.13 are important, both of which depend, in turn, on the first and second cross partial derivatives of the input demands

The expressions for relevant first and second partial derivatives of the firm's factor demands are given below.

(6.14)

$$\frac{\partial \hat{x}_1(w,t_1,t_2)}{\partial t_1} = \left(\frac{\mu^{\frac{1}{1-\mu}}(\mu-\rho)}{\rho(1-\mu)}\right)\cdot\left(\left[\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}}+\alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}}+\alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right]^{\frac{(\mu-\rho)}{\rho(1-\mu)}-1}\right.$$

$$\left.\left(\left(\frac{\alpha_1\rho}{\rho-1}\right)\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}-1}\left(\frac{1}{\alpha_1}\right)\right)\right)\cdot\left(\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{1}{\rho-1}}\right)$$

$$+\left(\mu^{\frac{1}{1-\mu}}\right)\left(\left[\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}}+\alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}}+\alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right]^{\frac{(\mu-\rho)}{\rho(1-\mu)}}\right)\left(\frac{1}{\rho-1}\right)\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{1}{\rho-1}-1}\left(\frac{1}{\alpha_1}\right)$$

(6.15)

$$\frac{\partial \hat{x}_1(w,t_1,t_2)}{\partial t_2} = \left(\frac{\mu^{\frac{1}{1-\mu}}(\mu-\rho)}{\rho(1-\mu)}\right)\cdot\left(\left[\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}}+\alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}}+\alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right]^{\frac{(\mu-\rho)}{\rho(1-\mu)}-1}\right.$$

$$\left.\left(\left(\frac{\alpha_2\rho}{\rho-1}\right)\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}-1}\left(\frac{1}{\alpha_2}\right)\right)\right)\cdot\left(\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{1}{\rho-1}}\right)$$

The expressions for the relevant first partials of $\hat{x}_2(w, t_1, t_2)$ are symmetric with respect to those given for $\hat{x}_1(w, t_1, t_2)$ above.

Expressions for selected second partials of $\hat{x}_1(w, t_1, t_2)$ are:

(6.16)

$$\frac{\partial^2 \hat{x}_1(w,t_1,t_2)}{\partial t_1 \partial t_1} = \left(\frac{\mu^{\frac{1}{1-\mu}}(\mu-\rho)}{\rho(1-\mu)}\right) \cdot \left(\left(\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}} + \alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}} + \alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right)^{\frac{(\mu-\rho)}{\rho(1-\mu)}-2}\right)$$

$$\left(\frac{(\mu-\rho)}{\rho(1-\mu)}-1\right)\left(\left(\frac{\alpha_1\rho}{\rho-1}\right)\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}-1}\left(\frac{1}{\alpha_1}\right)\right)\left(\left(\frac{\alpha_1\rho}{\rho-1}\right)\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{2}{\rho-1}}\left(\frac{1}{\alpha_1}\right)\right)$$

$$+\left(\frac{\mu^{\frac{1}{1-\mu}}(\mu-\rho)}{\rho(1-\mu)}\right) \cdot \left(\left(\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}} + \alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}} + \alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right)^{\frac{(\mu-\rho)}{\rho(1-\mu)}-1}\right)$$

$$\left(\left(\frac{2}{\rho-1}\right)\left(\frac{\rho}{\rho-1}\right)\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{2}{\rho-1}-1}\left(\frac{1}{\alpha_1}\right)\right)$$

$$+\mu^{\frac{1}{1-\mu}}\left(\frac{(\mu-\rho)}{\rho(1-\mu)}\right)\left(\left(\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}} + \alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}} + \alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right)^{\frac{(\mu-\rho)}{\rho(1-\mu)}-1}\right)$$

$$\left(\left(\frac{\alpha_1\rho}{\rho-1}\right)\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}-1}\left(\frac{1}{\alpha_1}\right)\right)$$

$$\left(\left(\frac{1}{\rho-1}\right)\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{1}{\rho-1}-1}\left(\frac{1}{\alpha_1}\right)\right)$$

$$+\mu^{\frac{1}{1-\mu}}\left(\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}} + \alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}} + \alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right)^{\frac{(\mu-\rho)}{\rho(1-\mu)}}$$

$$\left(\left(\frac{1}{\rho-1}\right)\left(\frac{1}{\rho-1}-1\right)\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}-2}\left(\frac{1}{\alpha_1^2}\right)\right)$$

(6.17)

$$\frac{\partial^2 \hat{x}_1(w,t_1,t_2)}{\partial t_2 \partial t_1} = \left(\frac{\mu^{\frac{1}{1-\mu}}(\mu-\rho)}{\rho(1-\mu)}\right)\cdot\left(\left(\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}}+\alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}}+\alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right)^{\frac{(\mu-\rho)}{\rho(1-\mu)}-2}\right)$$

$$\left(\frac{(\mu-\rho)}{\rho(1-\mu)}-1\right)\left(\left(\frac{\alpha_2\rho}{\rho-1}\right)\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}-1}\left(\frac{1}{\alpha_2}\right)\right)\cdot\left(\left(\frac{\alpha_1\rho}{\rho-1}\right)\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{2}{\rho-1}}\left(\frac{1}{\alpha_1}\right)\right)$$

$$+\left(\mu^{\frac{1}{1-\mu}}\right)\left(\frac{(\mu-\rho)}{\rho(1-\mu)}\right)\left(\left(\alpha_1\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{\rho}{\rho-1}}+\alpha_2\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}}+\alpha_3\left(\frac{w_3}{\alpha_3}\right)^{\frac{\rho}{\rho-1}}\right)^{\frac{(\mu-\rho)}{\rho(1-\mu)}-1}\right)$$

$$\left(\left(\frac{\alpha_2\rho}{\rho-1}\right)\left(\frac{w_2+t_2}{\alpha_2}\right)^{\frac{\rho}{\rho-1}-1}\left(\frac{1}{\alpha_2}\right)\right)$$

$$\left(\left(\frac{1}{\rho-1}\right)\left(\frac{w_1+t_1}{\alpha_1}\right)^{\frac{1}{\rho-1}-1}\left(\frac{1}{\alpha_1}\right)\right)$$

The expressions for the second partials of $\hat{x}_2(w, t_1, t_2)$ are symmetric with respect to those given for $\hat{x}_1(w, t_1, t_2)$ above.

3.6 Results

Three simulations were conducted for each of the eleven model cases and a "No Regulation" baseline case. The three simulations for each model case correspond to to three different productin technologies: independent production technology, technology that exhibits substitution and technology that exhibits complementarity. All simulations assume the following values for key model parameters: P = 1, w_i = 0.1, α_i = 0.333 and μ

= 0.5, where i = 1..3. The production technology parameter that reflects substitutability in production, ρ, varies across simulations. For production technology that exhibits substitution, ρ = 0.75, for complementarity, ρ = 0.25, and for independence, ρ = 0.50.

The equilibrium values of the regulators' policy instruments (emissions tax levels t_1 and t_2) are chosen as indicator variables for comparing simulation results. The equilibrium values of the regulators' policy instruments for each simulation, by production technology and model case, are presented in Table 4.1.

3.7 Discussion

The results presented in Table 4.1 have several policy implications. First, consider the results presented the second row (Case 1)of Table 4.1. The simulation results from Case 1 show that the degree of substitutability in the production technology influences the levels of the regulatory policy instruments even under symmetric, unified regulation of cross-media pollution. Compared with equilibrium tax levels under independent production technology, the unified regulator sets higher tax rates when the production technology exhibits substitution, and lower tax rates when the production technology exhibits complementarity. The unified regulator chooses to set different tax levels for different production technologies because marginal profit for the firm with respect to tax level and marginal environmental quality with respect to tax level, the two components of the unified regulator's objective function, differ across the three technologies. In particular, the cross-media components of the regulator's first order conditions have different signs depending on whether technology (and hence cross-media effects) exhibits substitution or complementarity.

Second, for production technology that exhibits zero cross-price effects (Independent production technology), neither the type of regulatory objective (divergent or convergent) nor the type of regulatory behavior (Nash or Stackelberg) under common agency (No Regulation Case and Cases 1-8) causes the regulatory outcome to differ from unified regulation outcome.

Third, comparing Case 1 and Case 3, divergent regulatory objectives and Nash regulatory behavior cause overregulation (tax levels in Case 3 higher than those in Case 1) under production technology exhibiting substitution and underregulation (tax levels in Case 3 lower than those in Case 1) under complementarity.

Fourth, Stackelberg regulatory behavior ameliorates overregulation for both regulators (compared to that under Nash behavior) in the case of production technology exhibiting substitution but ameliorates underregulation (compared to that under Nash behavior) for only the Stackelberg leader in the case of complementarity, exacerbating the underregulation of the Stackelberg follower under complementarity.

Fifth, congruence of regulatory objectives with social welfare results in the unified outcome for both Nash and Stackelberg regulatory behavior (Cases 4 and 5).

Sixth, the effects of moving from divergent regulatory objectives to mixed regulatory objectives depend on both the type of regulatory behavior (Nash or Stackelberg) and the type of production technology (Independent, Substitutability, or Complementarity). In the following paragraphs, these effects will be characterized in terms of differences in tax levels between Case 3 and the various cases of mixed regulatory objectives.

Moving from Case 3 to mixed regulatory objectives under Nash regulatory behavior (assuming Regulator 2 has the congruent regulatory objective, as in the description of model Case 6)[17] and independent production technology results in tax levels identical to those under unified regulation (Case 6, Column 1). Under substitutability (Case 6, Column 2), moving to mixed objectives results in a relatively small decrease in t_1 and a relatively large decrease in t_2. Both of these decreases are toward the unified outcome. Although both Q_1 and Q_2 decrease, profits increase, and overall welfare increases. Under complementarity (Case 6, Column 3), moving to mixed objectives results in a decrease in t_1 and an *increase* in t_2. Tax t_1 moves *away* from the level under unified regulation, and tax t_2 moves toward the level under unified regulation but *overshoots*. Nonetheless, overall welfare increases with the move to mixed objectives.

Moving from Case 3 to mixed regulatory objectives under Stackelberg regulatory behavior (Cases 7 and 8), the case in which the Stackelberg leader's (Regulator 1's) regulatory objective is made congruent with social welfare (Case 7) is distinguished from the case in which the Stackelberg follower's (Regulator 2's) regulatory objective is made congruent with social welfare (Case 8).

In Case 7, production technology exhibiting independence (Column 1) leads to the unified regulatory outcome. Substitutability in production technology (Column 2) leads to a large decrease in t_1 and a small decrease in t_2, relative to Case 3, both of which are changes toward the unified regulatory outcome. Hence, Q_1 decreases, Q_2 decreases, profits increase and overall welfare increases. Under production technology exhibiting complementarity (Column 3), a large increase in t_1 *overshoots* the unified regulatory

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[17] The results are symmetric for the case in which Regulator 1's objective is made congruent with social

outcome, and a small decrease in t_2 moves *away* from the unified outcome. Thus, Q_1 increases, Q_2 decreases and overall welfare increases, relative to that under Case 3.

In Case 8, production technology exhibiting independence (Column 1) leads to the unified regulatory outcome. In contrast to Case 7, substitutability in production technology (Column 2) leads to a *small* decrease in t_1 and a *large* decrease in t_2, relative to Case 3, both of which are changes toward the unified regulatory outcome. As in Case 7, Q_1 decreases, Q_2 decreases, profits increase and overall welfare increases, but in Case 8 Q_1 will decrease relatively less and Q_2 will decrease relatively more, compared with Case 7. Hence, comparing Case 7 and Case 8, under substitution in production technology, the Stackelberg leader accepts significantly lower environmental quality in her medium in order to improve overall social welfare when she has the congruent regulatory objective but forces the Stackelberg follower to accept relatively lower environmental quality when the follower's objective is congruent with social welfare. Under production technology exhibiting complementarity (Column 3), a small decrease in t_1 moves *away* from the unified regulatory outcome, and a large increase in t_2 *overshoots* the unified outcome. Thus, Q_1 decreases, Q_2 increases and overall welfare increases, relative to that under Case 3. Hence, comparing Case 7 and Case 8, under complementarity in production technology, the Stackelberg leader gains significantly higher environmental quality in her medium (and forces the Stackelberg follower to accept a small decrease in environmental quality in her medium) while securing an improvement in overall social welfare when she has the congruent regulatory objective, but the Stackelberg leader accepts a small decrease in environmental quality in her medium (and allows the Stackelberg follower a

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welfare.

relatively large increase in environmental quality in her medium) in order to gain an improvement in overall social welfare when the follower's objective is congruent.

Cases 9 and 10 investigate the implications of consolidating control of policy instruments under one regulator (i.e., removing common agency) under divergent regulatory objectives. In these cases, Regulator 1 is arbitrarily chosen as the regulator who controls both policy instruments. In Case 9, Regulator 1 must maintain the *objective function* of the other regulator at a constant level, in this case the level that obtained under Nash regulation (Case 3). In Case 10, Regulator 1 must maintain *environmental quality* in the other regulator's environmental medium at a constant level, in this case the level that obtains under Nash regulation (Case 3).

In Case 9, under independent production technology, Regulator 1 decreases both t_1 and t_2 (relative to Case 3 levels), but decreases t_2 relatively more. As a result, Q_1 decreases and Q_2 decreases relatively more, but profits increase such that Regulator 2's objective is maintained at the level that obtains under Case 3. Regulator 1's objective is increased by a relatively large amount, but overall welfare *decreases*. Case 9 is the only case under independent production technology in which welfare falls below that obtained under unified regulation. Under production technology exhibiting substitution, the changes in tax levels are qualitatively similar to but quantitatively smaller than those which occur under independent technology, i.e., substitution "ameliorates" Case 9 results. Under production technology exhibiting complementarity, the changes in tax levels are qualitatively similar to but quantitatively larger than those which occur under independent technology, i.e., complementarity "exacerbates" Case 9 results.

In Case 10, under independent production technology, the regulatory equilibrium is that same as that under unified regulation. Comparing this result with the result under independent production technology in Case 9, it is apparent that the specification of regulatory constraint, regulatory objective vs. environmental quality, is important when consolidating policy instruments under divergent objectives and independent production technology. Under production technology exhibiting substitution, Regulator 1 decreases t_1 by a relatively large amount and decreases t_2 by a relatively small amount. Both changes are toward the unified outcome and neither results in overshooting, thus overall welfare increases. Under production technology exhibiting complementarity, Regulator 1 increases t_1 by a relatively large amount, a change toward the unified outcome which *overshoots* the unified outcome, and decreases t_2 by a relatively small amount, a change *away* from the unified outcome. The net result is an increase in overall social welfare under complementarity.

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Table 3.1

Emissions Tax Pairs (t_1, t_2) By Production Technology and Model Case

	Production Technology		
Model Case	**Independent**	**Substitutes**	**Complements**
No Regulation	0.0, 0.0	0.0, 0.0	0.0, 0.0
Case1-Unified Regulation	0.1236, 0.1236	0.1340, 0.1340	0.185, 0.185
Case2-Stackelberg Divergent Objectives	0.1236, 0.1236	0.1364, 0.137017	0.1058, 0.1046
Case3-Nash Divergent Objectives	0.1236, 0.1236	0.1370, 0.137031	0.1047, 0.1047
Case4-Nash Congruent Objectives	0.1236, 0.1236	0.1340, 0.1340	0.185, 0.185
Case5-Stackelberg Congruent Objectives	0.1236, 0.1236	0.1340, 0.1340	0.185, 0.185
Case6-Nash Mixed Objectives	0.1236, 0.1236	0.13697, 0.1343	0.1039, 0.1217
Case7-Stackelberg Mixed Objectives Full R1	0.1236, 0.1236	0.1343, 0.13697	0.1215, 0.1039
Case8-Stackelberg Mixed Objectives Full R2	0.1236, 0.1236	0.1363, 0.1342	0.1037, 0.1217
Case9-Consolidated Instruments (R2 constant)	0.0689, 0.0466	0.08505, 0.07058	0.0630, 0.0403
Case10-Consolidated Instruments (Q2 constant)	0.1236, 0.1236	0.1342, 0.1369	0.1196, 0.1028

Chapter 4

Cross-Media Pollution: A Case Study of Groundwater Remediation In the San Francisco Bay Region

4.1 Introduction

Pollution remediation activities are designed to reduce pollution and associated health and environmental risks. However, some pollution remediation activities may simply transfer pollution and risks to other environmental media, or these activities may even generate new pollution and health risks. Chapter 4 is an empirical case study of the efficiency of groundwater pollution remediation activities at Superfund sites in the San Francisco Bay area of California. In this region, cleaning toxic solvents from groundwater results in increased air pollution, surface wastewater discharges, and increased traffic accident risk associated with site maintenance. The substitution exhibited between groundwater pollution and air pollution is an example of cross-media pollution. Because the two forms of pollution fall under the jurisdictions of different regulators, the situation is also one of common agency. When the cross-media pollution emissions and health risks caused by remediation activities are taken into account, simulation results indicate that groundwater pollution remediation may be carried out at an inefficiently high level in this region.

4.2 Background

4.2.1 Superfund Remediation In the San Francisco Bay Area

There are many hazardous waste remediation sites regulated under the federal Superfund program in the Bay Area (SFRWQCB 1997). The San Francisco Regional Water Quality Control Board (SFRWQCB), under an agreement with the US Environmental Protection Agency, currently administers the federal Superfund program in the region. In addition to the federal Superfund program, the state of California runs its own, separate California Superfund program to address sites not covered under the federal program. The SFRWQCB also oversees the sites regulated under the California Superfund program in the Bay Area. Typical remediation activities carried out at Bay Area Superfund sites include the treatment and removal of contaminated soil and the extraction and treatment of contaminated groundwater. Soil and groundwater remediation entails the installation and operation of groundwater monitoring wells, groundwater extraction wells and groundwater treatment system equipment. A more detailed description of Superfund soil and groundwater remediation activities in the region can be found in SFRWQCB (1993).

To develop a better understanding of the issues involved in groundwater remediation at Superfund sites in the region, a representative site located in Cupertino, CA, is chosen for an in depth analysis.

The following analysis refers to the representative site.

4.2.2 Groundwater Pollution Remediation at a Representative Superfund Site

Past production activities at the representative site resulted in soil and groundwater contamination consisting of hazardous organic chemicals. Under federal, state and local hazardous waste laws, the question arises as to whether the site should undergo remedial clean-up and if so, to what extent. In principle, given that contamination has occurred, remediation should be pursued if the total benefits of clean-up exceed the total costs. If total benefits exceed total costs, the efficient level of clean-up activity occurs where the marginal benefits of remediation activity equal the marginal costs.

Without remediation, contamination at the representative site has the potential to impose costs on society through two primary routes: (1) adverse human health effects and (2) increased drinking water treatment costs and/or alternative water supply costs. Pollution remediation activities can reduce the costs to society associated with contamination at the representative site. Reductions in the social costs of contamination below baseline levels constitute the social benefits of remediation. However, as the discussion below will show, the social costs of contamination (social benefits of remediation) are likely quite low for the representative site.

At the time contamination was discovered at the representative site, the health risk associated with soil pollution was minimal because the polluted soil was located under pavement, and therefore exposure through direct contact (e.g.'s: walking on or playing in the contaminated soil) was unlikely. In addition, containment under pavement prevented runoff of soil pollutants with surface water and prevented volatile soil pollutants from reaching the atmosphere and causing exposure through inhalation. The potential for soil contamination to affect drinking water located in deep groundwater aquifers (described more fully below) is not considered because soil contamination occurs at relatively shallow depths at the representative site, and because, in any event, the intervening shallow groundwater is already contaminated, as discussed below.

At the time contamination was discovered at the representative site, the health risk associated with shallow groundwater pollution was minimal because the pollution was confined to relatively shallow (100-200 ft. below ground level, "bgl") aquifers (aquifers A and B), which were not used as water sources. Furthermore, there were no plans to use these shallow groundwater aquifers as water sources at a later date.

In addition to the contaminated, shallow groundwater aquifers, there is also a much deeper (300-500 ft. bgl), uncontaminated groundwater aquifer (aquifer C) located beneath the representative site. This deep aquifer is used as a water source by local municipalities. The migration of pollutants from the shallow water aquifers to the deeper aquifer is slowed by a thick layer of relatively impermeable material.

In the event that pollutants were to somehow reach the deep aquifer, it is possible that human exposure could result. However, local water supply agencies monitor the quality of the water drawn from the deep aquifer, and monitoring would likely detect any contamination immediately. If contamination were detected in a water supply well, the policy of the water supply agencies is to shut-down the well immediately, install treatment equipment at the municipal well site, and resume pumping only after treatment achieves drinking water standards. Hence, even if contamination of the deep aquifer were to occur, it is unlikely that this event would result in human exposure to the contaminants.

Rather, deep aquifer contamination would simply force the installation of treatment equipment at the municipal well site. Since it might take many years for the contaminant plume to reach the deep water aquifer in the absence of remediation activity, the present value of future municipal well treatment might be small relative to current cost of remediation at the contaminated site.

In contrast to the relatively low potential benefits of groundwater remediation described above, the financial costs of remediation are relatively high (discussed in much greater detail below). In addition to the financial costs associated with groundwater remediation, cross-media environmental and human health costs are also generated by remediation activities.

Cross-media effects may be partitioned into direct cross-effects and indirect cross-effects. Direct cross-effects result immediately from remediation activity itself. For example, the use of air-stripping equipment to remove hazardous organic solvents from groundwater releases the contaminants into the air, where they may pose similar, or even greater, risks to health through inhalation pathways. Another example of a direct cross-effect associated with remediation activity is the increased air pollution and traffic accident risk associated with the increased automobile and truck driving (relative to society's next-best-alternative activity) necessary to monitor and maintain remediation equipment.

Indirect cross-effects arise from the economic linkages that exist between remediation activity and the rest of the economy. Remediation activity requires the purchase of economic goods and services, and the production of these goods and services produces pollution. Shifts in economic activity toward remediation and away from society's next-best-activity may lead to larger indirect pollution emissions and larger health risks. For example, remediation activities may be relatively electricity-intensive, resulting in an increase in air pollution emissions associated with electricity production over the level of emissions associated with society's next-best activity.

If pollution emissions caused by remediation activities are released into multiple media, and each medium is regulated by a different environmental regulator, then a common agency problem might arise. As shown in Chapter 3, common agency has the potential to exacerbate or ameliorate cross-media effects, depending on whether emissions are substitutes or complements. Common agency problems might also arise if remediation activities result in the release of different pollutants (different from those being remediated) into the same medium, but the different pollutants are regulated by different regulators. Because groundwater pollution and air pollution are regulated by different agencies in the San Francisco Bay region (groundwater pollution is regulated by the San Francisco Regional Water Quality Control Board in cooperation with the U.S. Environmental Protection Agency, and air pollution is regulated by the California Regional Air Quality Management District, also in cooperation with USEPA), the potential exists for common agency problems to arise.

A simulation model will be used to compare the environmental benefits of groundwater pollution remediation with the economic and cross-media environmental costs of remediation for Superfund sites in the San Francisco Bay region. It is assumed that groundwater pollution remediation in the region is similar in character to that of the representative site, and it is assumed that the region consists of approximately 20 representative sites (Levine-Fricke-Recon 1997).

Three scenarios will be considered, representing alternative levels of regional groundwater pollution remediation activity. The alternative levels of remediation activity are assumed to be exogenously-fixed, "command and control" pollution technology standards. The first scenario is the base case, denoted "Existing Situation." The Existing Situation is one of relatively stringent regulation. The second scenario, denoted "Source Control Only," represents a reduction in groundwater pollution remediation activity by approximately one-half. The Existing Situation and Source Control Only scenarios are defined in terms of the number of groundwater monitoring wells, the number of groundwater extraction wells, and the capacity of a single groundwater treatment facility operated at each of the twenty sites. It is assumed that all wells and the treatment facility are operated continuously under each scenario. The third scenario is denoted "No Site Remediation." The third scenario investigates the impacts of stopping all remediation and source control activities at all Superfund sites.

4.3 Model

4.3.1 A Multiregional Input-Output Framework

A static multiregional input-output (MRIO) model of the economy (Miller and Blair 1985), calibrated to recent data on economic activity and pollution emissions, is used to capture the indirect cross-effects of remediation projects in the San Francisco Bay region of California. The MRIO model is based on the IMPLAN (MIG 1997) commercial computer software model with associated Social Accounting Matrix, or SAM.

Two regions are represented in the MRIO model, the state of California and the "rest of the world." The rest of the world is divided into "domestic" (also denoted the "Rest of the U.S." or "ROUS") and "foreign."

All economic activity in each region is grouped into 41 aggregate "industries" within the model (Table 1). To simplify the analysis, it is assumed that the Electrical Equipment and Computers industry is the only industry engaged in pollution remediation within the California region. This industry accounts for most of the Superfund soil and groundwater remediation sites in the San Francisco Bay Area.

Direct cross-effects of remediation arise in California only, while indirect cross-effects can arise in both California and the rest of the world. This study limits consideration of indirect cross-effects to those originating in California. To the extent that this limitation biases model results, the bias would be conservative in that the model would tend to under-predict indirect cross-effects.

The major assumptions of a MRIO model are:

Constant Returns to Scale: The production function of each economic activity in each region is linear; i.e., output is directly proportional to inputs used in production.

No Supply Constraints: Raw materials are available in unlimited quantities at fixed prices. If the supply of a given material within a region is insufficient to meet demand, the material is imported from another region in the model or from the Rest of the World (ROW).

Fixed Commodity Input Structure: Changes in economic activity affect the level of industry output but do not affect input mix or proportions.

Homogeneous Sector Output: Changes in economic activity do not affect the mix of commodities produced by each industry.

Industry-Based Technology: Each industry uses only one technology to produce all its products; i.e, the output of a given industry consists of a primary commodity and byproduct commodities of the primary commodity (Industry-Based Technology contrasts with Commodity-Based Technology, in which each commodity is produced using only one technology, regardless of which industries produce the commodity).

Regional Purchase Coefficients (RPC's): An RPC is the proportion of regional input demand for a given commodity that is supplied by producers located within the region. It is assumed that all industries within a region have the same RPC for each input commodity.

In order to use the MRIO model to capture the indirect cross-effects of remediation activity, data on Superfund remediation costs for the region must be reconciled with the database supporting the input-output model. The following discussion describes how pollution remediation costs are captured in existing input-output databases and models, examines two potential problems with the existing framework, and presents a way to adjust existing databases and models to better reflect pollution remediation activities.

Broadly speaking, remediation projects involve two types of activities: initial, capital-intensive, installation activities, usually completed within a year; and ongoing operation and maintenance activities that may be continued for many years. The surveys conducted by the government to collect the input-output data used by the IMPLAN model draw a distinction between remediation expenditures for capital goods and remediation expenditures for "consumable goods" (i.e., annual operations and maintenance (O&M) expenditures) (BEA 1997). Remediation expenditures for capital goods are recorded as elements of final demand, whereas remediation expenditures for consumable goods are recorded as "costs of production" (Marc Planting, BEA, 6-17-1997).

The IMPLAN model and constituent databases inherit the government data-collection framework. In IMPLAN, remediation expenditures for capital goods are captured in the Gross Private Capital Formation (GPCF) component vector of final demand (identified as column type code 14001 in the IMPLAN SAM), and remediation expenditures for consumable goods are reflected in the elements of the column of the direct requirements matrix corresponding to the industry financing the remediation activity.

4.3.2 Correcting the MRIO Model for Remediation Activities

There are two potential problems with the way in which the aforementioned modeling framework handles pollution remediation activities. First, the existing framework implicitly assumes that remediation expenditures for capital goods are equal to the expenditures recorded in the final demand component of the regional database used to estimate the MRIO model. However, remediation expenditures for capital goods in the region may differ from industry-average or typical expenditures reflected in the base year data. For example, the regional database used to estimate the MRIO model used in the present analysis corresponds to 1994, a year which succeeded the majority of San Francisco Bay region expenditures for remediation capital (1987-1990 were the peak years for such expenditures (Levine-Fricke-Recon 1997)). To address this problem, any changes made to final demand to reflect remediation expenditures for capital goods within the region should be adjusted to reflect the remediation expenditures for capital goods made in the base year, which are already included in final demand. In the present analysis, it is assumed that all of the remediation expenditures made for capital goods in California occurred before 1994 and that, therefore, none of these expenditures are reflected in the 1994 regional database.

The second potential problem with the way in which the existing framework handles pollution remediation activities involves remediation expenditures for consumable goods. Because remediation expenditures for consumable goods are recorded in the NIPA as consumable costs associated with the production of industry output, these expenditures are components of the transactions table, and therefore also of the direct-requirements matrix, of the MIRO model. This implies that pollution remediation expenditures are directly proportional to industry output. Although this may be a good assumption for pollution *abatement* expenditures, which are likely to be relatively proportional to industry output, it seems not to be a good assumption for pollution *remediation* expenditures, which are made in anticipation of cleaning up a preexisting stock of pollution, and are therefore de-coupled from industry output. To address this problem, remediation expenditures for consumable goods should be removed from the transactions table and reallocated to final demand. Each industry engaged in remediation activity contributes a new vector of "pollution abatement consumables expenditures" to be added to existing final demands. (This remedy assumes that no other remediation activities are underway within the region. However, the method is readily generalized to multiple types of remediation activities.) The distinction made here between pollution abatement expenditures and pollution remediation expenditures within input-output models appears to be new to the environmental input-output literature (cf., Leontief 1970, Flick 1974, Steenge 1978, Lee 1982, Rhee and Miranowski 1984).

In this analysis, remediation expenditures for consumable goods will first be removed completely from the model. These expenditures will later be added back to final demand during the specification of each remediation scenario. Before describing how this is done, it should be mentioned that remediation expenditures for consumable goods suffer from a similar problem of potential over- or undercounting, based on differences between actual regional expenditures and expenditures recorded in base year databases, as do remediation expenditures for capital goods. Appropriate allowances should be made for differences between actual consumables expenditures and base year database expenditures. Note that the base year data for consumables expenditures comes from the NIPA database, which in most cases is a different base year from the capital expenditures base year. For example, the NIPA database used in the present analysis is for the year 1987. In the present analysis, it is assumed that 40 representative remediation sites were in operation throughout the state of California in 1987, and that these sites purchased consumable goods for remediation in the same deflated-dollar amounts as did the representative site in 1997.

Returning to the problem of removing remediation expenditures for consumable goods from the model, this is accomplished by removing the expenditures from the Gross (including imports to the California region) Regional Absorption Matrix (GRAM)of the IMPLAN model. The GRAM gives the proportion of each input commodity used to produce a dollar of each industry output within the region; the columns of this matrix are the "regional production functions" within the IMPLAN model. IMPLAN has a built-in feature that allows easy, direct editing of the GRAM. A difficulty arises in that the elements of the GRAM matrix are denominated as *proportions* of industry expenditures on inputs used for all purposes (production, abatement, and remediation), whereas the data on remediation expenditures for consumables are denominated in *dollars*. The Regional Use Matrix gives the dollar amount of each input (excluding inputs imported into the region) used to produce industry output within the region. The following relationships between the Regional Use Matrix and the Gross Regional Absorption Matrix allow one to translate dollar-demominated remediation cost data into changes in the Gross Regional Absorption Matrix:

$$GRAM^{new}_{ij} = USE^{new}_{ij} / (RTIO_j{*}RPC_i),$$

$$\text{where } USE^{new}_{ij} = USE^{orig}_{ij} - USE^{rem}_{ij},$$

$$\text{where } USE^{orig}_{ij} \equiv USE^{prod}_{ij} + USE^{abate}_{ij} + USE^{rem}_{ij},$$

for all row commodities i and column industries j, where $GRAM^{new}_{ij}$ denotes the value of the i^{th}, j^{th} element of the Gross Regional Absorption Matrix after adjustment for the removal of remediation expenditures for consumables, $RTIO_j$ denotes regional output of industry j, RPC_i denotes the regional purchase coefficient for commodity i, USE^{new}_{ij} denotes the new value of Regional Use Matrix element i,j after remediation expenditures for consumables have been removed, USE^{orig}_{ij} denotes the original value of the Regional Use Matrix element, and USE^{prod}_{ij} , USE^{abate}_{ij} and USE^{rem}_{ij}, represent the components of the partition of USE^{orig}_{ij} into dollars used for production, pollution abatement (included for completeness only), and pollution remediation, respectively.

When remediation expenditures for consumable goods are removed from the model, the reduction in expenditures represents a cost savings to the industry that had been engaged in remediation. It is assumed that this cost savings is passed on to industry shareholders through an increase in dividend payments, a component of Other Property-Type Income (OPTI), which itself is a component of value-added payments made by the industry. It is possible to edit OPTI for each industry directly within IMPLAN. OPTI should be increased by an amount equal to the sum of the differences between the $GRAM^{new}$ and $GRAM^{old}$ elements, multiplied by $RTIO_j$.

At this point the MRIO model is reestimated, and the resulting balanced model is now free of remediation activity.

4.3.3 Remediation Activities in the Corrected MRIO Model

Given the corrected, remediation-free, MRIO model developed above, how are increases remediation activity simulated? First, although Superfund remediation activities can be financed by the government using the Superfund itself, here it is assumed that a private firm occupying the contaminated site will finance the remediation activities. This is the case for the representative site and for many of the sites in the San Francisco Bay region. Second, it is assumed that firms finance remediation activities by transferring funds from stockholder dividend payments to remediation expenditures. The method used to implement this transfer within the corrected MRIO model is outlined below.[1]

A decrease in dividend payments to stockholders is traced through the model in the following way. Within the IMPLAN model, the Electrical Equipment and Computers industry, for example, makes factor payments to Other Property Type Income, a component of which is Corporate Profits, a subcomponent of which is (after tax) Dividend Payments of low, medium and high-income households (Tables 2 and 3). It is assumed that the fraction of Dividend Payments made to households within California is

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[1] The reduction in dividend payments to stockholders is a direct reduction in the household component of final demand, and the increase in remediation expenditures is a direct increase in the capital purchases component of final demand. Because remediation is financed by a transfer between factors of production, no change in total factor payments made by the remediating industry occurs (other than that implied by the net change in final demand), hence no adjustments to OPTI (analogous to the adjustments necessary to remove remediation expenditures from the GRAM matrix, as described above) are necessary.

approximately equal to California's share of the U.S. population, or 12%. Hence, a one dollar reduction in Dividend Payments made by California firms results in only a 12 cents reduction in dividend payments to California households. Households spend dividend payments as shown in Tables 4, 5 and 6. A one dollar decrease in Dividend Payments to California households results in a reduction in the household expenditures component of regional final demand as shown in Table 7. Hence, a one dollar reduction in Dividend Payments made by California firms to all stockholders results in a 12 cents reduction in Dividend Payments to *California* stockholders, which results in a reduction in the household expenditures component of California final demand equal to 12 cents times the values in Table 7.

The decrease in Dividend Payments is used to finance the firm's remediation activities. As outlined in the previous section, all pollution remediation expenditures (as opposed to abatement expenditures) are considered Capital Purchases (termed Gross Private Capital Formation in IMPLAN) elements of final demand. Both remediation expenditures for capital goods *and remediation expenditures for consumable goods* are treated as direct Capital Purchases made by the firm after the firm has paid corporate profits taxes (hence, remediation purchases are included in the Capital Purchases row of Table 3). For example, annual remediation purchases for the representative site are given in Table 10, broken-down by installation purchases (remediation expenditures for capital goods) versus operations and maintenance (O&M) purchases (remediation expenditures for consumable goods). Only a portion of the goods and services purchased for remediation are produced within California. Hence, the remediation expenditures in

Table 10 are reduced using the regional purchase coefficients listed in Table 11 to reflect changes in California purchases. The values in Table 10 are purchasers' prices. These prices must be converted to producers' prices by removing transportation and wholesale cost components in order to be consistent with the IMPLAN modeling framework, which assumes that expenditures are denominated in producers' prices. Transportation margins and wholesale margins are presented in Table 11. Transportation expenditures are allocated to the Road Transport and Rail, Air & Water Transport components of final demand. Wholesale services expenditures are allocated to the Producer Services component of final demand. The remaining Capital Purchases are distributed across industries within the Gross Private Capital Formation component of final demand as shown in Table 12.

The net change in regional final demand due to a dollar increase in remediation purchases is the sum of the decrease in the household expenditure component of final demand and the increase in the Gross Private Capital Formation component of final demand. The net change in regional final demand per dollar of remediation activity for remediation at the representative site is shown in Table 13 for several different scenarios (described below).

4.3.4 Scenario Specification

There are three scenarios "No Site Remediation" (the baseline), "Existing Situation," and "Source Control Only." In general, the No Site Remediation scenario reflects zero remediation activity, the Existing Situation scenario reflects a high level of remediation activity, and the Source Control Only scenario reflects a moderate amount of remediation activity. In each scenario, it is assumed that a total of 20 groundwater remediation sites, each identical to the representative site, are engaged in groundwater remediation in the San Francisco Bay area. The scenarios differ by the number of monitoring and extraction wells operated, and by the size of the groundwater treatment system operated, *per site.*

The representative site is an electronics manufacturing facility with existing soil and groundwater contamination in the San Francisco Bay area. It is assumed that the representative site is listed on the Superfund National Priorities List (NPL), and that the site is undergoing Superfund groundwater remediation activity typical of such activity in the region. It is assumed that no additional contamination is occurring at the site and that no additional contamination will occur at the site in the future.

Remediation expenditure data for capital goods and consumable goods used to install and operate monitoring wells, extraction wells and groundwater treatment systems are presented in Tables 8 and 9 (Levine-Fricke-Recon 1997). The designations "A Zone," "B Zone" and "C Zone" refer to the groundwater aquifer targeted by the well. Table 10 aggregates these data into per site costs according to the scenario descriptions below. *Note: the "Existing Situation Scenario" is not the baseline; the "No Site Remediation Scenario" is considered the baseline.*

Existing Situation Scenario

The Existing Situation scenario is characterized by 53 A-zone monitoring wells, 41 B-zone monitoring wells, 8 C-zone monitoring wells, 11 A-zone extraction wells, 7 B-zone extraction wells, and a 150 gallons per minute (gpm) groundwater treatment facility *per representative remediation site.*

Under these conditions, additional, albeit marginal, contamination would be removed from the site, and the groundwater contaminant plume would be prevented from reaching the deep (C-zone) municipal water supply aquifer.

Two types of remediation years are considered under the existing situation scenario, an "installation year," in which both installation (capital) and operation and maintenance, or "O&M," (consumables) remediation expenditures are made, and an "operation and maintenance-only year," in which only O&M expenditures are made.

Source Control Only Scenario

The Source Control Only scenario is characterized by 25 A-zone monitoring wells, 20 B-zone monitoring wells, 8 C-zone monitoring wells, 2 A-zone extraction wells, 2 B-zone extraction wells, and a 75 gallons per minute (gpm) groundwater treatment facility *per representative remediation site.*

Under these conditions, little additional contamination would be removed from the site, but the groundwater contaminant plume would be prevented from reaching the deep (C-zone), municipal water supply aquifer.

As with the Existing Situation scenario, both "installation years" and "operation and maintenance-only years" are considered under the Source Control Only scenario.

No Site Remediation Scenario

This is the baseline scenario. Under the No Site Remediation scenario, it is assumed that no remediation activities are undertaken at the sites, or, alternatively, that all monitoring and extraction wells at the sites are shut down and that the treatment system is turned off.

Under these conditions, no additional contaminants are removed from the site, and the contaminant plume under the site would likely (eventually) reach the regional drinking water aquifer and contaminate the groundwater drawn by one municipal drinking water well (Levine-Fricke-Recon 1997).[2] However, because there is considerable hydrogeological uncertainty concerning how long (probably very long) it would take the contaminant plume to reach municipal water supply intake wells (Levine-Fricke-Recon 1997), in the present analysis it is simply assumed that contamination of municipal water supply wells does not take place under the No Site Remediation Scenario. Hence, the immediate consequence of no remediation is that groundwater contamination remains on the site rather than being removed and treated.

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[2] The municipal water authority's most likely (least cost and legally feasible) response to this event would be to install a treatment system at the municipal well head to treat the contaminated groundwater drawn by the well (Levine-Fricke-Recon 1997). It is estimated that installation of municipal well water treatment equipment would entail $300,000 in initial capital costs and $500,000 in annual operations and maintenance costs (Levine-Fricke-Recon 1997). The allocation of treatment system costs across intermediate inputs and factors for the site treatment systems provides a good estimate of the allocation of treatment costs for the municipal well treatment system (Levine-Fricke-Recon 1997).

4.4 Results

4.4.1 No Site Remediation Scenario Results

Under the "No Site Remediation" (baseline) scenario, remediation activities are discontinued. Economic output by industrial sector for the baseline scenario is presented in Table 1. Baseline direct and indirect cross-media pollution emissions due to remediation activities in the San Francisco Bay region are zero. Baseline pollution emissions unrelated to remediation activities are presented in Tables 17 to 22.

4.4.2 Existing Situation Scenario Results

Economic Impacts

Table 16 presents the net direct and indirect economic impacts of San Francisco Bay groundwater remediation activity on the California economy for the Existing Situation scenario. The impacts are "net" in the sense that they include the decreases in economic output associated with the decreased household spending under remediation that results from decreased dividend payments made to households by firms shifting profits from dividend payments to remediation expenditures. The data are presented in terms of deviations from baseline scenario industry outputs (cf. Table 1).

Direct Cross-Media Impacts

Three direct cross-media impacts are considered: air pollution from air stripping equipment that is part of the groundwater remediation treatment system, traffic risk associated with using motor vehicles to service the remediation site, and air pollution from motor vehicles used to service the remediation site.

The direct cross-media air pollution impacts due to groundwater treatment (air stripping) at the representative site are measured in pounds per day of volatile organic compounds (VOCs). Emissions monitoring data from the Bay Area Air Quality Management District air emissions permit for remediation activities at the representative site indicate that remediation activities produce 11.0 lbs./day of VOCs (BAAQMD 1996). The estimated upper bound excess lifetime cancer risk for inhalation of VOC emissions at the representative site is $2*10^{-4}$ (Levine-Fricke-Recon 1990, p. 50). Hence, the estimated excess lifetime cancer risk due to direct cross-media air pollution from air stripping activities at twenty such representative sites in the San Francisco Bay region would be on the order of $4*10^{-3}$.

The direct cross-media traffic risk impact due to groundwater treatment at the representative site is calculated by multiplying the increase in vehicle miles traveled due to remediation activities for each scenario by the average traffic accident risk factor for California. It is assumed that the next-best alternative employment for remediation drivers would involve a similar commute to work and zero job-related driving. The change in vehicle miles traveled is calculated by dividing the direct remediation expenditures made for Automobile and Leasing services (Table 10) by the cost of vehicle services per mile, $0.45 (Levine-Fricke-Recon 1997). The difference in per site direct expenditure for Automobile and Leasing services between the No Site Remediation scenario and the Existing Situation scenario is $31,207 for an installation year and $9496 for an operation and maintenance-only year, yielding estimates of 69,349 additional vehicle miles driven per site in an installation year due to remediation activities and

21,103 additional vehicle miles driven per site in an operation and maintenance-only year. The California statewide-average fatality rate (fatalities per vehicle mile) for 1995 is $1.21*10^{-8}$ (CALTRANS 1996). Hence, under the Existing Situation scenario, the estimated increase in traffic risk for twenty such representative sites located in the San Francisco Bay region would be on the order of $20*69{,}349*1.21*10^{-8} = 1.7*10^{-2}$ fatalities per year in an installation year and $20*21{,}103*1.21*10^{-8} = 5.1*10^{-3}$ fatalitites per year in an operation and maintenance only year.

Motor vehicle air pollution emissions are another significant source of direct cross-media pollution risk (CARB 1990, USEPA 1993). Two hydrocarbon substances, benzene and 1,3-butadiene, account for 83 percent of motor vehicle emissions-related health risk (CARB 1990). Motor vehicles contribute a relatively large share (92 percent) of total emissions (vs. stationary emissions sources) for these substances. Over a seventy-year lifetime, exposure to ambient concentrations of these two substances is estimated to cause an additional 9018 to 18934 cancer cases in the state of California. Average state-wide hydrocarbon emissions levels were 0.60 grams/mile in 1989. The California Air Resources Board's Post-1987 Motor Vehicle Plan is expected to reduce hydrocarbon emissions levels to 0.33 grams/mile by 2010, chiefly by requiring the sale of low-emissions vehicles. The increase in direct cross-media motor vehicle hydrocarbon emissions is calculated as follows. It is assumed that the hydrocarbon emissions rate is 0.5 grams/mile. As derived above for the estimates of traffic risk, it is estimated that 69,349 additional vehicle miles per site are driven in an installation year due to remediation activities and that 21,103 additional vehicle miles per site are driven in an operation and maintenance-only year. Hence, remediation activities under the Existing Situation scenario for twenty sites in the San Francisco Bay region directly cause additional motor vehicle emissions of 1,528 lbs./year (20 sites * 69,349 miles/year/site * 0.5 grams/mile * 1 lb./454 grams) in an installation year and 465 lbs./year (20 sites * 21,103 miles/year/site * 0.5 grams/mile * 1 lb./454 grams) in an operation and maintenance-only year. Developing an exposure model for these emissions is beyond the scope of this study. However, if these emissions were inhaled at statewide-average ambient concentrations over a seventy year lifetime, then the associated individual lifetime cancer risk for twenty such sites in the San Francisco Bay region would be $5.9*10^{-5}$ to $4.24*10^{-4}$ (CARB 1990, pp. 10, 22).

Indirect Cross-Media Impacts

The net change in regional final demand due to existing remediation activity by the Electrical Equipment and Computers sector located in the San Francisco Bay region is presented in Table 14. This net change vector is multiplied by the Leontief inverse matrix of the MRIO model (Table 15) to derive the direct and indirect impacts on annual California economic output by industrial sector (Table 16). Data on pollution emissions in California per dollar of economic output produced by California industries (Tables 17 to 22) are used to translate the changes in annual economic output into changes in annual pollution emissions due to existing remediation activity (Tables 23 to 31).

4.4.3 Source Control Only Scenario Results

Economic Impacts

Table 16 presents the net direct and indirect economic impacts of San Francisco Bay groundwater remediation activity on the California economy for Source Control Only scenario. The data are presented in terms of deviations from baseline scenario industry outputs (cf. Table 1). In general, the smaller number of monitoring and extraction wells and the smaller treatment system required under the Source Control Only scenario producers smaller economic impacts, as compared to the Exisiting Situation scenario.

Direct Cross-Media Impacts

The Source Control Only scenario results in the same types of direct cross-media impacts as does the Existing Situation scenario, but the impacts are smaller due the reduction in remediation activity under this scenario.

The direct cross-media air pollution impacts due to groundwater treatment (air stripping) at the representative site are less under the Source Control Only scenario, as compared to impacts under the Existing Situation scenario, because a smaller-capacity treatment system is used under the Source Control scenario. Assuming that the pollutant concentration in the untreated groundwater would be the same as it is under the Existing Situation scenario, using a 75 gallons per minute treatment system under the Source Control Only scenario would generate only half, 5.5 lbs./day, the level of emissions generated by the 150 gallons per minute treatment system used under the Existing Situation scenario. Assuming that this reduction in emissions would lead to a proportional reduction in the concentration of VOCs potentially inhaled by exposed persons, and considering that excess cancer risk is linear in pollutant concentration, the upper bound lifetime excess cancer risk from inhaling VOCs from air stripping activity in the San Francisco Bay region under the Source Control Only scenario is one-half the risk under the Existing Situation scenario, or $2*10^{-3}$.

The methodology for calculating the direct cross-media traffic risk impact due to groundwater treatment at the site under the Source Control Only scenario is analogous to that used under the Existing Situation scenario. The difference in per site direct expenditure for Automobile and Leasing services between the No Site Remediation scenario and the Source Control Only scenario is $16,450 for an installation year and $5,165 for an operation and maintenance-only year, yielding estimates of 36,556 additional vehicle miles driven per site in an installation year due to remediation activities and 11,477 additional vehicle miles driven per site in an operation and maintenance-only year. Hence, under the Source Control Only scenario, the estimated increase in traffic risk for twenty such representative sites located in the San Francisco Bay region would be on the order of $20*36{,}556*1.21*10^{-8} = 8.8*10^{-3}$ fatalities per year in an installation year and $20*11{,}477*1.21*10^{-8} = 2.8*10^{-3}$ fatalitites per year in an operation and maintenance only year.

The methodology for calculating the direct cross-media motor vehicle hydrocarbon emissions under the Source Control Only scenario is analogous to that used for the Existing Situation scenario. Hence, remediation activities under the Source Control Only scenario for twenty sites in the San Francisco Bay region directly cause additional motor vehicle emissions of 805 lbs./year (20 sites * 36,556 miles/year/site * 0.5 grams/mile * 1 lb./454 grams) in an installation year and 253 lbs./year (20 sites * 11,477 miles/year/site * 0.5 grams/mile * 1 lb./454 grams) in an operation and maintenance-only year. At low doses, cancer risk from inhalation is approximately linear in pollutant concentrations (CARB 1990). Assuming that a reduction in exposure concentration occurs that is proportional to the reduction in emissions between the Existing Situation and Source Control Only scenarios, then the individual lifetime cancer risk associated with motor vehicle emissions under the Source Control Only scenario would be $3.1*10^{-5}$ to $2.23*10^{-4}$.

Indirect Cross-Media Impacts

The net change in regional final demand due to existing remediation activity by the Electrical Equipment and Computers sector located in the San Francisco Bay region is presented in Table 14. This net change vector is multiplied by the Leontief inverse matrix of the MRIO model (Table 15) to derive the direct and indirect impacts on annual California economic output by industrial sector (Table 16). Data on pollution emissions in California per dollar of economic output produced by California industries (Tables 17 to 22) are used to translate the changes in annual economic output into changes in annual pollution emissions due to groundwater pollution remediation activity by scenario, type of year (installation year vs. operation and maintenance only year), and by industrial sector. (Tables 23 to 31). The results presented in Tables 23 to 31 represent one of the major products of this Chapter of the dissertation.

4.5 Discussion and Conclusions

The benefits of groundwater pollution remediation activites in the San Francisco Bay region are reviewed and compared with the cross-media costs of these activities. It is found that the direct health risks caused by remediation activity are of the same (or larger) order of magnitude as the reduction in health risk due to remediation activity. Furthermore, it is found that the annual pollution reduction achieved by remediation never exceeded the annual *indirect* cross-media pollution generated by the production of goods and services required as inputs to remediation activities.

4.5.1 Benefits of Remediation

The benefits of remediation activity are measured in terms of pounds of chemicals removed from the soil and groundwater and reductions in associated health risks. Under the Existing Situation scenario, the rate of removal of volatile organic compounds (VOCs) from groundwater at ther representative site fell from a peak of approximately 1.2 lbs./day (8760 lbs./year for the 20 sites in the San Francisco Bay region) in 1989 to approximately 0.25 lbs./day (1825 lbs./year for the region) by 1994, and the rate of removal has remained relatively stable since (Levine-Fricke-Recon 1990, 1995, 1997). Under the Source Control Only scenario, it is assumed that the smaller treatment system would remove contaminants at approximately one-half the rate given for the Existing Situation scenario and that it would take longer for the removal rate to decline to its asymptotic level.

Approximately 22690 lbs. of VOC's have been removed from the soil and groundwater at the representative site since inception of the remediation project. This figure corresponds to the Existing Situation scenario and is a cumulative total over all years of the project. For twenty representative sites in the San Francisco Bay area, the cumulative total under the Existing Situation scenario would be 453,800 lbs. of VOC's removed.

In terms of health risk, the only direct exposure pathway for individuals living, working or playing under pre-remediation conditions at the representative site would involve inhaling VOCs volatilized from facility soils. Under the Existing Situation scenario, this pathway would result in an estimated excess cancer risk ranging from $2*10^{-11}$ to $1*10^{-10}$ (Levine-Fricke-Recon 1990). Under the most conservative future use scenario, contaminated groundwater at the representative site would be ingested as drinking water. The estimated excess lifetime cancer risk associated with ingestion of contaminated groundwater from the representative site is $4*10^{-5}$ to $1*10^{-4}$. However, "[although] future-use scenarios would lead to higher risks; existing laws, regulations and policies would prevent these future exposure pathways from becoming complete. Thus, future risks to area residents are expected to remain extremely low" (Levine-Fricke-Recon 1990, p. 19). Nonetheless, the maximum (gross) benefits of remediation activity at the representative site under the Existing Situation scenario would be the elimination of the estimated excess lifetime cancer risk associated with ingestion of contaminated groundwater, or $4*10^{-5}$ to $1*10^{-4}$. These maximum benefits could be achieved under the Source Control Only scenario, but the smaller groundwater extraction rates possible under this scenario imply that it would take longer to achieve the benefits. Hence, the maximum (gross) benefits associated with remediation activities at twenty representative sites in the San Francisco Bay region would be the elimination of an estimated excess lifetime cancer risk associated with ingestion of contaminated groundwater on the order of $2*10^{-3}$ (or, $20 * 1*10^{-4}$).

4.5.2 Cross-Media Costs of Remediation

Direct Effects

The direct cross-media effects of groundwater remediation in the San Francisco Bay region include: air pollution from air stripping equipment that is part of the groundwater remediation treatment system, traffic risk associated with using motor vehicles to service the remediation site, and air pollution from motor vehicles used to service the remediation site. In general, direct cross-media effects are higher under the Existing Situation scenario than under the Source Control Only scenario due to the reduced level of remediation activity under the Source Control Only scenario.

Under the Existing Situation scenario, the estimated excess lifetime cancer risk due to direct cross-media air pollution from remediation (air stripping) activities in the San Francisco Bay region is on the order of $4*10^{-3}$. Under the Source Control Only scenario, this risk falls to approximately $2*10^{-3}$.

Under the Existing Situation scenario, the estimated direct cross-media traffic risk impact from increased motor vehicle traffic due to remediation activities in the region is on the order of $1.7*10^{-2}$ fatalities per year in an installation year and $5.1*10^{-3}$ fatalities per year in an operation and maintenance only year. Under the Source Control Only scenario, these risks fall to approximately $8.8*10^{-3}$ and $2.8*10^{-3}$.

Under the Existing Situation scenario, the estimated excess individual lifetime cancer risk associated with increased motor vehicle air pollution emissions caused by remediation activities in the region would be on the order of $5.9*10^{-5}$ to $4.24*10^{-4}$. Under the Source Control Only scenario, these risks would fall to approximately $3.1*10^{-5}$ to $2.23*10^{-4}$.

Indirect Effects

A major result of this Chapter is the estimation of the indirect cross-media effects of groundwater remediation activities. These effects are due to the economic linkages between remediation activities and production activities throughout the rest of the economy. Private firms finance remediation activities by shifting expenditures from dividend payments to remediation expenditures. This shift in expenditures may produce significant economic and cross-media pollution effects. Both economic and environmental effects may be partitioned into "income effects" and "substitution effects."

Shifting expenditures from dividend payments to remediation activities increases the overall level of output of the region engaged in remediation. This is the "economic income effect" of regional remediation activity. Regional expenditures increase for two principal reasons: (1) remediation expenditures increase, and remediation expenditures are concentrated in construction and service industries which have relatively large regional purchase coefficients, and (2) dividend payments decrease, and a high percentage of dividend payments go to households outside the region, and of those payments made to regional households, a large proportion of expenditures goes for goods produced outside the region (chiefly domestic imports). The general increase in regional output results in an increase in indirect pollution emissions. The increase in regional pollution emissions resulting from a general increase in regional output is the "environmental income effect" of remediation activity on pollution emissions.

Shifting expenditures from dividend payments to remediation activity changes the distribution of final demand across industries within the region. Final demands increase for the output of industries A, B and C, and decrease for industries X, Y and Z. This is the "economic substitution effect" of regional remediation activity. The resulting shift in the distribution of output across industries has implications for the overall level of pollution emissions within the region, as remediation activity requires increased output from relatively pollution-intensive industries. This is the "environmental substitution effect" of regional remediation activity. In addition to changes in the overall level of pollution emissions, there are also finer substitution effects within the distribution of pollutants emitted, as a given industry may emit particular pollutants relatively more intensively than other pollutants, compared with other industries.

Table 16 presents the net direct and indirect economic impacts of San Francisco Bay groundwater remediation activity on the California economy for each scenario. The data are presented in terms of changes from baseline scenario industry outputs (Table 1). As expected, the overall economic impacts are small, relative to the total output of the California economy. The industries experiencing the largest net increases in dollar output (changes greater than $5 million for an installation year under the existing situation scenario) due to an increased remediation spending are management & accounting, sanitary services (landfills), producer services, equipment rental and leasing, engineering services and legal services. Also as expected, increasing remediation leads to slight decreases in agricultural, food & tobacco, textiles, furniture, and leather products, as households reduce expenditures due to reductions in dividend payments received. Of these sectors, furniture is a relatively air pollution-intensive sector (Tables 17 to 22) and food & tobacco (which includes food processing) is a relatively water pollution-intensive sector (Tables 17 to 22).

The relatively large increase in output of the sanitary services industry results in relatively large increases in pollution emissions (Tables 23 to 31) because sanitary services is a very pollution-intensive sector (Tables 17 to 22).

However, relatively small increases in output of relatively pollution-intensive industries can also generate significant pollution emissions. Other pollution-intensive industries that show net gains in output with increased remediation include: construction, chemicals, petroleum refining, electrical equipment and computers, rail, air and water transport, natural gas, and electricity. For these pollution-intensive sectors, small net increases in output can result in large increases in pollution emissions (e.g.'s, the relatively small net increase in output for the natural gas sector translates into relatively large increases in organic and inorganic toxic air emissions (Table 27), and relatively small increases in electricity services output results in relatively large increases in wastewater discharges (Table 29)).

4.5.3 Comparing Pollution Eliminated by Remediation With Indirect Cross-Media Pollution Generated by Remediation

As a *conservative* comparison of the "pollution vs. pollution" cross-media tradeoff associated with groundwater remediation activity, the pollution removed and treated by groundwater remediation activities is compared with the indirect cross-media pollution generated throughout the economy due to remediation, *assuming that the direct cross-effects of groundwater remediation are zero* (i.e., assuming air stripper emissions are controlled, and assuming no remediation-associated increases in motor vehicle emissions or traffic accident risk).

Figure 4.1 illustrates how the tradeoff between groundwater pollution removed and treated and cross-media pollution generated changes over time as remediation progresses under the Existing Situation scenario. Pounds of pollution reduced/generated per year are measured on the vertical axis, and time in years is measured on the horizontal axis. In Figure 4.1, marginal and average pollution reduction associated with remediation activities over time (in terms of pounds per year of groundwater pollution removed and treated) are compared with marginal and average indirect cross-media pollution generation due to pollution remediation over time (in terms of pounds per year of indirect cross-media pollution generated by the economy due to remediation activities). The derivations of the marginal and average curves illustrated in Figure 4.1 are described below.

The marginal pollution reduction curve, MPR, is derived from groundwater contamination removal rate data for the representative remediation site, scaled up to represent remediation activity throughout the San Francisco Bay region. The rate of removal of volatile organic compounds (VOCs) from groundwater at the representative site fell from a peak of approximately 1.2 lbs./day (8760 lbs./year for the 20 sites in the

San Francisco Bay region) in 1989 to approximately 0.25 lbs./day (1825 lbs./year for the region) by 1994, and the rate of removal has remained relatively stable since (Levine-Fricke-Recon 1990, 1995, 1997). These pollution removal values are used to construct the stylized MPR curve in Figure 4.1. Since the marginal pollution reduction curve is monotonically decreasing, the average (over time) pollution reduction curve, APR, must lie above the MPR curve and also decline monotonically. A stylized APR curve with these properties is shown in Figure 4.1.

The marginal pollution generation curve, MPG, is derived from the indirect cross-media pollution emissions impact estimates presented in Tables 23 to 31. To make a direct comparison of similar pollutants, only indirect cross-media emissions of reactive organic gases (ROG) are considered from the many possible types of cross-media emissions (see Tables 23 and 24). VOC and ROG contain many of the same chemical substances. Hence, from the perspective of showing the significance of indirect cross-media pollution, the comparison illustrated in Figure 4.1 conservatively neglects indirect cross-media emissions of other criteria air pollutants, toxic air pollutants, and wastewater discharges. The MPG curve in Figure 4.1 represents indirect cross-media emissions generated by "Operations and Maintenance Year-Only" (Table 24) remediation activity. MPG is assumed constant (5512 lbs/yr) for every year of the remediation program.

Average (over time) pollution generation due to the remediation program must reflect "Installation Year" (Table 23) emissions as well as "Operations and Maintenance Only" emissions. In the initial, Installation Year of the remediation program, both emissions due to installation activities (42524 lbs/yr) and emissions due to operations and maintenance activities (5512 lbs/yr) are generated. Hence, the average pollution generation curve, APG, intersects the y-axis at 48036 lbs/yr at time zero. Because MPG is constant and less than APG in year zero, APG falls monotonically and asymptotically toward MPG over time.

Total (cumulative over time) pollution reduced at any point in time is the product of the value of the APR curve at that point in time and the number of years since initiation of remediation activities. Similarly, total (cumulative over time) pollution generated at any point in time is the product of the value of APG and the number of years since project initiation. Because the APG curve lies everywhere above the APR curve in Figure 4.1, it appears that at no time has the total pollution reduced by groundwater remediation activity in the San Francisco Bay region exceeded the total indirect cross-media pollution generated by that activity, at least under the Existing Situation scenario.

If reducing net pollution released into the environment is a goal of hazardous waste remediation efforts in the San Francisco Bay region, serious consideration should be given to either reducing groundwater remediation activities or refining remediation methodologies to reduce indirect cross-media pollution.

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Table 4.1

Baseline Sector Output

Aggregated Sector Name	Aggregated IMPLAN Sector #	Disaggregated IMPLAN Sectors Included In Aggregated Sector	Industry Sector Output (Million 1994$)
Agriculture	1	1 to 27	33318.46
Mining	28	28 to 37	822.27
Natural Gas	38	38, 39	6428.63
Sand, Gravel & Clay	40	40 to 47	785.04
Construction	48	48 to 57	91338.42
Food & Tobacco	58	58 to 107	43542.24
Textiles	108	108 to 132	13713.89
Wood Products	133	133 to 147	6629.04
Furniture	148	148 to 160	4808.58
Pulp & Paper	161	161 to 173	7554.49
Printing	174	174 to 185	18254.02
Chemicals, Paint & Adhesives	186	186 to 209	20117.69
Petroleum Refining and Products	210	210 to 214	24006.11
Rubber & Plastics	215	215 to 220	9863.55
Leather Products	221	221 to 229	440.40
Concrete, Brick, Glass & Ceramics	230	230 to 253	6269.24
Primary Metals Production	254	254 to 272	6519.82
Fabricated Metal Products	273	273 to 306	15881.58
Heavy Machinery	307	307 to 338, 345 to 354	15166.85
Electrical Equip. & Computers	339	339 to 344, 355 to 383	60447.67
Autos, Trucks, Aircraft, Missiles	384	384 to 399	35659.22
Precision Instruments	400	400 to 414	29612.58
Misc. Light Manufacturing	415	415 to 432	4617.60
Rail, Air & Water Transport.	433	433, 436, 437	19456.44
Road Transport.	434	434, 435, 510	21260.95
Pipe Lines, Except Natural Gas	438	438	789.49
Consumer Services	439	439, 440, 441, 442, 448 to 468, 478, 481 to 493, 495 to 505, 522	593397.56
Electricity	443	443, 511, 514	12310.26
Gas Production and Distribution	444	444	14056.48
Water Supply and Sewerage Systems	445	445	469.07
Sanitary Services and Steam Supply	446	446	3365.36
Producer Services	447	447, 469 to 472, 474 to 476, 480	144885.53
Equipment Rental and Leasing	473	473	4571.66
Automobile Rental and Leasing	477	477	3046.47
Automobile Repair and Services	479	479	9950.21
Legal Services	494	494	18281.68
Engineering, Architectural Service	506	506	12613.06
Management & Accounting	507	507, 508	27993.00
Research, Development & Testing Se	509	509	10327.50
State & Local Government	512	512, 523	44668.62
Federal Government	513	513, 515, 520, 521	21200.87
Noncomparable Imports	516	516	0.00
Scrap & Used Goods	517	517, 518	0.00
Federal Government - Defence	519	519	6404.04
Rest of the World Industry	524	524	0.00
Total			1424845.63

Table 4.2

Distribution of Other Property-Type Income (OPTI)

SAM Row	Row #	1994 Million$	Percent
Households - Low Inc.	10001	4010.545	0.01731
Households - Medium Inc.	10002	20515.58	0.08855
Households - High Inc.	10003	49051.82	0.211718
Fed. Govt. - Non-Defence	11001	-19858.83	-0.08571
State/Local Govt. - Non-Educ.	12001	14014.37	0.060489
Corporate Profits (Enterprises)	13001	64709.7	0.279301
Capital Purchases	14001	83776.47	0.361597
Trade - Foreign	25001	974.233	0.004205
Trade - Domestic	28001	14490.81	0.062545
Total		231684.698	1

Table 4.3

Distribution of Corporate Profits (Enterprises)

SAM Row	Row #	1994 Million$	Percent		Within Households Percent
Households - Low Inc.	10001	742.914	0.011481		0.030278479
Households - Medium Inc.	10002	4785.547	0.073954		0.195041531
Households - High Inc.	10003	19007.58	0.293736		0.77467999
Fed. Govt. - Non-Defence	11001	20091.17	0.310482	Total	0.379170955
State/Local Govt. - Non-Educ.	12001	8211.975	0.126905		
Capital Purchases	14001	11870.52	0.183443		
Total		64709.706	1		

Table 4.4

Distribution of Purchases Made By Households - Low Income

Sector	Sector #	1994 Million$	Percent
Agriculture	1	225.4258	0.00355
Mining	28	0.9437323	1.49E-05
Sand, Gravel & Clay	40	3.05E-03	4.8E-08
Food & Tobacco	58	3071.559	0.048367
Textiles	108	536.47	0.008448
Wood Products	133	5.944665	9.36E-05
Furniture	148	106.7687	0.001681
Pulp & Paper	161	0.7030733	1.11E-05
Printing	174	98.05264	0.001544
Chemicals, Paint & Adhesives	186	823.1423	0.012962
Petroleum Refining and Products	210	841.2632	0.013247
Rubber & Plastics	215	0.1549904	2.44E-06
Leather	221	32.47227	0.000511
Concrete, Brick, Glass & Ceramics	230	0.1573648	2.48E-06
Primary Metals Production	254	2.53E-02	3.98E-07
Fabricated Metal Products	273	1.090503	1.72E-05
Heavy Machinery	307	17.68238	0.000278
Electrical Equip. & Computers	339	392.2051	0.006176
Autos, Trucks, Aircraft, Missiles	384	5.069387	7.98E-05
Precision Instruments	400	100.9246	0.001589
Misc. Light Manufacturing	415	13.66024	0.000215
Rail, Air & Water Transport.	433	378.2277	0.005956
Road Transport.	434	329.3017	0.005185
Pipe Lines, Except Natural Gas	438	6.098107	9.6E-05
Consumer Services	439	30572.71	0.481422
Electricity	443	718.5779	0.011315
Gas Production and Distribution	444	464.5915	0.007316
Water Supply and Sewerage Systems	445	260.6527	0.004104
Sanitary Services and Steam Supply	446	61.53719	0.000969
Producer Services	447	1929.898	0.03039
Equipment Rental and Leasing	473	18.97086	0.000299
Automobile Rental and Leasing	477	82.69473	0.001302
Automobile Repair and Services	479	350.9905	0.005527
Legal Services	494	606.2505	0.009547
Management & Accounting	507	4.8444	7.63E-05
State & Local Government	512	279.4807	0.004401
Federal Government	513	201.6482	0.003175
Scrap & Used Goods	517	209.68	0.003302
Fed. Govt. - Non-Defence	11001	1295.605	0.020402
State/Local Govt. - Non-Educ.	12001	2669.515	0.042036
Capital	14001	4684.551	0.073767
Trade - Foreign	25001	963.1034	0.015166
Trade - Domestic	28001	11142.32	0.175456
Total		63504.96737	1

Table 4.5

Distribution of Purchases Made By Households - Medium Income

Sector	Sector #	1994 Million$	Percent
Agriculture	1	669.1258	0.002913
Mining	28	2.327878	1.01E-05
Sand, Gravel & Clay	40	1.03E-02	4.48E-08
Food & Tobacco	58	8891.646	0.03871
Textiles	108	2319.973	0.0101
Wood Products	133	31.17047	0.000136
Furniture	148	452.4614	0.00197
Pulp & Paper	161	2.21578	9.65E-06
Printing	174	387.9925	0.001689
Chemicals, Paint & Adhesives	186	2260.441	0.009841
Petroleum Refining and Products	210	3102.55	0.013507
Rubber & Plastics	215	0.7692398	3.35E-06
Leather	221	123.8408	0.000539
Concrete, Brick, Glass & Ceramics	230	0.6199687	2.7E-06
Primary Metals Production	254	0.1026081	4.47E-07
Fabricated Metal Products	273	5.354774	2.33E-05
Heavy Machinery	307	88.1117	0.000384
Electrical Equip. & Computers	339	1485.091	0.006465
Autos, Trucks, Aircraft, Missiles	384	38.17958	0.000166
Precision Instruments	400	385.2326	0.001677
Misc. Light Manufacturing	415	71.81438	0.000313
Rail, Air & Water Transport.	433	1274.935	0.005551
Road Transport.	434	1004.988	0.004375
Pipe Lines, Except Natural Gas	438	22.4731	9.78E-05
Consumer Services	439	97377.24	0.423939
Electricity	443	2026.442	0.008822
Gas Production and Distribution	444	1211.077	0.005273
Water Supply and Sewerage Systems	445	800.4197	0.003485
Sanitary Services and Steam Supply	446	186.5976	0.000812
Producer Services	447	7085.414	0.030847
Equipment Rental and Leasing	473	67.32424	0.000293
Automobile Rental and Leasing	477	308.8101	0.001344
Automobile Repair and Services	479	1310.718	0.005706
Legal Services	494	1511.539	0.006581
Management & Accounting	507	14.53675	6.33E-05
State & Local Government	512	997.5701	0.004343
Federal Government	513	600.0987	0.002613
Scrap & Used Goods	517	961.5619	0.004186
Fed. Govt. - Non-Defence	11001	19530.93	0.085029
State/Local Govt. - Non-Educ.	12001	8287.274	0.036079
Capital	14001	20319.59	0.088463
Trade - Foreign	25001	4772.622	0.020778
Trade - Domestic	28001	39704.98	0.172859
Total		229696.172	1

Table 4.6

Distribution of Purchases Made By Households - High Income

Sector	Sector #	1994 Million$	Percent
Agriculture	1	969.9796	0.002185
Mining	28	2.851148	6.42E-06
Sand, Gravel & Clay	40	1.61E-02	3.62E-08
Food & Tobacco	58	11981.9	0.026995
Textiles	108	4805.073	0.010826
Wood Products	133	73.01354	0.000164
Furniture	148	936.1261	0.002109
Pulp & Paper	161	4.265145	9.61E-06
Printing	174	693.5428	0.001563
Chemicals, Paint & Adhesives	186	3185.527	0.007177
Petroleum Refining and Products	210	4202.246	0.009468
Rubber & Plastics	215	1.196792	2.7E-06
Leather	221	206.4059	0.000465
Concrete, Brick, Glass & Ceramics	230	1.242224	2.8E-06
Primary Metals Production	254	0.1702948	3.84E-07
Fabricated Metal Products	273	10.78766	2.43E-05
Heavy Machinery	307	181.3265	0.000409
Electrical Equip. & Computers	339	2367.876	0.005335
Autos, Trucks, Aircraft, Missiles	384	41.46656	9.34E-05
Precision Instruments	400	719.0475	0.00162
Misc. Light Manufacturing	415	153.7054	0.000346
Rail, Air & Water Transport.	433	3281.119	0.007392
Road Transport.	434	1850.57	0.004169
Pipe Lines, Except Natural Gas	438	30.43429	6.86E-05
Consumer Services	439	179757.3	0.404991
Electricity	443	2676.222	0.006029
Gas Production and Distribution	444	1707.696	0.003847
Water Supply and Sewerage Systems	445	1234.167	0.002781
Sanitary Services and Steam Supply	446	284.6434	0.000641
Producer Services	447	11564.74	0.026055
Equipment Rental and Leasing	473	142.8859	0.000322
Automobile Rental and Leasing	477	732.474	0.00165
Automobile Repair and Services	479	3108.925	0.007004
Legal Services	494	3971.228	0.008947
Management & Accounting	507	35.96798	8.1E-05
State & Local Government	512	1772.531	0.003993
Federal Government	513	1519.665	0.003424
Scrap & Used Goods	517	1230.633	0.002773
Fed. Govt. - Non-Defence	11001	52253.48	0.117726
State/Local Govt. - Non-Educ.	12001	18163.96	0.040923
Capital	14001	53642.44	0.120856
Trade - Foreign	25001	7726.273	0.017407
Trade - Domestic	28001	66630.12	0.150117
Total		443855.2398	1

Table 4.7

Distribution of Purchases Made By Households
(Weighted By Household Types)
Using Dividend Payments Funds

Sector	Sector #	Percent
Agriculture	1	0.002368602
Mining	28	7.40286E-06
Sand, Gravel & Clay	40	3.82681E-08
Food & Tobacco	58	0.02992717
Textiles	108	0.010612242
Wood Products	133	0.000156736
Furniture	148	0.002068966
Pulp & Paper	161	9.66084E-06
Printing	174	0.001586676
Chemicals, Paint & Adhesives	186	0.00787171
Petroleum Refining and Products	210	0.010369932
Rubber & Plastics	215	2.81589E-06
Leather	221	0.000480888
Concrete, Brick, Glass & Ceramics	230	2.76957E-06
Primary Metals Production	254	3.96407E-07
Fabricated Metal Products	273	2.3895E-05
Heavy Machinery	307	0.000399726
Electrical Equip. & Computers	339	0.00558079
Autos, Trucks, Aircraft, Missiles	384	0.00010721
Precision Instruments	400	0.001630217
Misc. Light Manufacturing	415	0.000335761
Rail, Air & Water Transport.	433	0.006989599
Road Transport.	434	0.004240252
Pipe Lines, Except Natural Gas	438	7.51084E-05
Consumer Services	439	0.4110008
Electricity	443	0.006734247
Gas Production and Distribution	444	0.004230389
Water Supply and Sewerage Systems	445	0.002957981
Sanitary Services and Steam Supply	446	0.000684586
Producer Services	447	0.027121028
Equipment Rental and Leasing	473	0.000315597
Automobile Rental and Leasing	477	0.001580066
Automobile Repair and Services	479	0.006706459
Legal Services	494	0.008503702
Management & Accounting	507	7.74298E-05
State & Local Government	512	0.004073994
Federal Government	513	0.003258042
Scrap & Used Goods	517	0.00306434
Fed. Govt. - Non-Defence	11001	0.108402284
State/Local Govt. - Non-Educ.	12001	0.04001211
Capital	14001	0.113111983
Trade - Foreign	25001	0.017996769
Trade - Domestic	28001	0.155319628
Total		1

Table 4.8

Capital Cost Components of Groundwater Remediation Activity
By Aggregated IMPLAN Sector, Type of Treatment System, and Type of Well

		Capital Costs of Remediation						
Aggr. Sector Name	Aggr. IMPLAN Sector #	Treatment System 75gpm $ per syste	Treatment System 150gpm $ per syste	Extraction Well A Zone $ per well	Extraction Well B Zone $ per well	Monitoring Well A Zone $ per well	Monitoring Well B Zone $ per well	Monitoring Well C Zone $ per well
Agriculture	1							
Mining	28							
Natural Gas	38							
Sand, Gravel & Clay	40			626.25	2426.25	26.25	26.25	26.25
Construction	48	43000	43000	1400	1400	200	200	200
Food & Tobacco	58							
Textiles	108							
Wood Products	133							
Furniture	148							
Pulp & Paper	161							
Printing	174							
Chemicals, Paint & Adhesives	186	44800	66000	200	800	0	0	0
Petroleum Refining and Products	210	12000	15000	2000	8000	0	0	0
Rubber & Plastics	215	4300	6000	503	622.7	503	622.7	862.1
Leather Products	221							
Concrete Brick, Glass & Ceramics	230			1662.5	2956.25	412.5	506.25	600
Primary Metals Production	254							
Fabricated Metal Products	273	7500	10000	3900	12900	50	50	50
Heavy Machinery	307	15000	24000	750	750	0	0	0
Electrical Equip. & Computers	339	35500	41500	3000	12000	0	0	0
Autos, Trucks, Aircraft, Missiles	384							
Precision Instruments	400	2400	3000					
Misc. Light Manufacturing	415							
Rail, Air & Water Transport.	433							
Road Transport.	434							
Pipe Lines, Except Natural Gas	438							
Consumer Services	439							
Electricity	443							
Gas Production and Distribution	444							
Water Supply and Sewerage Systems	445							
Sanitary Services and Steam Supply	446			9100	18900	7500	12500	17500
Producer Services	447							
Equipment Rental and Leasing	473			6000	15750	6000	11250	18000
Automobile Rental and Leasing	477	1499.85	2499.998	202.5	292.5	101.25	202.5	405
Automobile Repair and Services	479							
Legal Services	494	250000	250000	200	200	200	200	200
Engineering, Architectural Service	506	99999.6	99999.6	2000	4550	1900	2750	3475
Management & Accounting	507	30000	49999.2	1500	1999.2	999.6	1200	1500
Research, Development & Testing Se	509							
State & Local Government	512	99999.6	99999.6	399.6	500.4	300	399.6	499.2
Federal Government - Non-Defence	513	30000	49999.2	199.2	249.6	150	199.2	249.6
Noncomparable Imports	516							
Scrap & Used Goods	517							
Federal Government - Defence	519							
Rest of the World Industry	524			33643.05	84296.9	18342.6	30106.5	43567.15
TOTAL		264500	760997.6	31541.75	80155.2	16691.75	28105.2	41013.35

Table 4.9

Consumables (Annual Operations and Maintenance) Costs of Groundwater Remediation Activity By Aggregated IMPLAN Sector, Type of Treatment System, and Type of Well

Aggr. Sector Name	Aggr. IMPLAN Sector #	Consumables Costs of Remediation						
		Treatment System 75gpm $ per syste	Treatment System 150gpm $ per syste	Extraction Well A Zone $ per well	Extraction Well B Zone $ per well	Monitoring Well A Zone $ per well	Monitoring Well B Zone $ per well	Monitoring Well C Zone $ per well
Agriculture	1							
Mining	28							
Natural Gas	38							
Sand, Gravel & Clay	40							
Construction	48							
Food & Tobacco	58							
Textiles	108							
Wood Products	133							
Furniture	148							
Pulp & Paper	161							
Printing	174							
Chemicals, Paint & Adhesives	186	3000	6000					
Petroleum Refining and Products	210							
Rubber & Plastics	215							
Leather Products	221							
Concrete, Brick, Glass & Ceramics	230							
Primary Metals Production	254							
Fabricated Metal Products	273	800	1000	500	500	0	0	0
Heavy Machinery	307	3200	4000					
Electrical Equip. & Computers	339	1700	2000					
Autos, Trucks, Aircraft, Missiles	384							
Precision Instruments	400							
Misc. Light Manufacturing	415							
Rail, Air & Water Transport.	433							
Road Transport.	434							
Pipe Lines, Except Natural Gas	438							
Consumer Services	439							
Electricity	443	6600	11000					
Gas Production and Distribution	444							
Water Supply and Sewerage Systems	445	27300	54600					
Sanitary Services and Steam Supply	446							
Producer Services	447							
Equipment Rental and Leasing	473			0	0	192	96	144
Automobile Rental and Leasing	477	1404	1404	90	90	90	45	90
Automobile Repair and Services	479							
Legal Services	494							
Engineering, Architectural Service	506	31500	31500	2100	2100	0	0	0
Management & Accounting	507	8640	8640	40260	40260	42080	42080	42080
Research, Development & Testing Se	509	3300	3300	1680	1680	2480	1840	2160
State & Local Government	512	7160	7160					
Federal Government - Non-Defence	513							
Noncomparable Imports	516							
Scrap & Used Goods	517							
Federal Government - Defence	519							
Rest of the World Industry	524			44630	44630	44842	44061	44474
TOTAL		94604	130604	44630	44630	44842	44061	44474

Table 4.10

		Annual Costs per Representative Remediation Site				Distribution of Remediation Expenditures Across Sectors			
		Existing Situation Scenario		Source Control Only Scenario		Existing Situation Scenario		Source Control Only Scenario	
Aggr Sector Name	Aggr IMPLAN Sector #	Annual Total Costs per Installation Year 1994 Million$ (Purch s' Prices)	Annual Total Costs per O&M-Only Year 1994 Million$ (Purch s' Prices)	Annual Total Costs per Installation Year 1994 Million$ (Purch s' Prices)	Annual Total Costs per O&M-Only Year 1994 Million$ (Purch s' Prices)	Percent of Annual Total Costs per Installation Year (Purch.s' Prices)	Percent of Annual Total Costs per O&M-Only Year (Purch s' Prices)	Percent of Annual Total Costs per Installation Year (Purch.s' Prices.)	Percent of Annual Total Costs per O&M-Only Year (Purch.s' Prices.)
Agriculture	1	0	0	0	0	0	0	0	0
Mining	28	0	0	0	0	0	0	0	0
Natural Gas	38	0	0	0	0	0	0	0	0
Sand, Gravel & Clay	40	0.025400719	0	0.007171757	0	0.002686837	0	0.001499802	0
Construction	48	0.092117411	0	0.061550234	0	0.009743994	0	0.012871765	0
Food & Tobacco	58	0	0	0	0	0	0	0	0
Textiles	108	0	0	0	0	0	0	0	0
Wood Products	133	0	0	0	0	0	0	0	0
Furniture	148	0	0	0	0	0	0	0	0
Pulp & Paper	161	0	0	0	0	0	0	0	0
Printing	174	0	0	0	0	0	0	0	0
Chemicals, Paint & Adhesives	186	0.077943312	0.005860399	0.048641315	0.0029302	0.008244687	0.001061842	0.010172172	0.001104632
Petroleum Refining and Products	210	0.095848522	0	0.032980137	0	0.010138664	0	0.00689701	0
Rubber & Plastics	215	0.072780502	0	0.037349289	0	0.007698575	0	0.007810714	0
Leather Products	221	0	0	0	0	0	0	0	0
Concrete, Brick, Glass & Ceramics	230	0.082470527	0	0.032907077	0	0.008723566	0	0.006881731	0
Primary Metals Production	254	0	0	0	0	0	0	0	0
Fabricated Metal Products	273	0.153503626	0.009697007	0.045139569	0.002715162	0.016237305	0.001756995	0.009439865	0.001023566
Heavy Machinery	307	0.039451219	0.003802527	0.020153394	0.003042022	0.004173071	0.000688978	0.004214602	0.001146786
Electrical Equip. & Computers	339	0.163349801	0.002035512	0.068393188	0.001730185	0.017278813	0.000368813	0.014302805	0.000652248
Autos, Trucks, Aircraft, Missiles	384	0	0	0	0	0	0	0	0
Precision Instruments	400	0.002854055	0	0.002283244	0	0.000301896	0	0.000477486	0
Misc. Light Manufacturing	415	0	0	0	0	0	0	0	0
Rail, Air & Water Transport	433	0	0	0	0	0	0	0	0
Road Transport	434	0	0	0	0	0	0	0	0
Pipe Lines, Except Natural Gas	438	0	0	0	0	0	0	0	0
Consumer Services	439	0	0	0	0	0	0	0	0
Electricity	443	0.011434416	0.011434416	0.00686065	0.00686065	0.00120951	0.002071795	0.001434741	0.002586339
Gas Production and Distribution	444	0	0	0	0	0	0	0	0
Water Supply and Sewerage Systems	445	0.047273505	0.047273505	0.023636752	0.023636752	0.005000496	0.008565458	0.004943063	0.008910622
Sanitary Services and Steam Supply	446	1.110321295	0	0.548493871	0	0.117447553	0	0.114704421	0
Producer Services	447	0	0	0	0	0	0	0	0
Equipment Rental and Leasing	473	1.037950475	0.014212224	0.531070153	0.007329575	0.109792313	0.002575104	0.111060665	0.002763115
Automobile Rental and Leasing	477	0.031207085	0.009496125	0.016450325	0.005164704	0.003301023	0.001720597	0.003440193	0.001946999
Automobile Repair and Services	479	0	0	0	0	0	0	0	0
Legal Services	494	0.244842885	0	0.233583687	0	0.025898988	0	0.048848461	0
Engineering, Architectural Service	506	0.423522867	0.063200172	0.258363398	0.036387978	0.044799397	0.011451201	0.054030547	0.0137176
Management & Accounting	507	5.236632081	5.041345113	2.505794134	2.407496391	0.553920407	0.913438257	0.524027122	0.90758195
Research, Development & Testing Se	509	0.304255324	0.304255324	0.148880855	0.148880855	0.032183516	0.055127837	0.031134883	0.05612535
State & Local Government	512	0.136847807	0.00647457	0.116149078	0.00647457	0.014475486	0.001173123	0.024289811	0.002440794
Federal Government - Non-Defence	513	0.063755256	0	0.035950264	0	0.006743903	0	0.007518141	0
Noncomparable Imports	516	0	0	0	0	0	0	0	0
Scrap & Used Goods	517	0	0	0	0	0	0	0	0
Federal Government - Defence	519	0	0	0	0	0	0	0	0
Rest of the World Industry	524	0	0	0	0	0	0	0	0
Totals		9.453762691	5.519086895	4.781802371	2.652649043	1	1	1	1

Table 4.11

Transportation Margins, Wholesale Margins, and Regional Purchase Coefficients (RPC's)

Aggr. IMPLAN Sector #	Transportation Margins (Fraction of Purchasers' Price) (typical values assumed)	Wholesale Margins (Fraction of Purchasers' Price) (typical values assumed)	California RPC's (from IMPLAN software)
1	0.015	0.1	0.516798
28	0.015	0.1	0.456643
38	0.015	0.1	0.300804
40	0.015	0.1	0.002612
48	0.015	0.1	0.88271
58	0.015	0.1	0.717808
108	0.015	0.1	0.634194
133	0.015	0.1	0.332297
148	0.015	0.1	0.587691
161	0.015	0.1	0.004715
174	0.015	0.1	0.313388
186	0.015	0.1	0.61927
210	0.015	0.1	0.954558
215	0.015	0.1	0.001113
221	0.015	0.1	0.189404
230	0.015	0.1	0.002677
254	0.015	0.1	0.024417
273	0.015	0.1	0.014527
307	0.015	0.1	0.690261
339	0.015	0.1	0.601776
384	0.015	0.1	0.005537
400	0.015	0.1	0.739865
415	0.015	0.1	0.050606
433	0	0	0.753167
434	0	0	0.7772
438	0.015	0.1	0.635142
439	0	0	0.842214
443	0	0	0.574158
444	0	0	0.9506
445	0	0	1
446	0	0	1
447	0	0	0.83
473	0	0	0.8
477	0	0	0.9
479	0	0	0.9
494	0	0	0.9
506	0	0	0.9
507	0	0	0.85
509	0	0	0.8
512	0	0	0.998889
513	0	0	0.87155
516	0.015	0.1	0
517	0.015	0.1	0.8981
519	0	0	1
524	0.015	0.1	0

Table 4.12

Distribution of Remediation Expenditures Across Sectors			
Existing Situation Scenario		Source Control Only Scenario	
Producers' Prices		**Producers' Prices**	
Percent of Annual Total Costs per Installation Year	Percent of Annual Total Costs per O&M-Only Year	Percent of Annual Total Costs per Installation Year	Percent of Annual Total Costs per O&M-Only Year
0	0	0	0
0	0	0	0
0	0	0	0
0.002377851	0	0.001327325	0
0.008623435	0	0.011391512	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0.007296548	0.00093973	0.009002372	0.000977599
0.008972718	0	0.006103853	0
0.006813239	0	0.006912482	0
0	0	0	0
0.007720356	0	0.006090332	0
0	0	0	0
0.014370015	0.00155494	0.008354281	0.000905856
0.003693167	0.000609745	0.003729923	0.001014906
0.01529175	0.0003264	0.012657983	0.000577239
0	0	0	0
0.000267178	0	0.000422575	0
0	0	0	0
0.000639206	2.90747E-05	0.00055926	2.94542E-05
0.000639206	2.90747E-05	0.00055926	2.94542E-05
0	0	0	0
0	0	0	0
0.00120951	0.002071795	0.001434741	0.002586339
0	0	0	0
0.005000496	0.008565458	0.004943063	0.008910622
0.117447553	0	0.114704421	0
0.008522741	0.000387663	0.007456795	0.000392723
0.109792313	0.002575104	0.111060665	0.002763115
0.003301023	0.001720597	0.003440193	0.001946999
0	0	0	0
0.025898988	0	0.048848461	0
0.044799397	0.011451201	0.054030547	0.0137176
0.553920407	0.913438257	0.524027122	0.90758195
0.032183516	0.055127837	0.031134883	0.05612535
0.014475486	0.001173123	0.024289811	0.002440794
0.006743903	0	0.007518141	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
1	1	1	1

Table 4.13

Net Change in Final Demand Due to Remediation Activities

	Existing Situation Scenario		Source Control Only Scenario	
	Installation Year	O&M-Only Year	Installation Year	O&M-Only Year
Aggr. IMPLAN Sector #	Net Change in Annual Final Demand Per Annual Dollar Transferred From HH Dividends To Remediation Producers' Prices 1994$	Net Change in Annual Final Demand Per Annual Dollar Transferred From HH Dividends To Remediation Producers' Prices 1994$	Net Change in Annual Final Demand Per Annual Dollar Transferred From HH Dividends To Remediation Producers' Prices 1994$	Net Change in Annual Final Demand Per Annual Dollar Transferred From HH Dividends To Remediation Producers' Prices 1994$
1	-0.000284	-0.000284	-0.000284	-0.000284
28	-0.000001	-0.000001	-0.000001	-0.000001
38	0.000000	0.000000	0.000000	0.000000
40	0.000006	0.000000	0.000003	0.000000
48	0.007612	0.000000	0.010055	0.000000
58	-0.003591	-0.003591	-0.003591	-0.003591
108	-0.001273	-0.001273	-0.001273	-0.001273
133	-0.000019	-0.000019	-0.000019	-0.000019
148	-0.000248	-0.000248	-0.000248	-0.000248
161	-0.000001	-0.000001	-0.000001	-0.000001
174	-0.000190	-0.000190	-0.000190	-0.000190
186	0.003574	-0.000363	0.004630	-0.000339
210	0.007321	-0.001244	0.004582	-0.001244
215	0.000007	0.000000	0.000007	0.000000
221	-0.000058	-0.000058	-0.000058	-0.000058
230	0.000020	0.000000	0.000016	0.000000
254	0.000000	0.000000	0.000000	0.000000
273	0.000206	0.000020	0.000118	0.000010
307	0.002501	0.000373	0.002527	0.000653
339	0.008533	-0.000473	0.006948	-0.000322
384	-0.000013	-0.000013	-0.000013	-0.000013
400	0.000002	-0.000196	0.000117	-0.000196
415	-0.000040	-0.000040	-0.000040	-0.000040
433	-0.000357	-0.000817	-0.000418	-0.000817
434	-0.000012	-0.000486	-0.000074	-0.000486
438	-0.000009	-0.000009	-0.000009	-0.000009
439	-0.049320	-0.049320	-0.049320	-0.049320
443	-0.000114	0.000381	0.000016	0.000677
444	-0.000508	-0.000508	-0.000508	-0.000508
445	0.004646	0.008210	0.004588	0.008556
446	0.117365	-0.000082	0.114622	-0.000082
447	0.003819	-0.002933	0.002935	-0.002929
473	0.087796	0.002022	0.088811	0.002173
477	0.002781	0.001359	0.002907	0.001563
479	-0.000805	-0.000805	-0.000805	-0.000805
494	0.022289	-0.001020	0.042943	-0.001020
506	0.040319	0.010306	0.048627	0.012346
507	0.470823	0.776413	0.445414	0.771435
509	0.025747	0.044102	0.024908	0.044900
512	0.013971	0.000683	0.023774	0.001949
513	0.005487	-0.000391	0.006161	-0.000391
516	0.000000	0.000000	0.000000	0.000000
517	-0.000368	-0.000368	-0.000368	-0.000368
519	0.000000	0.000000	0.000000	0.000000
524	0.000000	0.000000	0.000000	0.000000

Table 4.14

Net Change In Final Demand Due to Remediation Activities

	Existing Situation Scenario		Source Control Only Scenario	
	Installation Year	O&M-Only Year	Installation Year	O&M-Only Year
Aggr. IMPLAN Sector #	Change in Annual Final Demand per 200 Million1994$	Change in Annual Final Demand per 116.76 Million1994$	Change in Annual Final Demand per 101.16 Million199	Change in Annual Final Demand per 56.12 Million1994$
1	-56846.45	-33186.84	-28753.47	-15950.65
28	-177.67	-103.72	-89.87	-49.85
38	0.00	0.00	0.00	0.00
40	1241.27	-0.54	350.26	-0.26
48	1522398.48	0.00	1017223.36	0.00
58	-718252.07	-419314.06	-363298.67	-201535.70
108	-254693.81	-148689.72	-128826.53	-71465.02
133	-3761.66	-2196.05	-1902.68	-1055.49
148	-49655.18	-28988.59	-25116.06	-13932.84
161	-231.86	-135.36	-117.28	-65.06
174	-38080.24	-22231.16	-19261.34	-10685.00
186	714785.60	-42343.84	468409.26	-19035.77
210	1464117.48	-145294.68	463532.90	-69833.25
215	1449.05	-39.45	744.11	-18.96
221	-11541.32	-6737.80	-5837.71	-3238.40
230	4067.01	-38.80	1615.70	-18.65
254	-9.51	-5.55	-4.81	-2.67
273	41177.16	2302.64	11987.20	577.57
307	500256.47	43541.54	255601.00	36621.89
339	1706502.65	-55259.43	702829.83	-18088.41
384	-2573.04	-1502.13	-1301.47	-721.97
400	409.95	-22841.21	11838.22	-10978.21
415	-8058.27	-4704.40	-4075.95	-2261.09
433	-71464.67	-95375.50	-42238.73	-45824.47
434	-2407.94	-56772.41	-7503.55	-27270.08
438	-1802.60	-1052.35	-911.77	-505.80
439	-9864019.20	-5758593.79	-4989313.98	-2767763.69
443	-22732.01	44535.37	1584.06	37984.15
444	-101529.33	-59272.61	-51354.49	-28488.30
445	929107.70	958654.53	464141.43	480129.97
446	23473080.55	-9591.84	11595405.19	-4610.14
447	690326.15	-385363.14	259672.02	-184982.10
473	17559195.80	236112.60	8984254.03	121923.93
477	556262.48	158668.04	294033.71	87695.67
479	-160955.02	-93965.21	-81412.57	-45162.67
494	4457728.95	-119146.65	4344212.18	-57265.68
506	8063891.44	1203333.67	4919248.90	692828.48
507	94164610.95	90653683.73	45058896.72	43291699.87
509	5149362.58	5149362.58	2519730.78	2519730.78
512	2794104.83	79739.87	2405017.25	109386.10
513	1097336.67	-45648.92	623306.00	-21940.33

Table 4.15

Leontief Inverse Matrix (41*41) for Basecase Scenario														
1.11E+00	7.01E-04	9.45E-04	3.86E-04	3.50E-03	1.47E-01	1.68E-02	4.45E-02	2.57E-03	2.60E-03	3.45E-04	2.56E-03	4.30E-04	1.21E-03	1.18E-02
1.37E-04	1.06E+00	1.99E-04	1.66E-03	9.73E-05	2.94E-04	6.77E-04	4.41E-04	3.18E-04	1.91E-03	2.27E-04	3.76E-03	2.95E-04	1.06E-03	3.58E-04
1.03E-03	4.50E-03	1.01E+00	3.20E-03	2.50E-03	1.17E-03	2.32E-03	1.81E-03	1.10E-03	3.26E-03	8.30E-04	8.44E-03	1.58E-01	4.76E-03	1.43E-03
6.73E-05	7.26E-05	2.40E-05	1.00E+00	4.47E-05	2.90E-05	2.93E-04	5.85E-05	5.55E-05	1.68E-04	5.69E-05	5.73E-04	5.91E-05	5.62E-04	1.42E-04
7.18E-03	2.99E-02	1.56E-01	1.44E-02	1.00E+00	7.50E-03	8.77E-03	1.14E-02	1.34E-02	1.19E-02	7.03E-03	1.23E-02	3.39E-02	1.42E-02	7.89E-03
3.54E-02	1.15E-03	1.37E-03	6.58E-04	9.60E-04	1.12E+00	2.14E-03	2.00E-03	1.01E-03	3.73E-03	7.19E-04	7.56E-03	1.11E-03	2.56E-03	7.69E-02
1.21E-03	1.50E-03	4.27E-04	5.19E-04	1.55E-03	5.23E-04	1.24E+00	1.71E-03	4.52E-02	8.51E-03	1.26E-03	2.44E-03	9.83E-04	1.47E-02	2.83E-02
4.93E-04	3.41E-03	3.02E-03	5.22E-04	1.92E-02	3.39E-04	4.49E-04	1.10E+00	3.91E-02	1.55E-02	2.27E-04	4.63E-04	8.77E-04	2.21E-03	1.54E-03
1.46E-05	8.66E-05	1.93E-04	3.26E-05	1.21E-03	1.53E-05	1.07E-04	1.48E-03	1.02E+00	9.32E-05	1.86E-05	2.35E-05	4.57E-05	4.30E-05	5.96E-05
4.34E-05	4.52E-05	2.04E-05	3.36E-05	5.21E-05	1.74E-04	4.47E-04	1.24E-04	1.80E-04	1.00E+00	6.83E-04	2.78E-04	3.35E-05	3.37E-04	1.42E-04
1.69E-03	3.83E-03	1.48E-03	2.62E-03	2.58E-03	5.90E-03	4.00E-03	3.35E-03	4.55E-03	3.68E-03	1.03E+00	4.70E-03	2.32E-03	4.90E-03	3.97E-03
1.76E-02	1.14E-02	5.50E-03	6.57E-03	6.74E-03	7.67E-03	7.86E-02	1.52E-02	1.47E-02	4.31E-02	1.51E-02	1.15E+00	1.16E-02	1.50E-01	3.77E-02
4.83E-03	2.09E-02	4.17E-03	7.01E-03	1.39E-02	2.85E-03	7.54E-03	5.18E-03	3.36E-03	8.26E-03	3.23E-03	1.44E-02	1.03E+00	1.37E-02	4.27E-03
6.27E-05	2.65E-04	4.31E-05	8.64E-05	1.04E-04	5.31E-05	5.58E-04	2.26E-04	2.30E-04	2.13E-04	8.53E-05	4.52E-04	4.84E-05	1.00E+00	3.75E-04
2.20E-05	1.17E-05	9.45E-06	5.25E-06	1.26E-05	1.25E-05	1.28E-03	3.76E-05	6.26E-04	2.34E-05	3.61E-05	1.24E-05	1.02E-05	3.67E-05	1.03E+00
2.32E-05	8.56E-05	3.83E-05	2.79E-05	1.60E-04	3.40E-05	1.62E-04	1.70E-04	1.01E-04	7.76E-05	2.32E-05	1.54E-04	4.21E-05	1.80E-04	5.44E-05
3.48E-05	4.85E-04	1.23E-04	2.51E-04	4.00E-04	4.51E-05	8.83E-05	7.94E-05	1.31E-03	1.19E-04	7.14E-05	1.40E-04	4.16E-05	2.66E-04	5.46E-05
9.07E-05	1.22E-03	2.59E-04	3.84E-04	9.68E-04	4.11E-04	2.67E-04	7.57E-04	8.68E-04	3.72E-04	1.18E-04	3.26E-04	1.30E-04	4.73E-04	3.05E-04
2.29E-03	5.29E-02	4.50E-03	1.46E-02	8.49E-03	1.71E-03	6.39E-03	4.87E-03	3.86E-03	6.49E-03	3.02E-03	2.30E-03	1.55E-03	6.44E-03	1.78E-03
1.93E-03	1.12E-02	4.26E-03	5.35E-03	1.60E-02	2.36E-03	2.86E-03	6.29E-03	3.54E-03	2.73E-03	3.44E-03	3.44E-03	2.17E-03	6.33E-03	2.30E-03
5.85E-05	9.71E-04	9.71E-05	2.81E-04	2.14E-04	4.61E-05	1.91E-04	1.30E-04	1.18E-04	1.81E-04	8.93E-05	8.18E-05	4.53E-05	1.67E-04	5.46E-05
5.46E-04	1.86E-03	9.07E-04	9.75E-04	2.59E-03	5.61E-04	2.74E-03	1.02E-03	1.43E-03	1.61E-03	4.67E-03	2.71E-03	6.18E-04	3.07E-03	1.19E-03
8.19E-05	1.91E-04	7.47E-05	1.10E-04	1.83E-04	1.73E-04	6.56E-04	2.56E-04	3.77E-04	1.97E-04	2.03E-04	2.94E-04	1.03E-04	3.28E-04	6.22E-04
3.35E-03	2.48E-02	2.11E-03	4.76E-03	2.97E-03	5.93E-03	3.70E-03	7.80E-03	5.18E-03	1.14E-02	8.76E-03	9.20E-03	4.87E-03	8.97E-03	4.50E-03
9.18E-03	1.67E-02	4.56E-03	1.60E-02	1.45E-02	1.93E-02	1.28E-02	1.78E-02	1.31E-02	2.93E-02	1.29E-02	2.11E-02	6.52E-03	4.05E-02	1.62E-02
1.94E-04	9.68E-04	1.56E-04	3.88E-04	3.99E-04	1.39E-04	2.52E-04	2.48E-04	1.40E-04	3.88E-04	1.52E-04	6.72E-04	2.24E-02	4.82E-04	1.86E-04
4.45E-02	9.36E-02	1.27E-01	5.42E-02	7.55E-02	3.33E-02	3.87E-02	3.94E-02	4.76E-02	3.85E-02	4.85E-02	3.92E-02	4.50E-02	5.27E-02	4.01E-02
2.18E-03	3.12E-02	4.80E-03	1.80E-02	1.58E-03	4.91E-03	9.06E-03	8.24E-03	5.11E-03	1.27E-02	3.96E-03	1.08E-02	6.10E-03	1.40E-02	4.95E-03
1.08E-03	5.98E-03	3.76E-03	1.21E-02	1.02E-03	4.06E-03	5.13E-03	5.40E-03	3.01E-03	1.06E-02	1.52E-03	1.64E-02	6.96E-03	9.32E-03	3.68E-03
3.08E-05	4.26E-05	5.98E-05	5.27E-05	1.05E-05	4.14E-05	4.07E-05	5.82E-05	2.72E-05	2.79E-04	1.46E-05	1.87E-04	4.09E-05	5.54E-05	6.46E-05
1.50E-03	6.46E-03	9.43E-04	1.20E-02	7.71E-04	2.28E-03	2.95E-03	3.49E-03	2.75E-03	1.15E-02	1.17E-03	2.43E-03	1.63E-03	4.39E-03	1.73E-03
2.63E-02	6.35E-02	2.11E-02	3.54E-02	4.35E-02	7.63E-02	6.44E-02	5.81E-02	7.89E-02	6.05E-02	5.50E-02	6.61E-02	4.10E-02	7.95E-02	6.40E-02
4.58E-04	1.21E-03	1.01E-03	5.62E-04	4.40E-03	1.50E-03	1.68E-03	1.57E-03	1.95E-03	2.04E-03	2.36E-03	2.21E-03	8.97E-04	2.63E-03	2.35E-03
5.15E-04	2.77E-03	4.78E-04	3.03E-04	8.16E-04	5.88E-04	8.50E-04	9.12E-04	1.02E-03	1.81E-03	1.66E-03	6.34E-04	3.20E-04	1.07E-03	4.78E-04
1.10E-03	6.34E-03	1.21E-03	1.06E-03	5.21E-03	1.17E-03	1.12E-03	2.43E-03	1.43E-03	1.97E-03	1.58E-03	1.36E-03	8.43E-04	1.82E-03	1.14E-03
1.56E-03	3.90E-03	2.00E-03	2.00E-03	2.19E-03	2.14E-03	3.07E-03	2.51E-03	3.71E-03	2.56E-03	6.61E-03	3.67E-03	1.19E-03	3.98E-03	2.96E-03
3.99E-04	1.32E-02	8.11E-03	3.85E-03	2.73E-02	5.28E-04	1.05E-03	9.93E-04	8.65E-04	1.33E-03	5.59E-04	8.07E-03	2.85E-03	3.82E-03	7.64E-04
4.27E-03	8.30E-03	4.70E-03	5.32E-03	7.90E-03	5.43E-03	7.06E-03	7.10E-03	1.69E-02	6.35E-03	1.20E-02	2.65E-02	5.99E-03	1.32E-02	5.54E-03
3.84E-04	1.32E-03	6.83E-04	9.03E-04	1.09E-03	7.35E-04	1.15E-03	1.28E-03	1.40E-03	1.08E-03	1.84E-03	2.68E-03	1.22E-03	1.93E-03	9.15E-04
5.96E-04	1.47E-03	1.17E-03	1.23E-03	5.16E-04	1.03E-03	8.68E-04	1.09E-03	7.98E-04	3.62E-03	5.74E-04	2.69E-03	8.69E-04	1.31E-03	1.42E-03
5.99E-04	1.55E-03	8.96E-04	1.41E-03	9.44E-04	1.28E-03	2.40E-03	1.33E-03	2.46E-03	1.40E-03	7.62E-03	1.44E-03	7.58E-04	1.79E-03	2.88E-03

Table 4.16

8.32E-04	5.43E-04	4.54E-04	3.86E-04	3.54E-04	4.68E-04	4.88E-04	1.57E-03	1.16E-03	2.17E-03	7.44E-04	3.83E-03	7.27E-04	2.58E-04	1.57E-03
3.33E-03	2.76E-02	6.79E-04	4.18E-04	5.49E-04	2.68E-04	5.20E-04	3.38E-04	2.70E-04	3.21E-04	2.03E-03	1.96E-04	3.69E-02	9.11E-05	2.19E-04
4.81E-03	5.05E-03	1.66E-03	1.18E-03	1.04E-03	8.85E-04	8.59E-04	1.33E-03	8.38E-03	5.91E-03	8.38E-03	7.82E-04	1.18E-02	1.37E-01	1.32E-03
2.10E-04	9.03E-05	5.26E-05	2.39E-05	4.15E-05	3.12E-05	4.03E-05	8.38E-05	2.55E-05	1.85E-05	1.21E-05	2.03E-05	3.81E-05	5.52E-06	8.11E-05
1.71E-02	2.58E-02	1.91E-02	1.60E-02	1.46E-02	9.96E-03	9.91E-03	1.20E-02	6.06E-02	2.70E-02	7.99E-02	3.13E-02	1.19E-01	3.62E-02	2.16E-01
1.14E-03	7.38E-04	6.47E-04	5.85E-04	6.91E-04	4.82E-04	1.08E-03	2.14E-03	3.40E-03	2.22E-03	1.08E-03	1.18E-02	7.31E-04	3.93E-04	1.89E-03
2.38E-03	8.72E-04	1.15E-03	1.47E-03	7.20E-04	1.11E-02	7.44E-03	1.18E-02	2.58E-03	6.57E-04	9.60E-03	1.03E-03	5.65E-04	1.62E-04	8.98E-04
2.86E-03	1.69E-03	1.68E-03	1.31E-03	7.85E-04	1.45E-03	1.12E-03	9.88E-03	1.30E-03	6.63E-04	1.58E-03	7.87E-04	2.45E-03	7.15E-04	4.27E-03
4.04E-05	2.26E-04	4.81E-05	1.09E-04	1.30E-03	6.00E-03	3.66E-04	1.81E-04	9.14E-05	4.80E-05	1.16E-04	5.52E-05	1.56E-04	4.82E-05	2.77E-04
1.55E-04	1.67E-04	6.58E-05	6.87E-05	1.28E-04	6.40E-05	1.74E-04	1.66E-04	3.68E-05	3.13E-05	3.30E-05	4.69E-05	2.47E-05	7.81E-06	1.47E-04
3.49E-03	5.14E-03	4.51E-03	4.85E-03	4.46E-03	3.57E-03	4.03E-03	5.85E-03	5.91E-03	4.46E-03	2.45E-03	5.56E-03	2.94E-03	1.03E-03	4.62E-03
2.82E-02	1.98E-02	1.37E-02	6.05E-03	1.09E-02	8.19E-03	1.06E-02	2.21E-02	3.99E-03	3.07E-03	2.46E-03	5.18E-03	4.56E-03	1.15E-03	2.05E-02
7.15E-03	8.23E-03	3.70E-03	3.07E-03	3.23E-03	2.59E-03	2.69E-03	4.46E-03	4.88E-02	3.34E-02	5.02E-03	2.39E-03	2.73E-02	3.14E-03	5.88E-03
1.12E-04	1.49E-04	1.27E-04	3.50E-04	1.59E-04	2.07E-04	1.32E-04	1.69E-04	6.82E-05	4.28E-05	7.73E-05	3.25E-05	5.30E-05	1.10E-05	1.50E-04
2.64E-05	1.40E-05	7.44E-06	1.19E-05	1.02E-05	2.72E-05	1.88E-05	5.21E-04	2.29E-05	2.79E-05	1.80E-05	6.29E-05	8.43E-06	4.73E-06	1.35E-05
1.00E+00	7.67E-05	4.92E-05	8.87E-05	6.19E-05	6.15E-05	5.71E-05	6.57E-05	4.95E-05	3.08E-05	3.08E-05	1.66E-05	4.32E-05	9.99E-06	7.79E-05
1.67E-04	1.01E+00	5.59E-03	2.96E-03	1.21E-03	9.62E-04	7.52E-04	1.38E-03	1.55E-04	4.37E-05	1.03E-04	3.29E-05	1.24E-04	5.00E-05	1.31E-04
2.39E-04	1.01E-03	1.00E+00	2.09E-03	7.29E-04	1.43E-03	6.44E-04	3.74E-04	3.74E-04	1.97E-04	3.41E-04	8.50E-05	2.66E-04	6.07E-05	8.53E-04
4.16E-03	1.87E-02	1.53E-02	1.08E+00	6.63E-03	2.92E-02	4.86E-03	6.13E-03	1.13E-02	3.58E-03	1.29E-02	1.02E-03	7.47E-03	1.02E-03	3.94E-03
4.11E-03	8.01E-03	6.22E-03	3.40E-02	1.15E+00	2.67E-02	9.89E-02	1.96E-02	7.66E-03	8.56E-03	8.83E-03	5.62E-03	7.31E-03	3.40E-03	1.14E-02
1.06E-04	5.58E-04	3.15E-04	1.43E-03	4.69E-04	1.00E+00	4.03E-04	1.75E-04	3.51E-04	1.49E-04	2.60E-04	5.12E-05	1.63E-04	3.00E-05	1.40E-04
1.38E-03	1.38E-03	1.97E-03	5.12E-03	4.67E-03	7.02E-03	1.02E+00	1.65E-03	1.65E-03	1.31E-03	9.23E-04	3.13E-03	1.41E-03	4.75E-04	3.73E-03
1.91E-04	2.29E-04	1.92E-04	2.32E-04	2.43E-04	1.91E-04	2.08E-04	1.00E+00	2.64E-04	1.61E-04	1.07E-04	2.15E-04	1.33E-04	4.69E-05	2.28E-04
1.22E-02	1.24E-02	5.45E-03	6.13E-03	8.17E-03	6.46E-03	4.91E-03	4.76E-03	1.06E+00	5.93E-03	1.28E-02	4.07E-03	2.57E-02	2.12E-03	4.06E-03
5.26E-02	2.72E-02	1.94E-02	1.20E-02	8.08E-03	1.27E-02	7.96E-03	1.58E-02	8.04E-03	1.21E+00	3.74E-03	7.99E-03	8.90E-03	1.56E-03	1.39E-02
3.89E-04	3.96E-04	1.70E-04	1.36E-04	1.33E-04	1.18E-04	1.19E-04	1.80E-04	3.05E-03	1.99E-03	1.00E+00	1.20E-04	1.47E-03	4.34E-03	1.91E-04
4.97E-02	4.27E-02	4.38E-02	4.59E-02	5.22E-02	3.44E-02	4.52E-02	5.25E-02	1.80E-01	2.08E-01	9.27E-02	1.17E+00	5.88E-02	3.63E-02	1.51E-01
1.47E-02	2.10E-02	7.43E-03	6.83E-03	6.33E-03	3.71E-03	4.91E-03	5.38E-03	5.99E-03	8.21E-03	5.47E-02	4.64E-03	1.00E+00	2.30E-03	4.00E-03
2.12E-02	2.14E-02	6.06E-03	3.92E-03	2.81E-03	2.59E-03	2.30E-03	3.18E-03	1.64E-03	2.12E-03	6.85E-03	2.22E-03	4.35E-02	1.22E+00	1.74E-03
6.21E-05	3.04E-04	2.89E-05	2.82E-05	3.56E-05	1.69E-05	2.06E-05	2.56E-05	5.19E-05	5.19E-05	1.34E-05	6.58E-05	9.07E-05	3.19E-05	1.00E+00
3.74E-03	4.11E-03	2.53E-03	1.84E-03	1.27E-03	1.22E-03	2.29E-03	5.91E-03	2.67E-03	8.64E-04	4.22E-04	1.77E-03	2.67E-03	4.63E-04	5.73E-03
5.83E-02	9.26E-02	7.33E-02	8.47E-02	7.73E-02	6.38E-02	6.55E-02	9.47E-02	8.92E-02	5.27E-02	3.13E-02	5.61E-02	4.65E-02	1.63E-02	6.89E-02
2.06E-03	2.27E-03	2.35E-03	2.98E-03	2.67E-03	1.65E-03	2.68E-03	1.69E-03	7.90E-03	2.75E-03	6.94E-04	1.73E-03	9.60E-04	2.90E-04	1.42E-03
1.17E-03	9.59E-04	1.01E-03	9.07E-04	7.66E-04	7.12E-04	1.03E-03	1.53E-03	1.65E-03	4.43E-03	8.16E-04	1.30E-03	1.10E-03	7.54E-04	5.94E-04
2.46E-03	1.77E-03	1.87E-03	1.63E-03	1.01E-03	5.15E-03	2.42E-03	1.78E-03	1.76E-03	2.16E-02	3.64E-03	1.34E-03	1.36E-03	4.57E-04	1.85E-03
3.28E-03	2.79E-03	3.13E-03	4.42E-03	5.38E-03	2.88E-03	4.72E-03	6.94E-03	6.22E-03	5.69E-03	2.16E-03	9.87E-03	3.76E-03	1.14E-03	6.12E-03
1.42E-03	2.03E-03	2.11E-03	3.10E-03	1.70E-03	1.03E-03	1.75E-03	1.05E-03	2.12E-03	1.07E-03	4.27E-03	1.32E-03	5.47E-03	1.96E-03	6.80E-03
7.81E-03	6.49E-03	1.21E-02	8.01E-03	5.15E-03	4.89E-03	1.12E-02	1.51E-02	2.74E-02	1.91E-02	5.95E-03	1.79E-02	7.01E-03	2.86E-03	2.57E-02
1.39E-03	1.12E-03	1.27E-03	1.44E-03	1.30E-03	8.60E-04	1.43E-03	2.41E-03	5.99E-03	3.51E-03	9.39E-04	2.78E-03	1.13E-03	4.43E-04	2.27E-03
1.79E-03	3.95E-03	8.90E-04	7.58E-04	8.45E-04	5.97E-04	6.05E-04	7.21E-04	2.16E-03	2.04E-03	9.97E-04	1.55E-03	2.98E-03	8.25E-03	1.52E-03
1.72E-03	1.75E-03	1.60E-03	1.86E-03	1.67E-03	1.62E-03	1.89E-03	3.09E-03	1.87E-03	3.20E-03	9.40E-04	5.71E-03	2.99E-03	2.02E-03	8.97E-03

Table 4.17

1.33E-03	7.14E-04	5.21E-04	8.53E-04	5.60E-04	1.17E-04	4.22E-04	8.44E-04	7.18E-04	3.75E-04	5.13E-04
4.91E-04	1.94E-04	1.79E-04	1.45E-04	2.00E-04	1.86E-05	8.19E-05	1.54E-04	1.31E-04	2.51E-04	1.05E-04
1.52E-02	1.34E-03	1.11E-03	5.83E-03	6.97E-04	1.53E-04	3.56E-04	8.41E-04	7.29E-04	1.43E-03	5.87E-04
1.71E-04	9.35E-06	6.88E-06	2.71E-05	1.97E-05	1.40E-06	4.85E-06	2.58E-05	2.55E-05	1.40E-05	3.18E-06
3.50E-02	1.44E-02	1.16E-02	1.19E-02	1.08E-02	1.70E-03	6.14E-03	1.04E-02	8.61E-03	5.86E-02	5.21E-03
1.77E-03	1.22E-03	1.20E-03	1.92E-03	1.53E-03	3.36E-04	1.12E-03	2.86E-03	2.63E-03	1.79E-04	1.23E-03
1.09E-03	8.01E-04	6.29E-04	2.51E-03	3.95E-04	6.03E-05	2.29E-04	6.23E-04	5.57E-04	2.35E-04	1.12E-03
1.25E-02	1.25E-03	4.34E-04	4.06E-04	2.79E-04	6.81E-05	2.64E-04	3.98E-04	2.90E-04	1.13E-03	1.21E-04
1.23E-04	5.03E-05	4.46E-05	4.65E-05	3.79E-05	9.28E-06	1.80E-05	6.24E-05	5.66E-05	7.27E-05	9.27E-06
1.16E-04	8.66E-05	4.27E-05	4.95E-05	2.91E-05	9.90E-06	3.06E-05	6.30E-05	5.01E-05	9.44E-06	1.28E-05
4.56E-03	8.22E-03	1.06E-02	5.41E-03	2.57E-03	1.11E-03	8.35E-03	1.14E-02	6.58E-03	5.17E-04	2.27E-03
4.44E-02	2.22E-03	1.66E-03	5.72E-03	5.08E-03	3.36E-04	1.20E-03	6.69E-03	6.62E-03	3.33E-03	6.93E-04
2.17E-02	4.07E-03	2.31E-03	2.82E-02	2.66E-03	6.42E-04	1.29E-03	3.35E-03	3.02E-03	2.00E-03	2.50E-03
1.68E-04	3.68E-05	3.95E-05	1.36E-04	4.61E-05	3.68E-06	1.39E-05	4.92E-05	4.54E-05	2.18E-05	8.84E-06
2.14E-05	3.09E-05	2.13E-05	2.12E-05	1.18E-05	2.40E-05	1.48E-05	3.29E-05	2.07E-05	2.32E-06	9.19E-05
9.08E-05	1.50E-05	1.33E-05	5.68E-05	2.93E-05	1.99E-06	5.73E-06	2.11E-05	1.94E-05	1.55E-05	4.18E-06
1.00E-04	4.57E-05	5.36E-05	1.38E-04	6.57E-05	4.58E-06	1.66E-05	6.33E-05	5.70E-05	3.53E-05	9.20E-06
6.24E-04	1.40E-04	1.93E-04	1.12E-03	1.02E-03	1.33E-05	4.32E-05	1.11E-04	9.38E-05	9.08E-05	3.61E-05
1.78E-03	3.47E-03	5.78E-03	2.29E-02	4.87E-03	1.40E-04	8.84E-04	2.24E-03	1.86E-03	2.30E-03	6.35E-04
8.33E-03	1.30E-02	1.16E-02	9.17E-03	1.25E-02	1.30E-03	5.58E-03	3.01E-02	2.82E-02	1.72E-03	1.24E-03
9.12E-04	1.10E-04	1.45E-04	5.72E-04	6.74E-04	1.37E-05	3.39E-05	1.22E-04	1.08E-04	4.76E-05	4.74E-05
3.17E-02	1.90E-03	3.62E-03	1.49E-03	9.96E-04	1.01E-03	9.99E-04	2.17E-03	1.44E-03	3.04E-04	2.96E-04
2.97E-04	2.71E-04	5.42E-04	2.27E-04	1.11E-04	7.36E-05	3.17E-04	4.26E-04	2.10E-04	3.18E-05	7.01E-05
7.98E-03	8.75E-03	4.72E-03	7.81E-03	2.73E-03	2.17E-03	5.55E-03	1.87E-02	1.79E-02	9.78E-04	1.46E-02
3.95E-02	5.80E-03	5.37E-03	1.45E-02	5.09E-03	7.95E-04	2.69E-03	6.73E-03	5.31E-03	1.83E-03	2.93E-02
1.48E-03	2.26E-04	1.24E-04	1.58E-03	9.64E-05	3.49E-05	7.01E-05	1.79E-04	1.60E-04	1.09E-04	1.41E-04
1.06E-01	1.10E-01	1.10E-01	1.75E-01	1.46E-01	2.96E-02	9.92E-02	1.17E-01	8.44E-02	1.24E-02	2.51E-02
2.91E-03	4.51E-03	3.99E-03	2.43E-03	4.77E-03	4.45E-04	1.99E-03	3.30E-03	2.74E-03	6.42E-03	2.44E-03
6.84E-02	3.95E-03	4.31E-03	6.73E-03	1.45E-03	2.73E-04	8.25E-04	1.59E-03	1.26E-03	6.48E-03	1.02E-03
5.52E-04	5.87E-05	2.64E-05	4.96E-05	3.98E-05	7.61E-06	1.62E-05	3.12E-05	2.53E-05	7.90E-05	5.47E-05
1.13E+00	6.60E-04	4.75E-04	1.07E-03	3.94E-04	3.12E-04	8.27E-04	9.39E-04	3.96E-04	1.44E-04	4.75E-04
7.02E-02	1.09E+00	1.81E-01	8.34E-02	4.21E-02	8.99E-03	1.38E-01	1.49E-01	7.63E-02	7.87E-03	1.15E-02
8.07E-04	3.09E-03	1.01E+00	7.41E-04	6.65E-04	1.25E-04	7.24E-04	2.69E-03	2.55E-03	3.90E-04	2.56E-04
5.57E-04	2.64E-03	1.30E-03	1.00E+00	6.30E-04	5.72E-04	1.09E-03	1.82E-03	1.60E-03	1.66E-04	5.33E-04
1.54E-03	5.41E-03	1.30E-03	2.69E-02	1.00E+00	1.40E-03	1.12E-03	3.44E-03	2.95E-03	4.03E-04	4.82E-03
5.76E-03	8.87E-03	4.70E-03	5.72E-03	2.99E-03	1.00E+00	9.29E-03	1.38E-02	8.61E-03	9.17E-04	5.06E-04
3.03E-03	9.72E-04	7.36E-04	7.60E-04	4.53E-04	1.58E-04	1.04E+00	5.51E-03	5.53E-03	6.75E-03	2.34E-04
1.69E-02	1.93E-02	2.56E-02	3.10E-02	5.66E-03	1.55E-02	7.13E-02	1.12E+00	9.59E-03	1.84E-03	4.67E-03
2.92E-03	3.28E-03	2.90E-03	6.14E-03	9.26E-04	3.66E-03	1.54E-03	1.92E-03	1.03E+00	2.51E-04	9.23E-04
7.77E-03	1.47E-03	9.82E-04	3.46E-03	1.05E-03	2.92E-04	6.65E-04	1.19E-03	9.84E-04	1.00E+00	9.47E-04
1.21E-03	3.51E-03	9.76E-03	8.52E-03	1.42E-03	2.65E-03	1.24E-03	4.49E-03	4.24E-03	2.90E-04	1.00E+00

Table 4.18

Annual Direct and Indirect Impacts On Output (Million 1994$, Producers' Prices)				
	Existing Situation Scenario		Source Control Only Scenario	
	Installation Year	O&M-Only Year	Installation Year	O&M-Only Year
Aggregated IMPLAN Sector #	(200 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	(116.76 Million1994 Annual Transfer From Household Dividend Payments To Remediation)	(101.16 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	(56.12 Million 1994$ Annual Transfer From Household Dividend Payments To Remediation)
1	-0.07	-0.04	-0.04	-0.02
28	0.03	0.01	0.02	0.01
38	0.69	0.04	0.30	0.02
40	0.01	0.00	0.00	0.00
48	3.78	1.01	2.18	0.49
58	-0.55	-0.26	-0.28	-0.13
108	-0.22	-0.13	-0.11	-0.06
133	0.37	0.03	0.19	0.02
148	-0.04	-0.02	-0.02	-0.01
161	0.01	0.01	0.00	0.00
174	1.41	1.02	0.69	0.49
186	2.57	0.56	1.39	0.27
210	2.44	0.16	0.94	0.08
215	0.01	0.00	0.01	0.00
221	-0.01	0.00	0.00	0.00
230	0.01	0.00	0.00	0.00
254	0.01	0.01	0.01	0.00
273	0.08	0.01	0.03	0.01
307	0.95	0.26	0.48	0.14
339	5.40	2.79	2.48	1.34
384	0.04	0.01	0.02	0.00
400	1.03	0.17	0.52	0.08
415	0.05	0.03	0.03	0.02
433	2.13	1.67	1.03	0.80
434	1.73	0.52	0.85	0.25
438	0.09	0.01	0.04	0.01
439	5.85	4.48	2.79	2.15
443	0.47	0.33	0.25	0.18
444	1.75	0.07	0.87	0.03
445	0.95	0.96	0.47	0.48
446	26.64	0.07	13.16	0.03
447	20.99	13.36	10.27	6.41
473	17.95	0.48	9.18	0.24
477	0.78	0.32	0.40	0.17
479	0.28	0.23	0.14	0.11
494	6.03	1.13	5.11	0.54
506	9.10	1.78	5.47	0.97
507	107.32	101.95	51.48	48.70
509	5.63	5.47	2.76	2.68
512	3.11	0.18	2.56	0.16
513	1.73	0.36	0.94	0.17
516	0.00	0.00	0.00	0.00
517	0.00	0.00	0.00	0.00
519	0.00	0.00	0.00	0.00
524	0.00	0.00	0.00	0.00
Total	230.52	139.06	116.62	66.82

Table 4.19

California 1993 Criteria Air Pollution Emissions Inventory Data
By Aggregated IMPLAN Sector

Aggregated IMPLAN Sector #	Aggregated Sector Name	TOG Emissions (Tons/Yr)	ROG Emissions (Tons/Yr)	CO Emissions (Tons/Yr)	NOX Emissions (Tons/Yr)	SOX Emissions (Tons/Yr)	PM Emissions (Tons/Yr)	PM10 Emissions (Tons/Yr)
1	Agriculture	615.9	167.9	282.8	1433.3	363.2	3610	1850.7
28	Mining	333.2	261.4	477 9	2397.8	228.5	2587.2	1042.9
38	Natural Gas	29621	9494 3	12405.2	22763.6	2660.7	941.8	918
40	Sand, Gravel & Clay	153.1	128.3	248.8	750	215.9	7013.6	2945
48	Construction	511	358.8	679.4	477.3	40.2	262.4	207.9
58	Food & Tobacco	4040.5	2985.9	2729.6	4021.6	483.2	3909.4	1568.5
108	Textiles	633.2	423.6	79.5	169.6	0.8	18.2	16 8
133	Wood Products	3604.3	2033.1	18364.8	4038.4	941.3	3903.1	2846.9
148	Furniture	4341.5	2450.4	11	33 4	0	14.2	9.1
161	Pulp & Paper	3293.4	1659.4	1657.9	2988.1	446	1053.4	885.8
174	Printing	3100.8	2586.7	417	129.3	0.4	111.9	87 1
186	Chemicals, Paint & Adhesives	6360.6	4810.7	11029	4167.7	787 6	8073.2	2530
210	Petroleum Refining and Products	21676.1	15642.6	7105	29439 5	28629 6	7305.8	4822.2
215	Rubber & Plastics	6486	2743	45 8	166.4	1 3	124 8	104 9
221	Leather Products	212.5	181.3	1 2	5 5	0	13 2	9 3
230	Concrete, Brick, Glass & Ceramics	1996.2	1334.1	5687.6	26476 5	4185 7	10181 6	7256 4
254	Primary Metals Production	1522.2	956.1	630 8	939	231 9	370 2	287.4
273	Fabricated Metal Products	8099.7	5734 5	588 3	817	131 8	224 9	176.6
307	Heavy Machinery	1910 2	1205.7	126	222.9	15 1	150 6	120 4
339	Electrical Equip & Computers	2868.1	1492.1	127	339 8	10 1	62 1	53 2
384	Autos, Trucks, Aircraft, Missiles	6070 9	3209 5	1536 2	717 6	25 3	306 7	275 9
400	Precision Instruments	1236.9	522.5	51 6	93 5	0 9	5.1	4 5
415	Misc. Light Manufacturing	1341 3	660 8	10 5	14 9	0	125.5	84 3
433	Rail, Air & Water Transport	6645.2	5604 6	33837 6	6596	420 9	554	509 3
434	Road Transport	193 3	166	8	17 9	0 4	20.7	13 6
438	Pipe Lines, Except Natural Gas	912 4	755 9	389 3	458 3	161 9	25 9	24
439	Consumer Services	5724 2	3434 1	3064 6	3679 1	111 5	326	265 2
443	Electricity	12517 9	2851 1	23922 1	41690 1	3649 8	3611 7	3059 6
444	Gas Production and Distribution	4472 3	725 1	2464	13363 3	18 7	72 3	67 3
445	Water Supply and Sewerage Systems	1878 9	500 8	2199 5	2883 7	226 1	166 7	145 6
446	Sanitary Services and Steam Supply	68929 8	1798 7	2252 7	1693 4	217	471 4	405 6
447	Producer Services	4833 4	3791 7	334 8	671	39 7	154 4	98 9
473	Equipment Rental and Leasing	192	131 7	1647 6	267 4	15 7	22 2	20 7
477	Automobile Rental and Leasing	4 5	3 7	58	1 5	0 1	1 7	1 2
479	Automobile Repair and Services	2135 3	1833 2	137 6	84 6	4 9	9	7 9
494	Legal Services	0 4	0 2	2 6	10 3	0	0 3	0 3
506	Engineering, Architectural Service	39 2	7 8	10 5	52 5	0 9	13 6	13 4
507	Management & Accounting	40 3	35 2	11 3	33 9	1 7	1 8	1 8
509	Research, Development & Testing Se	138 9	29 1	109 8	51 5	1 2	2 2	2 1
512	State & Local Government	913.6	361 7	705	934 9	56 1	236	218 9
513	Federal Government - Non-Defence	41	25 8	19 7	25 5	0 7	1 5	1 5
516	Noncomparable Imports	0	0	0	0	0	0	0
517	Scrap & Used Goods	0	0	0	0	0	0	0
519	Federal Government - Defence	3933 7	3345 9	4745 5	2797 8	247 7	77418 4	28725 5
524	Rest of the World Industry	0	0	0	0	0	0	0
Total		223594 9	86445	140213 1	177915 4	44575 1	133478 7	61786 2

Data Source California 1993 Air Pollution Emissions Inventory database
California Air Resources Board Sacramento, CA

Table 4.20

California 1993 Air Toxics Emissions Inventory Data
By Aggregated IMPLAN Sector

Heavy Metal Emissions Only
(Pollutants with CAS #'s between 7430000 and 7500000,
plus CAS # 7782492)

Aggregated IMPLAN Sector #	Aggregated Sector Name	Emissions (lbs./day)
1	Agriculture	1762.88
28	Mining	11746.34
38	Natural Gas	67863.73
40	Sand, Gravel & Clay	4517.48
48	Construction	30.42
58	Food & Tobacco	5114.09
108	Textiles	0.31
133	Wood Products	20999.53
148	Furniture	324.36
161	Pulp & Paper	7102.28
174	Printing	15.61
186	Chemicals, Paint & Adhesives	10919.87
210	Petroleum Refining and Products	40231.73
215	Rubber & Plastics	2807.90
221	Leather Products	53.86
230	Concrete, Brick, Glass & Ceramics	30091.53
254	Primary Metals Production	5963.80
273	Fabricated Metal Products	6273.39
307	Heavy Machinery	5979.09
339	Electrical Equip. & Computers	3183.99
384	Autos, Trucks, Aircraft, Missiles	42667.23
400	Precision Instruments	122.02
415	Misc. Light Manufacturing	86.93
433	Rail, Air & Water Transport.	621.61
434	Road Transport.	35.65
438	Pipe Lines, Except Natural Gas	1913.78
439	Consumer Services	1056.02
443	Electricity	61952.35
444	Gas Production and Distribution	12.90
445	Water Supply and Sewerage Systems	97.04
446	Sanitary Services and Steam Supply	10932.82
447	Producer Services	1334.91
473	Equipment Rental and Leasing	0.00
477	Automobile Rental and Leasing	0.00
479	Automobile Repair and Services	86.47
494	Legal Services	0.00
506	Engineering, Architectural Service	15.57
507	Management & Accounting	. 0.00
509	Research, Development & Testing Se	45.16
512	State & Local Government	369.26
513	Federal Government - Non-Defence	84.00
516	Noncomparable Imports	0.00
517	Scrap & Used Goods	0.00
519	Federal Government - Defence	12986.67
524	Rest of the World Industry	0.00
Total		359402.59

Data Source: 1993 Air Toxics Emissions Inventory database.
California Air Resources Board. Sacramento, CA.
(Latest available data as of July 1997.)

Table 4.21

California 1993 Air Toxics Emissions Inventory Data
By Aggregated IMPLAN Sector

Organic and Inorganic Emissions (Excl. Heavy Metals)
(Pollutants with CAS #'s less than 7430000
or more than 7500000, excl. CAS # 7782492)

Aggregated IMPLAN Sector #	Aggregated Sector Name	Emissions (lbs./day)
1	Agriculture	89730.49
28	Mining	1005760.61
38	Natural Gas	2379137.33
40	Sand, Gravel & Clay	67312.45
48	Construction	46880.08
58	Food & Tobacco	235808.73
108	Textiles	230715.74
133	Wood Products	1910477.82
148	Furniture	3379939.24
161	Pulp & Paper	3688154.11
174	Printing	1295130.69
186	Chemicals, Paint & Adhesives	5028786.04
210	Petroleum Refining and Products	2759495.22
215	Rubber & Plastics	9169789.70
221	Leather Products	12099.39
230	Concrete, Brick, Glass & Ceramics	1517875.99
254	Primary Metals Production	1544254.72
273	Fabricated Metal Products	10979154.83
307	Heavy Machinery	1543212.63
339	Electrical Equip. & Computers	2993613.88
384	Autos, Trucks, Aircraft, Missiles	11282382.81
400	Precision Instruments	899561.36
415	Misc. Light Manufacturing	867794.67
433	Rail, Air & Water Transport.	587639.34
434	Road Transport.	374144.50
438	Pipe Lines, Except Natural Gas	1893514.59
439	Consumer Services	5099439.30
443	Electricity	1361324.76
444	Gas Production and Distribution	251824.73
445	Water Supply and Sewerage Systems	375363.56
446	Sanitary Services and Steam Supply	433825.06
447	Producer Services	2980376.44
473	Equipment Rental and Leasing	0.00
477	Automobile Rental and Leasing	245.80
479	Automobile Repair and Services	520218.99
494	Legal Services	0.00
506	Engineering, Architectural Service	2297.14
507	Management & Accounting	3010.53
509	Research, Development & Testing Se	57892.57
512	State & Local Government	121288.83
513	Federal Government - Non-Defence	35495.59
516	Noncomparable Imports	0.00
517	Scrap & Used Goods	0.00
519	Federal Government - Defence	831787.47
524	Rest of the World Industry	0.00
Total		77856757.70

Data Source: 1993 Air Toxics Emissions Inventory database.
California Air Resources Board. Sacramento, CA.
(Latest available data as of July 1997.)

Table 4.22

Wastewater Discharges By Aggregated IMPLAN Sector
Water Quality Threat Level 1 (most threatening)
Million Gallons per Day (MGD)

Aggregated IMPLAN Sector #	Aggregated Sector Name	AGGR. DESIGN FLOW	AGGR. BASE FLOW
1	Agriculture	24.1	12.7009
28	Mining	33.4934	30.6601
38	Natural Gas	0	0
40	Sand, Gravel & Clay	30.08	26.48
48	Construction	9.9802	5.6812
58	Food & Tobacco	17.9721	13.3431
108	Textiles	0	0
133	Wood Products	42.8607	30.9107
148	Furniture	0	0
161	Pulp & Paper	16.8	13.95
174	Printing	0.0103	0.007
186	Chemicals, Paint & Adhesives	12.9057	5.9249
210	Petroleum Refining and Products	80.2845	73.2484
215	Rubber & Plastics	1	0.8756
221	Leather Products	0	0
230	Concrete, Brick, Glass & Ceramics	0.78	0.716
254	Primary Metals Production	40.0001	14.005
273	Fabricated Metal Products	0.3192	0.0607
307	Heavy Machinery	0	0
339	Electrical Equip. & Computers	0.65	0.1501
384	Autos, Trucks, Aircraft, Missiles	37.5004	36.6004
400	Precision Instruments	0	0
415	Misc. Light Manufacturing	0	0
433	Rail, Air & Water Transport.	1.1	0.6
434	Road Transport.	0	0
438	Pipe Lines, Except Natural Gas	0.144	0.072
439	Consumer Services	6.212	3.612
443	Electricity	15800.37	13825.29
444	Gas Production and Distribution	0	0
445	Water Supply and Sewerage Systems	10373.23	9245.994
446	Sanitary Services and Steam Supply	1001.939	1001.896
447	Producer Services	18.9935	3.0265
473	Equipment Rental and Leasing	0	0
477	Automobile Rental and Leasing	0	0
479	Automobile Repair and Services	0	0
494	Legal Services	0	0
506	Engineering, Architectural Service	0	0
507	Management & Accounting	0	0
509	Research, Development & Testing Se	0	0
512	State & Local Government	0	0
513	Federal Government - Non-Defence	160	15
516	Noncomparable Imports	0	0
517	Scrap & Used Goods	0	0
519	Federal Government - Defence	6.1733	1.2604
524	Rest of the World Industry	0	0
Total		27716.9	24362.07

Data Source:
California State Water Resources Control Board. 1997.
Waste Discharger System (WDS) data files.

Table 4.23

Wastewater Discharges By Aggregated IMPLAN Sector
Water Quality Threat Level 2 (moderately threatening)
Million Gallons per Day (MGD)

Aggregated IMPLAN Sector #	Aggregated Sector Name	AGGR. DESIGN FLOW	AGGR. BASE FLOW
1	Agriculture	426.0819	307.9069
28	Mining	5.1111	4.5511
38	Natural Gas	38.1214	33.3046
40	Sand, Gravel & Clay	86.4699	20.6738
48	Construction	87.5278	226.1183
58	Food & Tobacco	259.0643	184.5543
108	Textiles	0.05	0.05
133	Wood Products	10.093	4.8469
148	Furniture	0	0
161	Pulp & Paper	38.323	28.223
174	Printing	1.3874	1.237
186	Chemicals, Paint & Adhesives	12.3835	11.9587
210	Petroleum Refining and Products	84.4997	35.6177
215	Rubber & Plastics	0.0601	0.0221
221	Leather Products	0	0
230	Concrete, Brick, Glass & Ceramics	1.1764	1.1293
254	Primary Metals Production	0.0394	0.0257
273	Fabricated Metal Products	5.7274	3.1595
307	Heavy Machinery	0.0101	0.0101
339	Electrical Equip. & Computers	15.9402	9.7821
384	Autos, Trucks, Aircraft, Missiles	3.3821	2.3245
400	Precision Instruments	0.2721	0.1871
415	Misc. Light Manufacturing	0	0
433	Rail, Air & Water Transport.	4.1111	2.8389
434	Road Transport.	0.4322	0.3375
438	Pipe Lines, Except Natural Gas	0.892	0.762
439	Consumer Services	75.7622	94.7352
443	Electricity	781.958	776.2023
444	Gas Production and Distribution	0.068	0.088
445	Water Supply and Sewerage Systems	1491.606	537.051
446	Sanitary Services and Steam Supply	621.2628	621.5987
447	Producer Services	1.4621	1.7981
473	Equipment Rental and Leasing	0	0
477	Automobile Rental and Leasing	0	0
479	Automobile Repair and Services	0.0039	0.0015
494	Legal Services	0	0
506	Engineering, Architectural Service	0	0
507	Management & Accounting	0	0
509	Research, Development & Testing Se	0.016	0.016
512	State & Local Government	0.0534	0.0474
513	Federal Government - Non-Defence	0.504	0.504
516	Noncomparable Imports	0	0
517	Scrap & Used Goods		
519	Federal Government - Defence	3.7344	2.2114
524	Rest of the World Industry	0	0
Total		4057.587	2913.875

Data Source:
California State Water Resources Control Board. 1997.
Waste Discharger System (WDS) data files.

Table 4.24

Wastewater Discharges By Aggregated IMPLAN Sector
Water Quality Threat Level 3 (minor threat level)
Million Gallons per Day (MGD)

Aggregated IMPLAN Sector #	Aggregated Sector Name	AGGR. DESIGN FLOW	AGGR. BASE FLOW
1	Agriculture	566.6364	501.1016
28	Mining	13.057	11.804
38	Natural Gas	2.4611	2.7223
40	Sand, Gravel & Clay	77.6518	59.9218
48	Construction	38.8622	37.3008
58	Food & Tobacco	21.8786	15.1733
108	Textiles	0	0
133	Wood Products	0.0011	0.002
148	Furniture	0	0
161	Pulp & Paper	0.7458	0.276
174	Printing	0.1156	0.1156
186	Chemicals, Paint & Adhesives	10.0733	9.2234
210	Petroleum Refining and Products	17.5214	17.1842
215	Rubber & Plastics	0.4172	0.3272
221	Leather Products	0	0
230	Concrete, Brick, Glass & Ceramics	6.5272	6.4436
254	Primary Metals Production	0.9401	0.9428
273	Fabricated Metal Products	0.4373	0.4863
307	Heavy Machinery	0.4031	0.4421
339	Electrical Equip. & Computers	8.2911	6.7282
384	Autos, Trucks, Aircraft, Missiles	8.9519	8.8134
400	Precision Instruments	0	0
415	Misc. Light Manufacturing	0	0
433	Rail, Air & Water Transport.	1.9852	2.1
434	Road Transport.	0.3505	0.263
438	Pipe Lines, Except Natural Gas	3.1015	2.561
439	Consumer Services	46.4741	40.03
443	Electricity	44.3186	38.8408
444	Gas Production and Distribution	0.127	0.1118
445	Water Supply and Sewerage Systems	312.3096	230.7549
446	Sanitary Services and Steam Supply	96.295	67.9328
447	Producer Services	6.3915	6.61
473	Equipment Rental and Leasing	0.14	0.14
477	Automobile Rental and Leasing	0.0246	0.0102
479	Automobile Repair and Services	2.9721	3.0331
494	Legal Services	0	0
506	Engineering, Architectural Service	0.216	0.216
507	Management & Accounting	0.0015	0.0015
509	Research, Development & Testing Se	0.0845	0.0595
512	State & Local Government	25.9905	18.6679
513	Federal Government - Non-Defence	0	0
516	Noncomparable Imports	0	0
517	Scrap & Used Goods	0	0
519	Federal Government - Defence	39.3256	38.1099
524	Rest of the World Industry	0	0
Total		1355.08	1128.451

Data Source:
California State Water Resources Control Board. 1997.
Waste Discharger System (WDS) data files.

Table 4.25

Annual Direct and Indirect Impacts On Criteria Air Pollutants

Existing Situation Scenario

Installation Year

(200 Million1994$ Annual Transfer
From Household Dividend Payments To Remediation)

Aggregated IMPLAN Sector #	Change In TOG Emissions (Lbs./Year)	Change In ROG Emissions (Lbs./Year)	Change In CO Emissions (Lbs./Year)	Change In NOX Emissions (Lbs./Year)	Change In SOX Emissions (Lbs./Year)	Change In PM Emissions (Lbs./Year)	Change In PM10 Emissions (Lbs./Year)
1	-2.63	-0.72	-1.21	-6.12	-1.55	-15.42	-8.33
28	26.61	20.87	38.16	191.46	18.25	206.59	83.28
38	6371.78	2042.32	2668.48	4896.68	572.34	202.59	197.47
40	3.30	2.76	5.36	16.15	4.65	150.99	63.40
48	42.33	29.72	56.28	39.54	3.33	21.74	17.22
58	-102.45	-75.71	-69.21	-101.97	-12.25	-99.13	-39.77
108	-19.98	-13.37	-2.51	-5.35	-0.03	-0.57	-0.53
133	400.65	226.00	2041.41	448.90	104.70	433.86	316.46
148	-65.64	-37.05	-0.17	-0.51	0.00	-0.21	-0.14
161	8.57	4.32	4.31	7.77	1.16	2.74	2.30
174	478.67	399.31	64.37	19.96	0.06	17.27	13.45
186	1630.85	1229.59	2818.97	1065.25	201.31	2063.48	646.66
210	4402.91	3177.37	1443.19	5979.83	5815.32	1483.97	979.50
215	15.59	6.60	0.11	0.40	0.00	0.30	0.25
221	-8.08	-6.89	-0.05	-0.21	0.00	-0.50	-0.35
230	5.77	3.86	16.44	76.52	12.10	29.42	20.97
254	6.58	4.13	2.73	4.06	1.00	1.60	1.24
273	76.68	54.29	5.57	7.73	1.25	2.13	1.67
307	239.07	150.90	15.77	27.90	1.89	18.85	15.07
339	512.53	266.64	22.70	60.72	1.80	11.10	9.51
384	12.17	6.43	3.08	1.44	0.05	0.61	0.55
400	85.67	36.19	3.57	6.48	0.06	0.35	0.31
415	30.14	14.85	0.24	0.33	0.00	2.82	1.89
433	1451.76	1224.42	7392.42	1441.01	91.95	121.03	111.27
434	31.55	27.09	1.31	2.92	0.07	3.38	2.22
438	201.42	166.87	85.94	101.17	35.74	5.72	5.30
439	112.94	67.76	60.47	72.59	2.20	6.43	5.23
443	950.94	216.59	1817.27	3167.04	277.26	274.37	232.43
444	1114.70	180.73	614.14	3330.75	4.66	18.02	16.77
445	7576.20	2019.35	8868.94	11627.81	911.69	672.18	587.10
446	1091182.24	28474.03	35661.01	26807.10	3435.18	7462.42	6420.79
447	1400.47	1098.64	97.01	194.42	11.50	44.74	28.66
473	1508.12	1034.48	12941.58	2100.38	123.32	174.38	162.59
477	2.30	1.89	29.59	0.77	0.05	0.87	0.61
479	118.91	102.09	7.66	4.71	0.27	0.50	0.44
494	0.26	0.13	1.72	6.80	0.00	0.20	0.20
506	56.54	11.25	15.14	75.72	1.30	19.62	19.33
507	308.99	269.89	86.64	259.92	13.03	13.80	13.80
509	151.41	31.72	119.69	56.14	1.31	2.40	2.29
512	127.40	50.44	98.31	130.37	7.82	32.91	30.53
513	6.70	4.22	3.22	4.17	0.11	0.25	0.25
516	0.00	0.00	0.00	0.00	0.00	0.00	0.00
517	0.00	0.00	0.00	0.00	0.00	0.00	0.00
519	0.00	0.00	0.00	0.00	0.00	0.00	0.00
524	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1120453.94	42523.99	77039.65	62120.75	11642.93	13387.77	9961.86

Table 4.26

Annual Direct and Indirect Impacts On Criteria Air Pollutants

Existing Situation Scenario
O&M-Only Year

(116.76 Million1994$ Annual Transfer
From Household Dividend Payments To Remediation)

Aggregated IMPLAN Sector #	Change In TOG Emissions (Lbs./Year)	Change In ROG Emissions (Lbs./Year)	Change In CO Emissions (Lbs./Year)	Change In NOX Emissions (Lbs./Year)	Change In SOX Emissions (Lbs./Year)	Change In PM Emissions (Lbs./Year)	Change In PM10 Emissions (Lbs./Year)
1	-1.53	-0.42	-0.70	-3.57	-0.91	-9.00	-4.86
28	12.01	9.42	17.22	86.42	8.24	93.24	37.59
38	411.71	131.96	172.42	316.40	36.98	13.09	12.76
40	0.91	0.76	1.48	4.46	1.28	41.73	17.52
48	11.27	7.91	14.99	10.53	0.89	5.79	4.59
58	-48.99	-36.20	-33.10	-48.76	-5.86	-47.40	-19.02
108	-12.18	-8.15	-1.53	-3.26	-0.02	-0.35	-0.32
133	35.80	20.19	182.41	40.11	9.36	38.77	28.28
148	-42.76	-24.13	-0.11	-0.33	0.00	-0.14	-0.09
161	4.82	2.43	2.43	4.37	0.65	1.54	1.30
174	346.62	289.15	46.61	14.45	0.04	12.51	9.74
186	357.25	269.35	617.51	233.35	44.10	452.01	141.65
210	284.59	205.37	93.28	386.51	375.88	95.92	63.31
215	5.91	2.50	0.04	0.15	0.00	0.11	0.10
221	-4.27	-3.64	-0.02	-0.11	0.00	-0.27	-0.19
230	1.21	0.81	3.46	16.09	2.54	6.19	4.41
254	2.78	1.74	1.15	1.71	0.42	0.68	0.52
273	13.31	9.42	0.97	1.34	0.22	0.37	0.29
307	64.93	40.98	4.28	7.58	0.51	5.12	4.09
339	264.30	137.50	11.70	31.31	0.93	5.72	4.90
384	3.39	1.79	0.86	0.40	0.01	0.17	0.15
400	13.92	5.88	0.58	1.05	0.01	0.06	0.05
415	19.84	9.78	0.16	0.22	0.00	1.86	1.25
433	1140.38	961.80	5806.84	1131.93	72.23	95.07	87.40
434	9.54	8.19	0.39	0.88	0.02	1.02	0.67
438	27.19	22.52	11.60	13.66	4.82	0.77	0.72
439	86.50	51.89	46.31	55.60	1.68	4.93	4.01
443	672.44	153.16	1285.05	2239.51	196.06	194.01	164.36
444	41.94	6.80	23.11	125.32	0.18	0.68	0.63
445	7700.43	2052.47	9014.37	11818.48	926.64	683.20	596.72
446	2881.00	75.18	94.15	70.78	9.07	19.70	16.95
447	891.69	699.51	61.77	123.79	7.32	28.48	18.25
473	40.63	27.87	348.67	56.59	3.32	4.70	4.38
477	0.96	0.79	12.37	0.32	0.02	0.36	0.26
479	97.94	84.09	6.31	3.88	0.22	0.41	0.36
494	0.05	0.02	0.32	1.27	0.00	0.04	0.04
506	11.06	2.20	2.96	14.81	0.25	3.84	3.78
507	293.54	256.39	82.31	246.92	12.38	13.11	13.11
509	147.18	30.83	116.34	54.57	1.27	2.33	2.23
512	7.56	2.99	5.83	7.73	0.46	1.95	1.81
513	1.39	0.88	0.67	0.87	0.02	0.05	0.05
516	0.00	0.00	0.00	0.00	0.00	0.00	0.00
517	0.00	0.00	0.00	0.00	0.00	0.00	0.00
519	0.00	0.00	0.00	0.00	0.00	0.00	0.00
524	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	15796.25	5512.01	18055.47	17067.34	1711.29	1772.38	1223.73

Table 4.27

Annual Direct and Indirect Impacts On Criteria Air Pollutants

Source Control Only Scenario

Installation Year

(101.16 Million1994$ Annual Transfer
From Household Dividend Payments To Remediation)

Aggregated IMPLAN Sector #	Change In TOG Emissions (Lbs./Year)	Change In ROG Emissions (Lbs./Year)	Change In CO Emissions (Lbs./Year)	Change In NOX Emissions (Lbs./Year)	Change In SOX Emissions (Lbs./Year)	Change In PM Emissions (Lbs./Year)	Change In PM10 Emissions (Lbs./Year)
1	-1.35	-0.37	-0.62	-3.15	-0.80	-7.94	-4.29
28	13.91	10.91	19.95	100.09	9.54	107.99	43.53
38	2793.31	895.33	1169.83	2146.64	250.91	88.81	86.57
40	1.54	1.29	2.50	7.55	2.17	70.60	29.64
48	24.41	17.14	32.45	22.80	1.92	12.53	9.93
58	-52.85	-39.05	-35.70	-52.60	-6.32	-51.13	-20.51
108	-10.20	-6.82	-1.28	-2.73	-0.01	-0.29	-0.27
133	204.10	115.13	1039.94	228.68	53.34	221.02	161.21
148	-33.21	-18.75	-0.08	-0.26	0.00	-0.11	-0.07
161	4.22	2.13	2.12	3.83	0.57	1.35	1.13
174	235.01	196.05	31.60	9.80	0.03	8.48	6.60
186	884.83	667.13	1529.45	577.96	109.22	1119.56	350.85
210	1702.10	1228.33	557.92	2311.72	2248.12	573.68	378.66
215	7.77	3.29	0.05	0.20	0.00	0.15	0.13
221	-4.11	-3.50	-0.02	-0.11	0.00	-0.26	-0.18
230	2.62	1.75	7.47	34.79	5.50	13.38	9.54
254	3.21	2.02	1.33	1.98	0.49	0.78	0.61
273	29.59	20.95	2.15	2.98	0.48	0.82	0.65
307	121.18	76.49	7.99	14.14	0.96	9.55	7.64
339	235.35	122.44	10.42	27.88	0.83	5.10	4.37
384	5.99	3.17	1.52	0.71	0.02	0.30	0.27
400	43.40	18.33	1.81	3.28	0.03	0.18	0.16
415	14.84	7.31	0.12	0.16	0.00	1.39	0.93
433	701.53	591.67	3572.19	696.33	44.43	58.49	53.77
434	15.49	13.30	0.64	1.43	0.03	1.66	1.09
438	86.43	71.61	36.88	43.42	15.34	2.45	2.27
439	53.75	32.25	28.78	34.55	1.05	3.06	2.49
443	504.34	114.87	963.81	1679.67	147.05	145.51	123.27
444	554.21	89.85	305.34	1655.99	2.32	8.96	8.34
445	3784.61	1008.75	4430.38	5808.55	455.43	335.78	293.28
446	539032.86	14065.88	17616.17	13242.43	1696.95	3686.36	3171.80
447	685.01	537.38	47.45	95.10	5.63	21.88	14.02
473	771.01	528.87	6616.25	1073.79	63.05	89.15	83.12
477	1.19	0.98	15.35	0.40	0.03	0.45	0.32
479	58.42	50.16	3.76	2.31	0.13	0.25	0.22
494	0.22	0.11	1.45	5.76	0.00	0.17	0.17
506	34.03	6.77	9.11	45.57	0.78	11.80	11.63
507	148.24	129.48	41.57	124.70	6.25	6.62	6.62
509	74.33	15.57	58.76	27.56	0.64	1.18	1.12
512	104.89	41.53	80.94	107.33	6.44	27.09	25.13
513	3.63	2.29	1.75	2.26	0.06	0.13	0.13
516	0.00	0.00	0.00	0.00	0.00	0.00	0.00
517	0.00	0.00	0.00	0.00	0.00	0.00	0.00
519	0.00	0.00	0.00	0.00	0.00	0.00	0.00
524	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	552839.87	20621.98	38211.51	30083.50	5122.60	6576.94	4865.88

Table 4.28

Annual Direct and Indirect Impacts On Criteria Air Pollutants

Source Control Only Scenario
O&M-Only Year

(56.12 Million1994$ Annual Transfer
From Household Dividend Payments To Remediation)

Aggregated IMPLAN Sector #	Change In TOG Emissions (Lbs./Year)	Change In ROG Emissions (Lbs./Year)	Change In CO Emissions (Lbs./Year)	Change In NOX Emissions (Lbs./Year)	Change In SOX Emissions (Lbs./Year)	Change In PM Emissions (Lbs./Year)	Change In PM10 Emissions (Lbs./Year)
1	-0.74	-0.20	-0.34	-1.72	-0.44	-4.34	-2.34
28	6.28	4.93	9.00	45.18	4.31	48.75	19.65
38	200.42	64.24	83.94	154.03	18.00	6.37	6.21
40	0.44	0.37	0.71	2.14	0.62	20.05	8.42
48	5.52	3.88	7.34	5.16	0.43	2.83	2.25
58	-23.63	-17.46	-15.96	-23.52	-2.83	-22.86	-9.17
108	-5.85	-3.92	-0.74	-1.57	-0.01	-0.17	-0.16
133	17.39	9.81	88.62	19.49	4.55	18.83	13.74
148	-20.52	-11.58	-0.05	-0.16	0.00	-0.07	-0.04
161	2.31	1.16	1.16	2.10	0.31	0.74	0.62
174	166.09	138.56	22.34	6.93	0.02	5.99	4.67
186	172.37	129.96	297.94	112.59	21.28	218.09	68.35
210	137.67	99.35	45.13	186.98	181.84	46.40	30.63
215	2.84	1.20	0.02	0.07	0.00	0.05	0.05
221	-2.06	-1.76	-0.01	-0.05	0.00	-0.13	-0.09
230	0.58	0.39	1.66	7.75	1.22	2.98	2.12
254	1.36	0.85	0.56	0.84	0.21	0.33	0.26
273	5.92	4.19	0.43	0.60	0.10	0.16	0.13
307	35.53	22.43	2.34	4.15	0.28	2.80	2.24
339	127.45	66.31	5.64	15.10	0.45	2.76	2.36
384	1.64	0.87	0.41	0.19	0.01	0.08	0.07
400	6.68	2.82	0.28	0.50	0.00	0.03	0.02
415	9.51	4.68	0.07	0.11	0.00	0.89	0.60
433	546.12	460.60	2780.87	542.08	34.59	45.53	41.86
434	4.58	3.93	0.19	0.42	0.01	0.49	0.32
438	13.12	10.87	5.60	6.59	2.33	0.37	0.35
439	41.41	24.84	22.17	26.61	0.81	2.36	1.92
443	357.38	81.40	682.97	1190.24	104.20	103.11	87.35
444	20.88	3.39	11.51	62.40	0.09	0.34	0.31
445	3856.28	1027.85	4514.28	5918.54	464.05	342.14	298.83
446	1387.71	36.21	45.35	34.09	4.37	9.49	8.17
447	427.57	335.42	29.62	59.36	3.51	13.66	8.75
473	20.21	13.86	173.41	28.14	1.65	2.34	2.18
477	0.49	0.41	6.37	0.16	0.01	0.19	0.13
479	46.96	40.32	3.03	1.86	0.11	0.20	0.17
494	0.02	0.01	0.15	0.61	0.00	0.02	0.02
506	6.05	1.20	1.62	8.10	0.14	2.10	2.07
507	140.21	122.47	39.31	117.94	5.91	6.26	6.26
509	71.98	15.08	56.90	26.69	0.62	1.14	1.09
512	6.54	2.59	5.05	6.69	0.40	1.69	1.57
513	0.67	0.42	0.32	0.42	0.01	0.02	0.02
516	0.00	0.00	0.00	0.00	0.00	0.00	0.00
517	0.00	0.00	0.00	0.00	0.00	0.00	0.00
519	0.00	0.00	0.00	0.00	0.00	0.00	0.00
524	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	7795.41	2701.95	8929.22	8567.83	853.17	882.04	611.94

Table 4.29

Annual Direct and Indirect Impacts
Organic and Inorganic Toxic Air Emissions (Excl. Heavy Metals)
(Pollutants with CAS #'s less than 7430000
or more than 7500000, excl. CAS # 7782492)

	Existing Situation Scenario		**Source Control Only Scenario**	
	Installation Year (200 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**O&M-Only Year** (116.76 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**Installation Year** (101.16 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**O&M-Only Year** (56.12 Million 1994$ Annual Transfer From Household Dividend Payments To Remediation)
Aggregated IMPLAN Sector #	**Change in Emissions (Lbs./Year)**	**Change in Emissions (Lbs./Year)**	**Change in Emissions (Lbs./Year)**	**Change in Emissions (Lbs./Year)**
1	-49.84	-29.07	-25.66	-14.01
28	10440.27	4712.25	5457.60	2463.56
38	66530.97	4298.87	29166.34	2092.73
40	188.38	52.07	88.08	25.01
48	504.82	134.43	291.09	65.83
58	-777.29	-371.69	-400.94	-179.26
108	-946.59	-576.87	-483.10	-277.32
133	27607.59	2466.89	14063.99	1198.49
148	-6643.58	-4327.24	-3361.49	-2077.27
161	1247.34	701.43	614.26	336.56
174	25990.58	18820.82	12760.56	9018.54
186	167093.79	36602.54	90658.10	17660.46
210	72867.13	4709.85	28169.40	2278.44
215	2866.19	1085.55	1428.92	522.83
221	-59.78	-31.61	-30.39	-15.23
230	570.25	119.90	259.30	57.74
254	868.13	366.17	423.16	179.06
273	13511.55	2345.01	5214.72	1042.53
307	25107.74	6819.12	12727.19	3731.86
339	69545.35	35862.72	31934.72	17293.84
384	2940.11	819.59	1447.69	395.35
400	8099.44	1316.23	4103.14	631.51
415	2535.11	1668.97	1248.21	799.65
433	16689.42	13109.76	8064.72	6278.20
434	7937.90	2400.93	3897.51	1152.67
438	54341.09	7334.36	23318.71	3540.31
439	13080.18	10017.76	6225.38	4795.61
443	13443.91	9506.62	7130.11	5052.49
444	8159.62	307.00	4056.81	152.86
445	196762.90	199989.42	98290.79	100152.16
446	892787.83	2357.18	441028.05	1135.41
447	112263.01	71478.65	54911.16	34274.72
473	0.00	0.00	0.00	0.00
477	16.30	6.81	8.45	3.51
479	3766.10	3102.01	1850.27	1487.40
494	0.00	0.00	0.00	0.00
506	430.72	84.22	259.21	46.10
507	3000.77	2850.68	1439.60	1361.63
509	8204.11	7974.61	4027.33	3899.96
512	2198.77	130.45	1810.25	112.88
513	753.90	156.94	409.10	75.23
516	0.00	0.00	0.00	0.00
517	0.00	0.00	0.00	0.00
519	0.00	0.00	0.00	0.00
524	0.00	0.00	0.00	0.00
Total	1823874.17	448373.32	892482.32	220752.05

Table 4.30

Annual Direct and Indirect Impacts
Heavy Metal Emissions Only

(Pollutants with CAS #'s between 7430000 and 7500000, plus CAS # 7782492)

Aggregated IMPLAN Sector #	Existing Situation Scenario		Source Control Only Scenario	
	Installation Year (200 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**O&M-Only Year** (116.76 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**Installation Year** (101.16 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**O&M-Only Year** (56.12 Million 1994$ Annual Transfer From Household Dividend Payments To Remediation)
	Change in Emissions (Lbs./Year)	**Change in Emissions (Lbs./Year)**	**Change in Emissions (Lbs./Year)**	**Change in Emissions (Lbs./Year)**
1	-0.98	-0.57	-0.50	-0.28
28	121.93	55.03	63.74	28.77
38	1897.76	122.62	831.96	59.69
40	12.64	3.49	5.91	1.68
48	0.33	0.09	0.19	0.04
58	-16.86	-8.06	-8.70	-3.89
108	0.00	0.00	0.00	0.00
133	303.46	27.12	154.59	13.17
148	-0.64	-0.42	-0.32	-0.20
161	2.40	1.35	1.18	0.65
174	0.31	0.23	0.15	0.11
186	362.84	79.48	196.86	38.35
210	1062.36	68.67	410.69	33.22
215	0.88	0.33	0.44	0.16
221	-0.27	-0.14	-0.14	-0.07
230	11.31	2.38	5.14	1.14
254	3.35	1.41	1.63	0.69
273	7.72	1.34	2.98	0.60
307	97.28	26.42	49.31	14.46
339	73.97	38.14	33.97	18.39
384	11.12	3.10	5.47	1.50
400	1.10	0.18	0.56	0.09
415	0.25	0.17	0.13	0.08
433	17.65	13.87	8.53	6.64
434	0.76	0.23	0.37	0.11
438	54.92	7.41	23.57	3.58
439	2.71	2.07	1.29	0.99
443	611.82	432.64	324.48	229.93
444	0.42	0.02	0.21	0.01
445	50.87	51.70	25.41	25.89
446	22499.14	59.40	11114.34	28.61
447	50.28	32.02	24.59	15.35
473	0.00	0.00	0.00	0.00
477	0.00	0.00	0.00	0.00
479	0.63	0.52	0.31	0.25
494	0.00	0.00	0.00	0.00
506	2.92	0.57	1.76	0.31
507	0.00	0.00	0.00	0.00
509	6.40	6.22	3.14	3.04
512	6.69	0.40	5.51	0.34
513	1.78	0.37	0.97	0.18
516	0.00	0.00	0.00	0.00
517	0.00	0.00	0.00	0.00
519	0.00	0.00	0.00	0.00
524	0.00	0.00	0.00	0.00
Total	27259.26	1029.80	13289.73	523.60

Table 4.31

Annual Direct and Indirect Impacts
Wastewater Discharges
SWRQB Water Quality Threat Level 1 (most threatening)

Aggregated IMPLAN Sector #	Existing Situation Scenario		Source Control Only Scenario	
	Installation Year (200 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**O&M-Only Year** (116.76 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**Installation Year** (101.16 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**O&M-Only Year** (56.12 Million 1994$ Annual Transfer From Household Dividend Payments To Remediation)
	Change in Emissions (MGY)	**Change in Emissions (MGY)**	**Change in Emissions (MGY)**	**Change in Emissions (MGY)**
1	-0.01	0.00	0.00	0.00
28	0.32	0.14	0.17	0.08
38	0.00	0.00	0.00	0.00
40	0.07	0.02	0.03	0.01
48	0.06	0.02	0.04	0.01
58	-0.04	-0.02	-0.02	-0.01
108	0.00	0.00	0.00	0.00
133	0.45	0.04	0.23	0.02
148	0.00	0.00	0.00	0.00
161	0.00	0.00	0.00	0.00
174	0.00	0.00	0.00	0.00
186	0.20	0.04	0.11	0.02
210	1.93	0.13	0.75	0.06
215	0.00	0.00	0.00	0.00
221	0.00	0.00	0.00	0.00
230	0.00	0.00	0.00	0.00
254	0.01	0.00	0.00	0.00
273	0.00	0.00	0.00	0.00
307	0.00	0.00	0.00	0.00
339	0.00	0.00	0.00	0.00
384	0.01	0.00	0.00	0.00
400	0.00	0.00	0.00	0.00
415	0.00	0.00	0.00	0.00
433	0.02	0.01	0.01	0.01
434	0.00	0.00	0.00	0.00
438	0.00	0.00	0.00	0.00
439	0.01	0.01	0.00	0.00
443	136.53	96.55	72.41	51.31
444	0.00	0.00	0.00	0.00
445	4846.68	4926.16	2421.11	2466.96
446	2061.85	5.44	1018.53	2.62
447	0.11	0.07	0.06	0.03
473	0.00	0.00	0.00	0.00
477	0.00	0.00	0.00	0.00
479	0.00	0.00	0.00	0.00
494	0.00	0.00	0.00	0.00
506	0.00	0.00	0.00	0.00
507	0.00	0.00	0.00	0.00
509	0.00	0.00	0.00	0.00
512	0.00	0.00	0.00	0.00
513	0.32	0.07	0.17	0.03
516	0.00	0.00	0.00	0.00
517	0.00	0.00	0.00	0.00
519	0.00	0.00	0.00	0.00
524	0.00	0.00	0.00	0.00
Total	7048.53	5028.68	3513.60	2521.16

Table 4.32

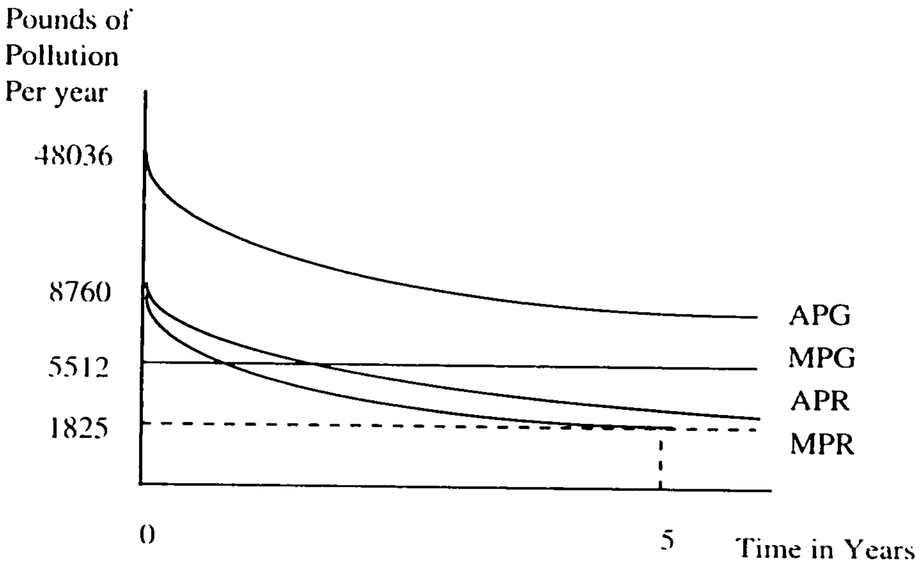
Annual Direct and Indirect Impacts Wastewater Discharges SWRQB Water Quality Threat Level 2 (moderately threatening)				
	Existing Situation Scenario		Source Control Only Scenario	
	Installation Year (200 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**O&M-Only Year** (116.76 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**Installation Year** (101.16 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**O&M-Only Year** (56.12 Million 1994$ Annual Transfer From Household Dividend Payments To Remediation)
Aggregated IMPLAN Sector #	**Change in Emissions** (MGY)	**Change in Emissions** (MGY)	**Change in Emissions** (MGY)	**Change in Emissions** (MGY)
1	-0.17	-0.10	-0.09	-0.05
28	0.05	0.02	0.02	0.01
38	0.93	0.06	0.41	0.03
40	0.06	0.02	0.03	0.01
48	2.43	0.65	1.40	0.32
58	-0.61	-0.29	-0.31	-0.14
108	0.00	0.00	0.00	0.00
133	0.07	0.01	0.04	0.00
148	0.00	0.00	0.00	0.00
161	0.01	0.01	0.00	0.00
174	0.02	0.02	0.01	0.01
186	0.40	0.09	0.22	0.04
210	0.94	0.06	0.36	0.03
215	0.00	0.00	0.00	0.00
221	0.00	0.00	0.00	0.00
230	0.00	0.00	0.00	0.00
254	0.00	0.00	0.00	0.00
273	0.00	0.00	0.00	0.00
307	0.00	0.00	0.00	0.00
339	0.23	0.12	0.10	0.06
384	0.00	0.00	0.00	0.00
400	0.00	0.00	0.00	0.00
415	0.00	0.00	0.00	0.00
433	0.08	0.06	0.04	0.03
434	0.01	0.00	0.00	0.00
438	0.02	0.00	0.01	0.00
439	0.24	0.19	0.12	0.09
443	7.67	5.42	4.07	2.88
444	0.00	0.00	0.00	0.00
445	281.52	286.13	140.63	143.29
446	1279.22	3.38	631 92	1.63
447	0.07	0.04	0.03	0.02
473	0.00	0.00	0.00	0.00
477	0.00	0.00	0.00	0.00
479	0.00	0.00	0.00	0.00
494	0.00	0.00	0.00	0.00
506	0.00	0.00	0.00	0.00
507	0.00	0.00	0.00	0.00
509	0.00	0.00	0.00	0.00
512	0.00	0.00	0.00	0.00
513	0.01	0.00	0.01	0.00
516	0.00	0.00	0.00	0.00
517	0.00	0.00	0.00	0.00
519	0.00	0.00	0.00	0.00
524	0.00	0.00	0.00	0.00
Total	1573.20	295.89	779.03	148.27

Table 4.33

Annual Direct and Indirect Impacts Wastewater Discharges SWRQB Water Quality Threat Level 3 (minor threat level)				
	Existing Situation Scenario		**Source Control Only Scenario**	
	Installation Year (200 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**O&M-Only Year** (116.76 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**Installation Year** (101.16 Million1994$ Annual Transfer From Household Dividend Payments To Remediation)	**O&M-Only Year** (56.12 Million 1994$ Annual Transfer From Household Dividend Payments To Remediation)
Aggregated IMPLAN Sector #	**Change In Emissions (MGY)**	**Change In Emissions (MGY)**	**Change In Emissions (MGY)**	**Change In Emissions (MGY)**
1	-0.28	-0.16	-0.14	-0.08
28	0.12	0.06	0.06	0.03
38	0.08	0.00	0.03	0.00
40	0.17	0.05	0.08	0.02
48	0.40	0.11	0.23	0.05
58	-0.05	-0.02	-0.03	-0.01
108	0.00	0.00	0.00	0.00
133	0.00	0.00	0.00	0.00
148	0.00	0.00	0.00	0.00
161	0.00	0.00	0.00	0.00
174	0.00	0.00	0.00	0.00
186	0.31	0.07	0.17	0.03
210	0.45	0.03	0.18	0.01
215	0.00	0.00	0.00	0.00
221	0.00	0.00	0.00	0.00
230	0.00	0.00	0.00	0.00
254	0.00	0.00	0.00	0.00
273	0.00	0.00	0.00	0.00
307	0.01	0.00	0.00	0.00
339	0.16	0.08	0.07	0.04
384	0.00	0.00	0.00	0.00
400	0.00	0.00	0.00	0.00
415	0.00	0.00	0.00	0.00
433	0.06	0.05	0.03	0.02
434	0.01	0.00	0.00	0.00
438	0.07	0.01	0.03	0.00
439	0.10	0.08	0.05	0.04
443	C.38	0.27	0.20	0.14
444	0.00	0.00	0.00	0.00
445	120.96	122.94	60.42	61.57
446	139.80	0.37	69.06	0.18
447	0.25	0.16	0.12	0.08
473	0.14	0.00	0.07	0.00
477	0.00	0.00	0.00	0.00
479	0.02	0.02	0.01	0.01
494	0.00	0.00	0.00	0.00
506	0.04	0.01	0.02	0.00
507	0.00	0.00	0.00	0.00
509	0.01	0.01	0.00	0.00
512	0.34	0.02	0.28	0.02
513	0.00	0.00	0.00	0.00
516	0.00	0.00	0.00	0.00
517	0.00	0.00	0.00	0.00
519	0.00	0.00	0.00	0.00
524	0.00	0.00	0.00	0.00
Total	263.57	124.15	130.98	62.17

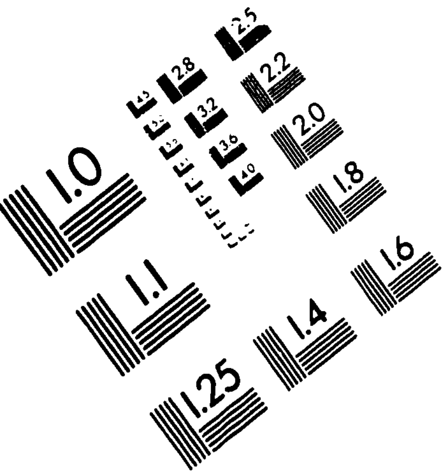
Figure 4.1

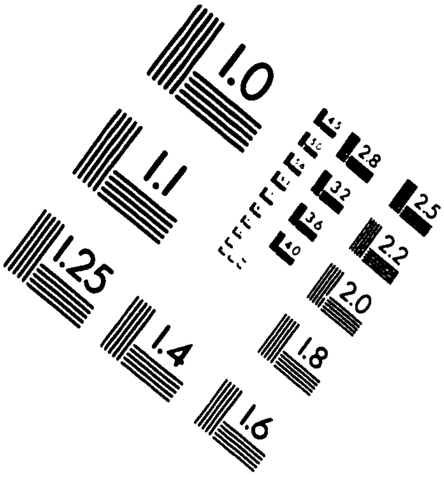
Groundwater Remediation: A Comparison of Pollution Removed and Indirect Cross-Media Pollution Generated

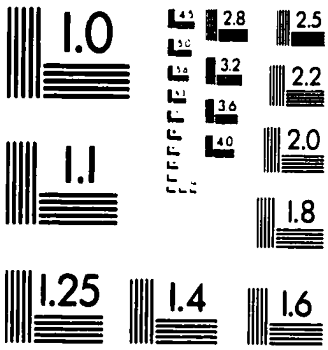


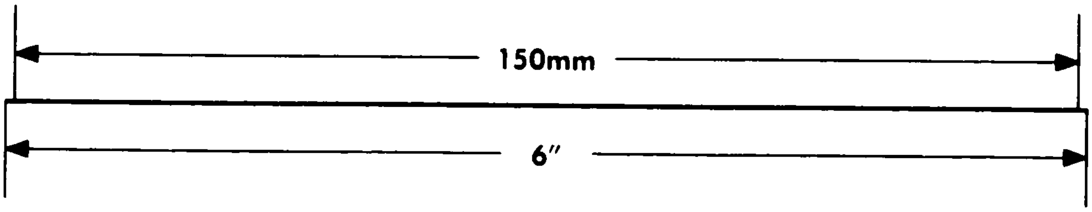
APR = Average Pollution Removed by Remediation
MPR = Marginal Pollution Removed by Remediation
APG = Average Indirect Cross-Media Pollution Generated by Remediation
MPG = Marginal Indirect Cross-Media Pollution Generated by Remediation

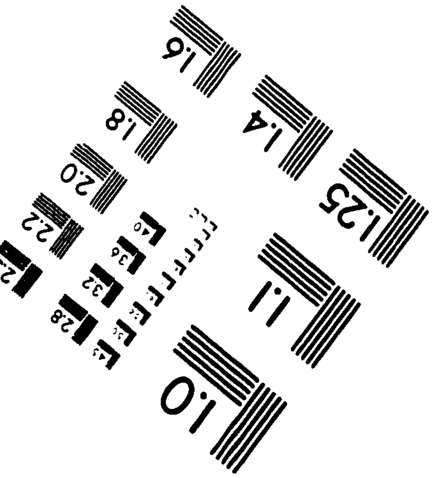
IMAGE EVALUATION
TEST TARGET (QA-3)

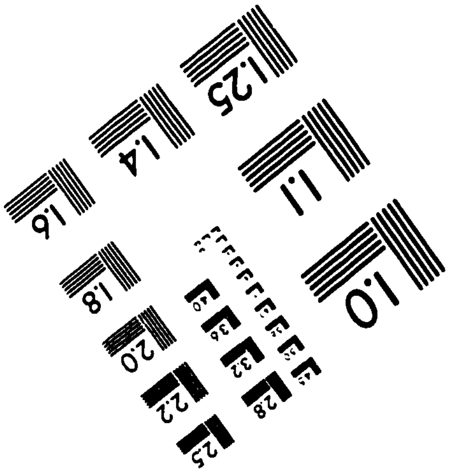












APPLIED IMAGE . Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989